PART 1

Perimeter Groundwater Operable Unit (OU-5) Remedial Investigation/Feasibility Study Report

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LIST OF ACRONYMS

ac ft	acre foot of water
ACWS	Arden Cordova Water Service
AFB	Air Force Base
AL	Action level
AOT	Advanced oxidation technology
ARAR	applicable or relevant and appropriate requirement
ARGET	American River groundwater extraction and treatment system
ARSA	American River Study Area
atm	atmosphere
ATSDR	Agency for Toxic Substances Disease Registry
Basin Plan	Water Quality Control Plan for the Sacramento and San Joaquin River Basins
bgs	below the ground surface
BLRA	Baseline Risk Assessment
BOR	Bureau of Reclamation
Cal-EPA	California Environmental Protection Agency
CAO	Cleanup and Abatement Order
CatOx	catalytic oxidation
CCR	California Code of Regulations
CDA	Central Disposal Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (as amended)
CFR	Code of Federal Regulations
COC	contaminant of concern
CRWQCB-CVR	California RWQB-Central Valley Region
CVEI	Central Valley Environmental, Inc.
CZ	Containment zone
DAA	detailed analysis of alternatives
DCA	dichloroethane
DCE	dichloroethene
DHS	California Department of Health Services
DNAPL	dense non-aqueous phase liquid
DTSC	California Department of Toxic Substances Control
DWHA	Drinking Water Health Advisory
DWR	Department of Water Resources
ea	each
EBMUD	East Bay Municipal Utility District
EE/CA	Engineering Evaluation/Cost Analysis
EMSI	Engineering Management Support, Inc.
EPA	U.S. Environmental Protection Agency
ESD	explanation of significant difference
FOWD	Fair Oaks Water District

LIST OF ACRONYMS (continued)

Freon-11	trichlorofluoromethane
Freon-113	1,1,2-trichloro-1,2,2-trifluoroethane
Freon-12	dichlorodifluoromethane
FS	Feasibility Study
FSC	Folsom South Canal
ft	feet
FTE	Full-time equivalent
ft/year	feet per year
GAC	granular activated carbon
GAC-FB	GAC-fluidized bed
GET	Groundwater extraction and treatment
gpd	gallons per day
gpm	gallons per minute
GMP	General Monitoring Plan
GRA	General Response Action
GWTP	groundwater treatment plant
HI	Hazard index
hp	horsepower
HQ	Hazard quotient
kW	kilowatt
I&C	instrumentation and controls
IRCTS	Inactive Rancho Cordova Test Site
IRIS	Integrated Risk Information System
lin ft	lineal feet
LPGAC	liquid-phase granular activated carbon
LS	lump sum
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDL	method detection limit
MGD	million gallons per day
ug/L	micrograms per liter
mg/kg	milligram per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
msl	mean sea level
NAS	National Academy of Sciences
NCP	National Contingency Plan
NDMA	n-nitrosodimethylamine
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NSC	Non Standard Chemical
O&M	operation and maintenance

OEHHA	Office of Environmental Health Hazard Assessment
OU	Operable Unit
PAH	Polynuclear aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCD	Partial Consent Decree
PCE	tetrachloroethene
PGOU	Perimeter Groundwater Operable Unit
PHG	Public Health Goal
PQL	Practical quantitation limit
PRG	Preliminary Remediation Goal
PVC	polyvinyl chloride
QA	Quality Assurance
RAO	remedial action objectives
RCRA	Resource Conservation and Recovery Act of 1976 (as amended)
RfD	reference dose
RHD	Rebel Hill Ditch
RI	Remedial Investigation
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SARA	Superfund Amendments and Reauthorization Act
scfm	Standard cubic feet per minute
SCWC	Southern California Water Company
SDWA	Safe Drinking Water Act
SMAQMD	Sacramento Metropolitan Air Quality Management District
SMUD	Sacramento Municipal Utility District
SNARL	Suggested No Adverse Response Level
SVOC	Semi-Volatile Organic Compound
SVRA	State Vehicle Recreation Area
SWMU	Solid Waste Management Unit
TAL	Target Analyte List
TBC	To-be-considered criteria
TCA	Trichloroethane
TCE	Trichloroethene
TDH	total dynamic head
TDS	Total dissolved solids
TIC	Tentatively Identified Compound
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
UAO	Unilateral Administrative Order
USBR	U. S. Bureau of Reclamation
USGS	U. S. Geological Survey
UTL	upper tolerance limit
UV	Ultraviolet

VPGAC	vapor-phase granular activated carbon
VOC	volatile organic compound
w	watt
WDR	Waste Discharge Requirement
WGOU	Western Groundwater Operable Unit
WNN	Western Non-Aerospace Non-Industrial Area
WQO	Water Quality Objectives
WRND	White Rock North Dump
WRSD	White Rock South Dump
WS/MUN	Water supply well/Municipal

1 INTRODUCTION

1.1 Purpose, Scope and Organization of the PGOU RI/FS Report Part 1

1.1.1 Purpose

The purpose of this Operable Unit (OU) remedial investigation (RI)/feasibility study (FS) is to prepare an RI/FS report that evaluates remedial alternatives for addressing contaminants of potential concern (COCs) in groundwater in the Perimeter Groundwater OU [OU-5] (PGOU) [Figure 1-1]. The PGOU area is located at the Aerojet-General Corporation (Aerojet) Superfund Site (Site) in Sacramento, California.

The Operable Unit RI/FS Program Plan (Exhibit II) for the Site is administered through the Partial Consent Decree (PCD), which was initially entered by the Court in June 1989 and then subsequently modified on several occasions. The PCD initially required the completion of a site-wide RI/FS prior to beginning remedial action at the Site. Pursuant to the PCD, Aerojet has completed a substantial portion of the Phase I RI/FS. In 1998, the PCD was modified and now contains provisions for completing the RI/FS through a series of operable units. The RI/FS for OU-3, the Western Groundwater Operable Unit (WGOU) [EMSI et. al., 1999] was the first RI/FS completed for the Aerojet Site and the PGOU RI/FS will be the second. This RI/FS Report will complete the RI/FS for Site-related chemicals in groundwater at or beyond the Aerojet Site perimeter in accordance with the Final PGOU RI/FS Work Plan (Aerojet et. al., 2002a) and the PCD.

The PGOU RI/FS is being conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (a.k.a. Superfund) as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The Site CERCLIS Identification Number is CAD980358832. The United States Environmental Protection Agency (EPA), the California EPA through the Regional Water Quality Control Board – Central Valley Region (CRWQCB-CVR), and the State Department of Toxic Substances Control (DTSC) are the oversight Agencies for the project. This PGOU RI/FS also meets the substantive requirements of the following CRWQCB Cleanup and Abatement Orders (CAOs):

- CAO 96-230 for the American River Study Area; and

- CAO 500-718 for perchlorate treatment at the existing groundwater extraction and treatment facility in Zone 1 (GET D).

This RI/FS report addresses chemicals in groundwater at and beyond the Aerojet Site perimeter for those areas not previously addressed by the WGOU, including the American River Study Area and several off-site properties currently or formerly owned or leased by Aerojet. Figure 1-2 shows four groundwater management Zones (Zones 1 through 4) and seven Sectors (A through G) previously defined by Aerojet to distinguish areas with different groundwater flow directions.

1.1.2 Scope

The scope of this OU RI/FS can be described as follows:

- Characterize subsurface conditions; assess the nature and extent of chemicals in groundwater within the PGOU; and provide sufficient data for preparing the Baseline Risk Assessment (BLRA) and the Feasibility Study.

- Prepare a BLRA that provides an evaluation of the potential threat to human health and the environment in the absence of any remedial action. The BLRA provides the basis for determining whether remedial action is necessary and the justification for performing remedial action.

- Prepare an FS by developing and evaluating a range of remedial alternatives that provides for protection of human health and the environment, and that considers technical, institutional, and cost considerations in accordance with CERCLA, as amended by SARA, and the National Contingency Plan (NCP) so that relevant information regarding the remedial alternatives can be presented to a decision maker and an appropriate remedy can be selected; and

- Integrate the FS with all applicable RI, BLRA, and treatability study activities to ensure that all remedial alternatives are developed, screened, and evaluated in a systematic and objective manner.

This RI/FS report has been developed to comply with guidelines prepared under the provisions of CERCLA, SARA, the latest revision to the NCP (40 Code of Federal Regulations (CFR) Part 300.430 (USEPA, 1990a)), and the following EPA guidance documents:

- USEPA, 1988a, Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (Interim Final), EPA/540/6-08/004, OSWER Directive 9355.3-01, October.

- USEPA, 1988b, CERCLA Compliance with Other Laws Manual, OSWER Directive 9234.1-01, August.

- USEPA, 1988c, Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites, OSWER Directive 9238.1-02, December.

- USEPA, 1989c, CERCLA Compliance with Other Laws Manual Clean Air Act, and Other Environmental Statutes and State Requirements, OSWER Directive 9234.1-02, August.

- USEPA, 1996c, Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, OSWER Directive 9283.1-12, October.

- USEPA, 2000, A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, EPA 540-R-00-002, OSWER Directive 9355.0-75, July.

1.1.3 Organization of Report

This RI/FS report documents the characterization of subsurface conditions and the nature and extent of COCs in groundwater for the PGOU, summarizes the potential risks that may be posed to human health and the environment by COCs in groundwater in the PGOU, documents the formulation and evaluation of remedial alternatives, and provides all data and documentation for the decision-making process in the Record of Decision (ROD). The report is organized in general conformance with the suggested format contained in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988a) as follows:

- Section 1 provides background information on the PGOU, a summary of the site conceptual model as presented in the RI (Appendices A-D), and a summary of the Baseline Risk Assessment (Appendix E);

- Remedial action objectives (RAOs), potential applicable or relevant and appropriate requirements (ARARs), and preliminary remediation goals are discussed in Section 2. Section 2 also includes a presentation of general response actions (GRAs) and the identification and screening of remedial technologies/process options;

- A description, history, and evaluation of the effectiveness of each of the current remedial actions located within the PGOU are provided in Section 3;

- The development of remedial alternatives is included in Section 4;

- The detailed analysis of alternatives is discussed in Section 5 and the comparative analysis of alternatives is conducted in Section 6;

- Section 7 includes an evaluation of the impacts on the Zone 1 and 2 remedial alternatives if a cleanup goal for TCE of 0.8 ug/L is contemplated; and

- Section 8 provides the references used in Part 1 of this RI/FS report.

1.2 PGOU Background

This section provides a description of the PGOU including the characteristics of topography, climate, land use, groundwater use, and surface water. Discussions regarding historical industrial operations and current remedial actions within the PGOU are also included.

1.2.1 PGOU Description

The general boundaries for the PGOU are shown on Figure 1-2. The PCD defines the PGOU as *"all remaining plumes of chemicals in groundwater at and beyond the Aerojet Site that are not addressed by the Western Groundwater OU, the Area 41 soil and groundwater OU, or the remedial program for the IRCTS, ... and shall include, without limitation, the plumes of chemical in groundwater at Areas 39 and 40 and the remaining plumes of chemicals in groundwater migrating from the Aerojet-General Operating Plant beneath the IRCTS. The American River Study Area is included in this OU..* (PCD Exhibit II, 2002).

The RI was completed for the areas described above and includes analysis of groundwater at and beyond the Aerojet Site perimeters, with the exception of the perimeters addressed previously by the WGOU. As discussed and agreed previously with the oversight Agencies, based on the data presented for Area 40, groundwater from Area 40 is migrating west, onto the Site (Section C5). It was therefore agreed that Area 40 would be removed from the PGOU. Groundwater from Area 40 flows onto the Site along a relatively small portion of the eastern Site perimeter. From there, the groundwater appears to flow towards the northern Site perimeter and the existing GET A containment system (Section C5). The TCE in soil and groundwater resides within a shallow alluvial and bedrock aquifer at concentrations suggesting the potential presence of dense non-aqueous phase liquid (DNAPL). It is uncertain whether Cleanup Standards are technically achievable in Area 40, and downgradient hydraulic containment already exists. In addition, additional investigation and potential interim response actions for Area 40 are being considered. Accordingly, Area 40 was removed from the PGOU. It is currently being addressed as part of the Island Operable Unit where pilot testing of a remedial system for the chemicals in groundwater is currently ongoing.

This RI/FS follows the previous Zone and Sector nomenclature (described in the following paragraphs) to distinguish among the different geographic areas and groundwater flow directions within the PGOU. The source(s) and types of chemicals, potential exposure pathways, potential receptors, and existing and potential future remedial alternatives may vary depending on the direction of groundwater flow in each area.

The Aerojet site was divided into four Zones during preparation of the Phase 1 RI. As presented on Figure 1-2, Zones 1 through 4 are located in the northwest, southwest, southeast, and northeast portions of the site, respectively. Because the PGOU RI/FS includes groundwater beyond the Aerojet Site boundaries, each PGOU Zone incorporates portions of that Zone and areas at and beyond the property boundary where impacted groundwater migrated (e.g., The Zone 3 PGOU incorporates a portion of Zone 3 and the impacted groundwater areas downgradient of Zone 3). The location of each PGOU Zone is presented on Figure 1-2 and the PGOU Zones are shown individually on Figures A-1, B-1, C-1 and D-1.

Early groundwater investigations also divided the Site into groundwater management Sectors A through G, based on different groundwater flow directions. Each Sector is shown on Figure 1-2. As discussed in Section 3, the letter designations for the current remedial action groundwater extraction and treatment (GET) facilities (Figure 1-3) correspond to the Sector in which they are located. In addition, the site was also divided geographically into management areas (or manufacturing Line Areas) based on the types of industrial operations conducted in each area. In the RI and in this FS report, the management areas are included within the discussions for each Zone. Table 1-1 shows the relationships among the groundwater flow sectors, management areas and zones for the Site.

The following areas were defined for the PGOU:

- The Zone 1 PGOU is located northeast of the Aerojet property and includes the previously defined American River Study Area (ARSA). The western portions of the Zone 1 PGOU overlap with the eastern portions of the WGOU;

- The Zone 2 PGOU is located along the southern Aerojet property boundary, east of the WGOU and west of the White Rock North Dump and Zone 3 PGOU;

- The Zone 3 PGOU is located south of the southern Aerojet property boundary and the Aerojet-owned former Ehnizs Property, and east along the Aerojet property boundary; and

- The Zone 4 PGOU is located along the northern Aerojet property boundary.

These areas are evaluated in this RI/FS because chemicals are present upgradient or beyond the Aerojet property boundaries. The PGOU addresses chemicals in groundwater at or beyond approximately 12.5 miles of the 17.3-mile Aerojet property perimeter that were not included in the WGOU.

1.2.2 PGOU Characteristics

This section describes the characteristics of the PGOU area including topography, climate, land use, groundwater use, and surface water.

1.2.2.1 Topography

The Aerojet Site and the PGOU areas are characterized by a relatively flat topographic surface sloping less than 1 degree to the west. Some areas in the eastern portion of the Site south of GET B dip to the south and east. The elevations in PGOU range from approximately 200 feet above mean sea level (msl) in the east to approximately 60 feet above msl in the west.

Most of the on-site topography is dominated by rows of dredge tailings remaining from gold mining operations that began in the early 1900's. The tailings consist of alternating rows of loose cobble mounds and intervening low areas comprised of silt and clay ("slickens"). Much of the areas surrounding Aerojet, including Gold River, portions of the IRCTS, and areas south of GET B, were also dredged, although development has obscured most of the tailings (Figure 1-2). The dredging apparently disturbed the sediments to depths ranging from 20 to 80 feet below ground surface (bgs).

Other topographic features include two ancestral American River terrace scarps that generally trend northeast-southwest across the Site. Alder Creek trends east-west through an incised channel cut through the sediments just south of the northern Site perimeter. To the north, a ridge of 30- to 60-foot high bluffs parallel the north side of the American River.

1.2.2.2 Climate

The climate in the Sacramento area is mild and generally characterized as Mediterranean with an average annual precipitation of 17 inches. The majority of rainfall occurs between December and March. Temperatures range from 25° F lows in the winter to 115° F highs in the summer. The average daily high temperature is 53°F in the winter and 95°F in the summer. Normal relative humidity is 46 percent during the day and 82 percent at night. The prevailing winds in the area are from the southwest at an average wind speed of 8 miles per hour.

1.2.2.3 Land Use

The Aerojet-owned property upgradient of the PGOU is zoned for industrial use. The facilities that support industrial operations are grouped into manufacturing areas comprised of multiple buildings. Large areas of undeveloped land are located within and between the manufacturing areas, and between the property boundaries. The majority of land between active manufacturing areas and the property boundary served as "buffer space" between operations and neighboring properties. Large areas of the buffer lands located along the northern and northwestern property boundaries were removed from the Superfund Site in 2000 and may be developed, as appropriate, in the future. Figure 1-4 presents the Aerojet superfund site boundaries and the current and projected land use in PGOU.

The Aerojet property was designated as a "Special Planning Area" by Sacramento County Ordinance, Title V, Chapter 8, Article 3 of the Zoning Code of Sacramento County (Sacramento County, 1993). This ordinance identifies existing permitted uses and "provides a regulatory mechanism for making land use decisions that maintain a safe environment in which the subject property can be used given the special requirements of the property owner".

Land uses in the PGOU around the Aerojet property include: residential, commercial, industrial, agricultural, and recreational. The largest developed areas are located west and north of Aerojet and include the Cities of Rancho Cordova and Folsom, and the community of Gold River. These areas have combined populations of approximately 109,000 people.

The majority of land in the PGOU surrounding the southern and eastern property boundaries is undeveloped. The Prairie City State Vehicle Recreation Area (SVRA) is mainly undeveloped and is used for off-road recreation. Aggregate mining is conducted south of southern Zone 3, and south of White Rock Road on the Inactive Rancho Cordova Test Site (IRCTS) and on other privately-owned land.

Aerojet is the current property owner of the IRCTS. The IRCTS was formerly owned and operated for rocket manufacturing and testing by the McDonnell Douglas Aircraft Company that was subsequently purchased by The Boeing Company. The RI/FS activities on the IRCTS are being conducted pursuant to the 1994 California DTSC Imminent and/or Substantial Endangerment Order (DTSC, 1994), and the 1997 CRWQCB Cleanup and Abatement Order (CAO) 97-093 (CRWQCB, 1997). The RI/FS activities are addressed jointly by The Boeing Company and Aerojet.

A former Sacramento County municipal landfill is located on the IRCTS, and a second former landfill, the White Rock South Dump (WRSD), is located adjacent to the eastern boundary of the IRCTS. A third municipal landfill, the former White Rock North Dump (WRND) is located at the northwest corner of White Rock and Grant Line Roads, and is adjacent to portions of the eastern and southern PGOU boundaries. The former WRND is currently owned by Aerojet and chemicals in groundwater beneath and south of the WRND are addressed under CRWQCB CAO 96-150 (CRWQCB, 1996a).

1.2.2.4 Groundwater Use

Groundwater within the PGOU is considered a Federal Classification IIA drinking water aquifer and is designated for municipal use as a potential drinking water source in the Basin Plan (RWQCB, 1998). Groundwater on Aerojet is not used for any purposes, and future groundwater use is encumbered by environmental restrictions. Future groundwater use within the PGOU and not within the Aerojet property boundary is regulated under Sacramento County Ordinance. The Sacramento County Environmental Management Department manages a "Consultation Zone" that requires all parties to consult with the RWQCB-CVR prior to drilling a well within a 2,500-foot distance from chemicals in groundwater around the Aerojet Site.

Groundwater is used for domestic and industrial purposes in the PGOU beyond the Aerojet property boundaries. The water supply wells located within a one-mile radius of the PGOU are shown on Figure 1-5. Nearby water purveyors that use groundwater include:

- Golden State Water Company (GSWC), known locally as the Arden-Cordova Water Service (ACWS);
- The Sacramento County Water Agency;
- The Cal-American Water Company; previously the Citizens Utilities Company; and
- The Fair Oaks Water District.

One municipal water supply well (AC-21) currently owned by GSWC is located north of Aerojet in the Zone 1 PGOU, and one water supply well is located south of Aerojet in the Zone 3 PGOU (well 1059). GSWC also operates four additional water supply wells (AC-20, -17, -22A, and -22B) just west of the Zone 1 PGOU in the WGOU. The Fair Oaks Water District operates one municipal well to the west of the PGOU. These public water supply wells are monitored in accordance with the provisions in Exhibit IV (PCD, 1989) and the annual groundwater monitoring plan (Aerojet, 2008).

Groundwater is also used for industrial and domestic purposes to the south and southwest of the Aerojet Site. Groundwater is used for gravel mining operations at Well 1943 (AKT-1) and for gravel mining and domestic consumption at Well 1059. Several domestic wells south of the Aerojet property are used for domestic or agricultural purposes and are monitored by Aerojet (Aerojet, 2003).

A well survey was conducted to identify privately-owned water supply wells (domestic wells) currently used for domestic consumption or irrigation that are located within a one-mile radius of the PGOU. The locations of wells identified during the survey were reviewed relative to the nearest known groundwater impacts to determine whether one-time sampling or recurring monitoring of the well was appropriate.

The results of the well survey are summarized in Table 1-2, and the identified wells are shown on Figure 1-5. Wells located within one mile east of Sunrise Boulevard in the western portion of the survey area are shown on Figure 1-5; however, the wells in this area were included in the WGOU well survey (December 15, 2004) and are not repeated here.

Municipal water supply wells located within a one-mile radius of the PGOU boundary were also included in the survey. Municipal water supply wells are owned and operated by various water purveyors and are identified as municipal water supply wells (WS/MUN) in the table and designated as "Water Supply Wells" on the figure. In general, the current status of municipal water supply wells is known, and most wells are monitored under the Aerojet or the Inactive Rancho Cordova Test Site groundwater monitoring plans. There were no municipal wells identified that are not monitored and located near or downgradient of the PGOU.

Other water supply wells in or near PGOU that are currently being used include: Well 1156 in Zone 1 which supplies water to the pond in Sailor Bar Park and which has been equipped by Aerojet with a treatment system to remove volatile organic compounds. Well 1029 within Zone 2 is used as industrial supply by the tenant currently on the property and Well 1028 is used for stock watering by a cattle company.

There were records for 23 private water supply wells that were not located during the well survey. It is suspected that many of these wells were installed prior to the availability of municipal water service and development of the area. The majority of private wells that could not be found were located in Zone 1, in an area that has been extensively redeveloped during the past 40 to 50 years.

Five private water supply wells, including three domestic wells (Wells 1031, 1301, and 1917); one irrigation well (Well 1024); and one well that is not currently used but that may be used for irrigation in the future (Well 1874) were not monitored by Aerojet as of 2004 (Table 1-2). Wells 1024 and 1874 are being incorporated into Aerojet's monitoring program. Wells 1031, 1301, and 1917 are in an area with planned development and if the wells are still accessible should be sampled to verify that the well water is not impacted. In addition, Well 1045 is located in the CSUS Aquatic Center building near Lake Natoma. The status of this well has not been confirmed.

1.2.2.5 Surface Water

Discussions of regional and local surface water within and near the PGOU are provided in this section.

Regional Surface Water

Regional surface water bodies in the vicinity of the PGOU include Folsom Lake, Lake Natoma, the American River, and the Folsom South Canal. The American River drains a substantial portion of the western Sierra Nevada, east of Sacramento County. Flows on the American River are controlled by the United States Bureau of Reclamation (USBR) through Folsom Dam, and to a lesser extent, Nimbus Dam. Folsom Dam is located approximately 3.5 miles northeast (upstream) of Lake Natoma. Lake Natoma is formed by Nimbus Dam, and is located approximately ¼ to ½ mile north of Aerojet's northern property boundary.

The Lower American River was designated as a Wild and Scenic River from Nimbus Dam to the confluence with the Sacramento River by the National Park Service in 1981. Additional surface water supply cannot be obtained from the American River because surface water rights for the Upper and Lower American River are fully allocated.

The Folsom South Canal originates at the southwest end of Lake Natoma, and trends along portions of the northern and western Aerojet property boundaries. The USBR controls water releases in the canal. The Folsom South Canal is a concrete-lined canal and was intended to provide cooling water for the Sacramento Municipal Utility District's (SMUD) Rancho Seco Nuclear Power Plant and municipal water for the East Bay Municipal Utility District (EBMUD). The nuclear power plant is being decommissioned and current use of the canal is limited to relatively small amounts of water by SMUD, ACWS, and various other water purveyors and agricultural water users.

Portions of the eastern PGOU are in the upper reaches of the Consumnes River Watershed. There are no dams on the Consumnes River and flow rates vary seasonally.

Local Surface Water

Local surface water features in or near the PGOU include: Alder Creek, Rebel Hill Ditch, Buffalo Creek, the Area 20 Administration Ditches, the Westlake storm-water retention cells, the headwaters for Morrison Creek, Coyote Creek, and various man-made ditches and ponds (Figure 1-6). Buffalo Creek, the Area 20 Administration Ditches, and the Westlake storm-water retention cells are used to divert and control storm-water runoff from the Aerojet property.

Alder Creek is located near the northeastern Aerojet property boundary in Zone 4 and receives storm water runoff from urban Folsom as well as undeveloped areas on and east of Aerojet. Alder Creek is generally ephemeral, although the western portion of the creek often flows year-round. Alder Creek flows west and drains into Lake Natoma.

Rebel Hill Ditch traverses the property from northeast to southwest through Zones 4, 3, and 2. This ditch was originally constructed to provide water for the gold dredging activities. Aerojet currently discharges treated groundwater from the GET A and GET B interim remedial action systems to Rebel Hill Ditch (RHD). The treated groundwater from GET A infiltrates along RHD in northern Zone 4, and the treated groundwater from GET B infiltrates along RHD from Zone 3 into the southern portions of Zone 2, but does not flow beyond the property boundaries.

Remnants of a former irrigation ditch, the Valley Ditch, are generally present near Folsom Boulevard in portions of the Zone 1 PGOU (Figure 1-6). The Valley Ditch was used for irrigation beginning in approximately 1870. Segments of the Valley Ditch traversed the Aerojet property where the Westlake Stormwater Retention Basins are now located, although the Ditch was apparently not used to convey stormwater or discharges from the Aerojet Site. Most of the Valley Ditch was destroyed by development, probably in the 1970's, and the ditch has not conveyed irrigation water since.

Most storm-water runoff originating in the northern (Administration Area) portions of Aerojet is diverted to the Westlake storm-water retention cells via the Area 20 Administration Ditches and Buffalo Creek. Storm-water runoff from the northeastern portions of the Site flows through Buffalo Creek to the Westlake storm-water retention cells. Analytical sampling of the storm-water runoff is conducted prior to discharging the water to Buffalo Creek and ultimately the American River. Storm-water discharges to Buffalo Creek/American River are regulated through the National Pollution Discharge Elimination System (NPDES). Aerojet also discharges treated groundwater from ARGET and GET E/F to Buffalo Creek under a separate NPDES permit. Most storm-water runoff generated in the southwestern portions of the Aerojet Site infiltrates locally and does not leave the Aerojet property.

The areas northwest of the Site are developed and there are no known areas where runoff exits the Aerojet Site, except for Buffalo and Alder Creeks as noted above. The Sacramento County Department of Public Works – Water Resources Division manages stormwater from the developed areas off of the Aerojet property in the PGOU. Stormwater runoff from these areas enters the County's stormwater collection system and ultimately the American River.

Morrison Creek originates south of GET B near Grant Line Road approximately 1,000 feet south of White Rock Road. Water in Morrison Creek flows southeast through the southern portion of the IRCTS property and into the Sacramento River (Figure 1-6). The upper portions of Morrison Creek are ephemeral, and water is rarely present in the summer. Coyote Creek is also ephemeral and is located east of the SVRA and flows to the Consumnes River.

1.2.3 Historical Industrial Operations

The Aerojet Site has been used to develop rocket propulsion systems in support of national defense, space exploration, and satellite deployment since the 1950's. During the 1950's through the 1970's, Aerojet was a vital part of the regional economy employing more than 20,000 people at any one time. Industrial activities that supported this work include: solid rocket motor manufacturing, testing, and rehabilitation (hogout);

liquid rocket engine manufacturing and testing; and chemical manufacturing. Currently Aerojet employs approximately 2,000 people testing and manufacturing rocket propulsion systems and pharmaceuticals.

A variety of chemicals have been manufactured and/or used at the Site, including solvents, propellants, fuels, oxidizers, metals, and various other chemicals produced to support industrial operations (ICF Technology, 1989). Historical operations at the Site have resulted in the discharge of chemicals to the vadose zone and percolation into the underlying groundwater. Exhibit III of the Partial Consent Decree identifies Potential Source Areas within the Aerojet Site.

Volatile organic compounds (VOCs) are the most common chemicals in groundwater and trichloroethylene (TCE) is the most prevalent. Other VOCs commonly detected in groundwater in the PGOU include:

- 1,1,1-trichloroethane (1,1,1-TCA);
- 1,1-dichloroethane (1,1-DCA);
- 1,2-dichloroethane (1,2-DCA);
- 1,1-dichloroethylene (1,1-DCE);
- 1,2-dichloroethylene (1,2-DCE); and
- Freon-113.

Rocket propellant constituents and potential combustion by-products were also detected in groundwater, most commonly perchlorate and N-nitrosodimethylamine (NDMA). Other chemicals reported less frequently in PGOU groundwater include: hydrocarbon fuels, 1,4-dioxane, and nitrate.

Although numerous chemicals were used on the Aerojet Site, TCE, perchlorate, and NDMA are the primary chemicals of potential concern and are present in varying concentrations variously distributed in each of the zones. TCE was primarily used as a solvent for cleaning and degreasing purposes. Perchlorate was combined with various cations (primarily ammonium or potassium) and used as an oxidizer in solid rocket propellants. NDMA was either an impurity in hydrazine-based liquid rocket fuels or was formed as a combustion by-product of these fuels.

Rocket engine/motor testing, and motor rehabilitation (propellant hogout) were also conducted in other portions of the IRCTS that are being jointly investigated by Aerojet and The Boeing Company under a separate Cleanup and Abatement Order (CAO 97-093) issued by the Regional Water Quality Control Board (RWQCB). It is recognized in this FS that there are additional groundwater plumes containing perchlorate and solvents south of the PGOU boundaries. The Regional Board Order provides that the remediation efforts under the IRCTS CAO will be coordinated and may be combined with any remedial action associated with this RI/FS for the PGOU.

In addition, there are potential sources of COCs within the PGOU other than the IRCTS and the Aerojet Facility. Chlorinated solvents, including TCE, were commonly used by different industries. Perchlorate appears to have been a common constituent of fertilizers

(ES&T, 1999). NDMA appears to have been associated with various industrial and food processing industries and has been a contaminant in foods (ATSDR 1989).

1.2.4 Current Remedial Actions

Since the mid-1980's, Aerojet has installed and operated five interim remedial action perimeter groundwater extraction and treatment (GET) facilities (GETs A, B, D, E, and F) currently designed to remove VOCs, NDMA and/or perchlorate, as necessary from groundwater beneath the site. These GET systems were targeted at containing chemicals in groundwater at the Aerojet property boundaries. Treated groundwater from the systems is either discharged to Buffalo Creek or recharged to the groundwater system via surface discharge and infiltration, or by recharge wells. A sixth GET system, the American River Groundwater Extraction and Treatment (ARGET) system began operations in July 1998 in the ARSA. The treatment systems at each GET system vary, but generally include combinations of air-stripping for VOC removal; ultraviolet (UV) light/chemical oxidation for removal of NDMA, most VOCs, and 1,4-dioxane; and ion-exchange or biological reduction for perchlorate removal.

Four of these GET facilities, GETs A, B, D, and ARGET, are located within the PGOU on the perimeter boundary of the Aerojet site and are included for evaluation as a final remedy in this FS. GETs E and F were addressed in the WGOU RI/FS (EMSI, Aerojet, and HSI Geotrans, 2000). A description, history, and evaluation of the effectiveness of each of these GET systems are provided in Section 3 and the locations of each GET facility are shown on Figure 1-3.

1.2.4 Previous Investigations

The geologic and hydrologic conditions, distribution of chemicals in groundwater, and evaluation of source areas at the Aerojet site have been formally studied since 1989. The background information for the RI/FS and previous interpretations of geologic, hydrologic, and chemical conditions in the PGOU groundwater were presented in the following reports:

- 1980's: Miscellaneous initial source site investigations detail the soil sampling and monitor well installations in source areas. These investigations generated the historical soils data referenced in the Stage 1 RI's, and can be found in the Potential Source Site Reports, Appendix D of the Scoping Report (ICF Technology).

- 1989-1991: Scoping Report and Phase 1 RI/FS Workplan (ICF Technology). These reports identified and summarized existing history of the Aerojet site, the interim remedial measures, and the potential source sites; evaluated chemical use and disposal; and proposed locations and analytical methods for sampling and analysis, including an analytical approach to evaluate non-standard chemicals for the Stage 1 RI/FS.

- 1989-2001: GET Effectiveness Reports (GenCorp Aerojet). In accordance with the PCD, these reports were prepared periodically for each GET facility to assess the effectiveness of each facility in intercepting chemicals in groundwater at or near the periphery of the Aerojet property. The reports contain hydrologic data and research and are the basis for the current hydrogeologic model. These reports included, as necessary, recommendations to improve hydraulic capture or add groundwater monitor wells which were then implemented.

- 1993: Stage 1 RI Reports (ICF Kaiser Engineers). These reports contain the results of comprehensive Site-wide soil-gas, soil, and groundwater chemical sampling and screening performed at the potential source sites.

- 1995 through 2000: Stage 2 RI Sampling and Analysis Work Plans (GenCorp Aerojet). These Work Plans outlined the data collection activities recommended to complete the RI/FS at the source areas. Most data collection involved completing the characterization of non-VOCs detected in soil or groundwater.

- 1993 through present: Annual Groundwater Monitoring Plans (GenCorp Aerojet). These monitoring plans contain the locations, chemical analyses, and sampling frequencies for monitoring the downgradient extent of chemical plumes, operation of the GET remedial systems, and public water supply wells. New monitor wells necessary for monitoring the water quality in the vicinity of the water supply wells are also included in these plans.

- 1996: Final Engineering Evaluation/Cost Analysis (EE/CA) for the American River Study Area (GenCorp Aerojet). The EE/CA recommended a removal action that consisted of a groundwater extraction system on the north and south sides of the American River; conveyance of the water to a location on the Aerojet Site for treatment of the extracted groundwater; and discharge of the treated water to Buffalo Creek under an NPDES permit for the American River Study Area.

- 1997: Final Closure and Post Closure Maintenance Plan for the Aerojet Landfill (Minshew Engineering). This Plan describes closure and post-closure monitoring for the Landfill and summarizes waste, vadose zone (soil-gas and soil sampling) and groundwater sampling conducted in 1994-1995 at the closed Aerojet Landfill.

- 1997: Technical Memorandum – Evaluation of Perchlorate – Southeastern Zone 2 (GenCorp Aerojet). Groundwater potentiometric measurements in southeastern Zone 2 were summarized in this report. These results were used to evaluate the lateral and vertical extent of perchlorate in portions of this Zone.

- 1998: Technical Memorandum – Evaluation of Perchlorate and N-Nitrosodimethylamine (NDMA) in Groundwater – Aerojet Site – Zone 1 and Western Zone 2 Study Areas (GenCorp Aerojet). This document reported the results of perchlorate and NDMA groundwater sampling using recently-lowered detection limits in Zones 1 and 2.

- 2000: Western Groundwater OU RI/FS (GenCorp Aerojet). This RI/FS addressed groundwater along the western perimeter of the Aerojet Site and the areas west and northwest of the Site. The EPA issued a ROD in July 2001 and a Unilateral Administrative Order [(UAO) EPA, 2002] requiring that Aerojet implement a groundwater pump and treat remedy to contain chemicals in groundwater at the western Site perimeter and restore the groundwater west and northwest of the Aerojet property to below Cleanup Standards by constructing several lines of groundwater extraction wells and associated treatment facilities.

- 2006: Aerojet Superfund Site, Quality Assurance Project Plan (GenCorp Aerojet). The QAPP describes the quality assurance (QA) organization and the parameters used to ensure precision, accuracy, representativeness, completeness, and comparability of the data generated and reported at the Site.

1.2.5 Remedial Investigation Approach

The RI for the Site was formally initiated in 1989 and has included investigations of historical operations, materials used, waste disposal practices and the collection of soil, surface water, and groundwater physical and analytical data. The following sections briefly summarize the approach for collecting the data used to prepare the PGOU RI.
The PGOU addresses groundwater and the most common data collection methods for groundwater included the construction and analytical sampling of wells located downgradient of potential source areas. Physical data from groundwater were also collected to assess the hydraulic gradients and aquifer properties used during development of the SCM. Section 2.9.1 describes the methodology used to develop the groundwater monitoring network. The development of the analytical sampling program, including the Target Analyte Lists for each zone, is summarized in Section 2.9.2. The approach followed for addressing tentatively identified compounds (TICs) is presented in Section 2.9.3. Section 2.9.4 describes the geographic distribution of the current data and explains the criteria for posting data on the figures provided in Sections 3 through 6 of this report.

1.2.5.1 Development of Groundwater Monitoring Network

Over 2,000 monitor wells have been constructed at the Site since 1980. Most wells were installed using mud-rotary drilling methods due to the depths required for the groundwater investigations. Wells were generally installed to assess groundwater downgradient of suspected source areas and some wells were installed as sentinel wells upgradient of water supply wells. The layered stratigraphy and site accessibility restrictions have necessitated the construction of numerous "nested" wells that contain from three to six individual wells screened at various depths within a single borehole. Nested wells are currently installed with a maximum of three screened intervals.

The screened intervals for most monitor wells were generally constructed within the more permeable portions of the aquifer, where contaminants are most likely to reside. However, chemicals may also be present in the less permeable materials, particularly closer to the source areas. The current monitor well network was developed through an on-going, phased "step-out" approach to assess the lateral and vertical extents of chemicals in groundwater. The characterization of chemicals in groundwater is inherently uncertain due to the heterogeneous fluvial aquifer beneath the PGOU and complex contaminant migration pathways. Furthermore, reductions in analytical detection limits for some chemicals (e.g., perchlorate and NDMA) have resulted in the discovery of chemicals beyond the extents previously defined by using the earlier, higher limits.

1.2.5.2 Development of Groundwater Analytical Program

The development of the analytical sampling program for the PGOU was complicated by the large number of chemicals handled upgradient at the Site. A systematic process of chemical identification, screening, and assessment was conducted during the Stage 1 RI and subsequent groundwater monitoring. This process followed CERCLA guidance and has resulted in the development and refinement of analytical methods for identifying unique or specialty chemicals, the formation of Target Analyte Lists (TALs) for the PGOU groundwater, and an approach for managing TICs.

Over 400 compounds handled at the Aerojet facility have been identified based on interviews with Aerojet personnel, reviews of historical data, and reviews of Site documentation related to chemical handling and use (ICF Kaiser Engineers, 1989 and 1993). These compounds were divided into two groups:

- Chemicals for which there were standard analytical methods; and

- Chemicals for which there were no standard analytical methods.

Approximately 116 of the chemicals identified in the record search have standard analytical methods and these chemicals were analyzed for in samples collected during the Stage 1 RI. In addition, Aerojet's analytical laboratory developed methods to detect some unique or specialty chemicals manufactured or handled at Aerojet. These compounds include Prowl (pendimethalin), hydrazine, perchlorate, nitroguanadine, NDMA, and 10,10-oxybisphenoxarsine (OBPA).

The chemicals for which analytical methods did not exist were placed on the non-standard chemical (NSC) list and evaluated following CERCLA and RCRA guidance. These guidance documents recognize that the development of analytical methods to detect all potential NSCs is time-consuming and expensive, and can delay the investigation and remedy process. Therefore, CERCLA recommends using TALs using standard analytical methods to identify the presence of a range of chemicals in an efficient manner. The use of TALs provides a method for identifying, screening, and characterizing chemicals that should be adequate to identify appropriate levels of risk and provide a basis for selecting remedies.

In addition to the development of TALs, analytical methods were recommended for groundwater sampling conducted in each of the four management zones. The suite of chemicals varied slightly in each zone, but generally consisted of the following:

- VOCs;
- Semi-volatile organic compounds (SVOCs);
- Perchlorate;
- NDMA;
- Metals;
- Chromium VI;
- Total petroleum hydrocarbons (as diesel) ;
- Nitrate and nitrite;
- General minerals (anions and cations); and
- Field measurements (pH, electrical conductivity, temperature).

All monitor wells were sampled for the comprehensive suite of analytes specific to the zone they were located in during the Stage 1 RI (ICF, 1993). Since 1991, the initial samples from all new monitor wells are analyzed for this comprehensive suite of analytes, and then subsequently monitored for three consecutive quarters for a reduced list of analytes based on the initial sample results. After completing the initial year of monitoring, the well may be added to a Groundwater Monitoring Program. The monitoring frequencies and analytes specified in each Groundwater Monitoring Plan vary, and as a result, the groundwater data coverage varies throughout the PGOU.

1.2.5.3 Tentatively Identified Compound (TIC) Approach

Another component of the analytical program plan development was the institution of a formal process for evaluating TICs. Analytical methods using gas-chromatography/mass spectroscopy can tentatively identify compounds through the use of extensive chemical databases. The current TIC databases and those used during the Stage 1 RI included over 150,000 compounds. During Stage 1, TIC data were evaluated based on frequency of detection and repeatability. This evaluation resulted in the addition of 1,4-dioxane, 1-methyl-2-pyrrolidinone, and butyl-benzene sulfonamide to the TAL.

The TIC approach followed during the PGOU RI included the following steps:

Step 1: Each TIC reported during the remedial investigation was summarized in the Aerojet site database. An inventory was created and the distribution of TICs in groundwater and soil were mapped.

Step 2: The results from Step 1 were evaluated and data gaps were identified. Confirmation sampling was performed at wells with reported TICs, to confirm that the TICs were repeatable.

Step 3: The data collected as part of PGOU RI/FS work plan were evaluated and compared to previously existing information and the inventory and maps were updated.

Step 4: Retention times and goodness of fit for unknown TICs detected during PGOU RI/FS in soils and groundwater were evaluated. For TICs with a possible identification confirmed in groundwater, laboratory TIC results (mass spectra compound fingerprint) from PGOU RI/FS were examined and an attempt to determine probability of correct identification of TICs was made.

Step 5: TICs for which the mass spectra data have been reviewed and the correct identification confirmed were added to the TAL and available toxicity and risk information for these compounds were evaluated.

This process was completed most recently in 1999 for off-site monitor wells included in the 1999-2000 Groundwater Monitoring Plan (Aerojet, 1999) and documented in the Final 2000-2001 Groundwater Monitoring Plan (Aerojet, 2000). No TICs were confirmed in subsequent samples collected from the wells with previous TICs reported, and no compounds were added to the TALs.

1.2.5.4 Data Distribution and Posting Criteria

Sections 3 to 6 present information on the distribution of chemicals in groundwater beneath Zones 1 to 4. Chemical iso-concentration maps were prepared for the most common and widely distributed chemicals within each layer in each zone. The data posted on the iso-concentration maps represent the most recent primary sample result collected from the well within the sampling period. Most of the monitor wells within the PGOU have been sampled numerous times over periods ranging from 1 to 15 years. During this period, data trends and "representative" chemical concentrations for most locations were evaluated. The current data for each Zone and each aquifer layer were compared to previous chemical isoconcentration maps to evaluate the consistency of the data with respect to chemical concentration trends and well locations. In addition, duplicate and replicate sample results were not posted in the tables or on the figures unless the results vary significantly from the primary sample results.

1.3 Conceptual Model

The conceptual model for the PGOU is presented in the Baseline Risk Assessment (Appendix E) and is summarized in the following sections. The summary includes discussions of the conceptual regional geologic model, the conceptual regional hydrologic model, regional groundwater flow characteristics, and the conceptual nature and extent of contamination in Zones 1 through 4.

1.3.1 Conceptual Regional Geologic Model

The Regional Site Conceptual Geologic model is shown on Figure 1-7 and a site-wide geologic cross-section is included as Figure 1-8. The Site is located near the eastern edge of the Sacramento Valley, near the contact between the Sierra Nevada metamorphic basement rocks and the Great Valley Sedimentary Sequence. This area is characterized by shallow-dipping (generally less than 1 degree) Cretaceous-, Tertiary-, and Quaternary-age marine and fluvial sediments overlying steeply dipping Jurassic crystalline basement rocks (Department of Water Resources (DWR, 1974)). The erosional surface of the basement rock dips to the west beneath the PGOU at approximately 4 degrees (ICF, 1989).

The sedimentary sequence includes undifferentiated Quaternary sediments and the Laguna, Mehrten, Valley Springs, Ione, and Chico Formations. These sediments generally strike north-south and form a wedge that thickens from tens of feet at the eastern Aerojet property boundary to greater than 2,000 feet near the western Aerojet property boundary. The sediments of interest include the undifferentiated Quaternary sediments, the Laguna, Mehrten, and Valley Springs Formations, and contain hydrostratigraphic Layers A through F as described below and in the RI report. In addition, a bedrock layer is present in eastern Zone 4 and Area 40. Descriptions of each of these geologic formations are provided in the Scoping Report (ICF, 1989) and the various GET effectiveness evaluations prepared by Aerojet for the Site.

1.3.2 Conceptual Regional Hydrologic Model

The site-wide conceptual hydrologic model for the PGOU is presented on Figure 1-7. The saturated sediments beneath the Aerojet Site were previously assigned to hydrostratigraphic Layers A through F based on lithologic descriptions, water levels, geophysical data, pumping test data, chemical data, and relative depths and thicknesses. Layer A is the shallowest layer and Layer F is the deepest layer. The layers were initially developed locally for the earliest GET effectiveness and hydrologic evaluations. Data collected from numerous aquifer pumping tests conducted at the GET extraction wells were used to confirm and refine the hydrogeologic model for the Site.

Each layer is comprised of relatively continuous lenses of permeable sediments separated by relatively lower permeability sediments. Layer A is defined as the first encountered groundwater that is often, but not always, encountered in the Quaternary sediments. Layer A is not present or is unsaturated in many areas of the Site. Layer B is relatively thin and is also dry or absent in some areas of the Site. Layers C, D, E, and F are located within the deeper geologic formations and are generally continuous across the western and southern portions of the Site, but are not present in the northern and eastern portions of the Site due to the eastward thinning of the sedimentary wedge.

1.3.3 Regional Groundwater Flow Characteristics

Groundwater flow is radial from the interior of the Aerojet Site towards the various Aerojet property boundaries. Groundwater flows from the Aerojet Site in essentially all directions except east, and flow towards the western property boundaries is addressed under the WGOU. As a result, multiple interim remedial action GET facilities were necessary to provide hydraulic containment at the property boundaries. The regional groundwater flow direction beyond the Aerojet property boundaries is generally to the southwest. Local variations in groundwater flow directions are present near the various GET extraction wells. Groundwater flow directions and gradients may also vary between layers across the Site.

Potentiometric surface maps are presented for each layer that is present beneath Zones 1 through 4 in Sections 3 to 6, respectively of the RI report. In general, the groundwater flow directions are different in each zone, reflecting the radial groundwater flow pattern from the interior of the Aerojet Site. Groundwater flow directions beyond the Aerojet property boundaries are to the north, west, and south. However, the groundwater flow direction in the eastern portions of the PGOU is to the west back onto the Aerojet site and to the North and South. The vertical head potentials are typically downwards in the shallow layers (e.g., Layers A and B), but are reversed in the deeper layers. The potential upward vertical gradients are typically highest in the deepest layers. Hydrographs are also presented in the RI report to show water level trends.

1.3.4 Conceptual Nature and Extent of Contamination

The nature and extent of chemicals in groundwater is provided in this section along with a description of the existing interim remedial measures. Groundwater flow direction and hydraulic gradients are also presented. Separate discussions are included for each of the four zones.

1.3.4.1 Zone 1

The portion of Zone 1 addressed as part of the PGOU RI/FS is located adjacent to and north of the northwestern Aerojet property boundary (Figure 1-2). Historical activities that potentially contributed COCs to groundwater beneath Zone 1 include solid and liquid rocket motor manufacturing, degreasing and cleaning operations, liquid and solid waste disposal, and chemical waste burning.

Existing remedial actions in Zone 1 include the GET D and ARGET systems. GET D consists of extraction and recharge wells along portions of the northwestern Aerojet property boundary. Currently, approximately 860 gallons per minute (gpm) of treated groundwater from the GET D treatment facility is recharged to the aquifer through a series of recharge wells. The ARGET hydraulic containment system is located off-site downgradient (northwest) of GET D, and includes extraction wells located on the north and south sides of the American River. Currently, approximately 2,410 gpm of extracted groundwater is conveyed via two underground pipelines to the ARGET treatment facility located on the Aerojet property. Treated groundwater from the ARGET facility is surface discharged to Buffalo Creek and ultimately the American River.

Delays in completing the PGOU RI/FS prompted Aerojet and the Agencies to agree to a program whereby material modifications pursuant to Exhibit VI of the PCD (i.e., "early action commitments") would be made to the existing GETs to enhance the current groundwater containment systems and that would also be consistent with the remedy the selected for PGOU. Aerojet agreed and has implemented early action commitments to the existing ARGET system consisting of three new extraction wells; installation of the fourth extraction well along with expansions of the existing pipelines is currently in progress.

The saturated sediments beneath Zone 1 have been divided into hydrostratigraphic layers B, C, D, E, and F. Layer B is the shallowest layer, although it is unsaturated or absent in the northwestern portions of Zone 1. Layer B ranges from approximately 1 to 20 feet thick, Layers C and D range from approximately 40 to 90 feet thick, and Layer E ranges from approximately 120 to 200 feet thick. The base of Layer F has not been investigated; however, the more permeable portions of Layer F are up to 50 feet thick. Each of the layers beneath Zone 1 dip gently to the west-southwest at approximately 0.5 to 0.8 degrees.

Groundwater beneath Zone 1 flows from the Aerojet Site towards the west and northwest. The hydraulic gradient is relatively flat near the American River and in the community of Gold River and is steeper on Aerojet property. The hydraulic gradient across the Zone 1 PGOU ranges from 0.006 to 0.02 ft/ft. The depth to groundwater increases from east to west. The shallowest groundwater typically occurs at depths of approximately 50 feet bgs near the Nimbus Fish Hatchery and increases in depth to approximately 100 feet bgs near Sunrise and Gold Country Boulevards.

COCs reported in Zone 1 groundwater samples during the RI sampling period (i.e., January 2000 through June 2004) at concentrations that exceeded their respective screening level [see discussion of maximum contaminant levels (MCLs) and potential ARARs in Appendix F of this FS report] include: 1,1-DCA; 1,1-DCE; 1,2-DCA; cis-1,2-DCE; cis/trans-1,2-DCE; benzene, carbon tetrachloride, PCE, TCE, vinyl chloride, 1,4-dioxane, aluminum, chromium, hexavalent chromium, iron, manganese, molybdenum, zinc, chloride, sodium, NDMA, and perchlorate. Many of these parameters were detected in only a few wells or were detected at relatively low concentrations. The most common and widely distributed compounds in Zone 1 are chlorinated VOCs. TCE is the most common VOC and its extent encompasses the extents of all other COCs. TCE was reported on the north and south sides of the American River with the highest concentrations detected near the Nimbus Fish Hatchery. Perchlorate was reported in groundwater south of the American River, but was only reported in one well north of the river. Figures 1-9 through 1-12 show the combined maximum extent of TCE, NDMA, and perchlorate reported above their respective screening levels in Layers C, D, E, and F, respectively.

1.3.4.2 Zone 2

The portion of Zone 2 addressed as part of the PGOU RI/FS is located adjacent to and south of the central and eastern portions of the southern Aerojet property boundary (Figure 1-2). Historical activities that potentially contributed COCs to groundwater beneath Zone 2 include solid rocket motor manufacturing and rehabilitation, degreasing and cleaning operations, and propellant and waste-solvent burning.

The saturated sediments beneath Zone 2 have been divided into hydrostratigraphic layers A through E. There are several wells screened in Layer F; however, Layer F is below the depths at which chemicals have been found in groundwater in the Zone 2 PGOU. Therefore, Layer F is not addressed further in this FS. Layer A is dry approximately 3,000 feet south of White Rock Road, and groundwater north of White Rock Road may percolate downwards into Layer B. Where saturated, the thickness of Layer A ranges from approximately 15 to 50 feet. Layer B is approximately 10 to 40 feet thick in the western portion of Zone 2 PGOU, but is absent in the east. Layer C ranges from 25 to 125 feet in thickness, Layer D ranges from 40 to 60 feet thick, and Layer E ranges from 50 to 100 feet thick. Layers C, D, and E are present throughout the areas of Zone 2 located within the PGOU. Groundwater beneath Zone 2 generally flows southwest, although the flow direction may more southerly in eastern Zone 2. The hydraulic gradients ranged from approximately 0.01 to 0.013 ft/ft in Layers A through E.

COCs have been detected in Layers A, B, C, and D. TCE and perchlorate were the most common and widely distributed COCs, although 1,1-DCE; 1,2-DCA; cis-1,2-DCE; cis/trans-1,2-DCE; PCE; chloroform, methylene chloride, vinyl chloride; iron; and manganese were reported at least one time at concentrations exceeding their respective screening levels. Figures 1-13 through 1-17 show the combined maximum extents of COCs reported above their respective screening levels in Layers A, B, C, D, and E, respectively.

1.3.4.3 Zone 3

Zone 3 is located in the southeastern portion of the Aerojet Site (Figure 1-2). Historical and current operations in Zone 3 have included liquid rocket engine and solid rocket motor testing; waste propellant, solvent, and chemical burning; parts cleaning, metals pickling, and high-altitude atmospheric testing. Area 40 is included in Zone 3 and is located along the eastern boundary of Aerojet property. This area was historically used to burn chemical waste and for TCE separation.

Existing remedial actions in Zone 3 include the GET B system, which provides treatment for groundwater flowing to the south and southwest from the rocket testing facilities on Aerojet. Currently, approximately 1,240 gpm of groundwater is extracted from a series of extraction wells located on Aerojet property along White Rock Road near Gate 7, and on the former Ehnisz Property (southern Zone 3). The treated groundwater from GET B is discharged to Rebel Hill Ditch where it infiltrates back into the groundwater.

Delays in completion of the PGOU RI/FS prompted Aerojet and the Agencies to agree to a program whereby material modifications pursuant to Exhibit VI of the PCD (i.e., "early action commitments") would be made to the existing GETs to enhance the current groundwater containment systems and be consistent with the remedy the Agencies will select for PGOU. Aerojet agreed and has implemented early action commitments to the existing GET B system consisting of four new extraction wells; installation of the associated pipelines is currently in progress.

The saturated sediments beneath Zone 3 have been divided into hydrostratigraphic Layers A through F. Layers A and B are saturated north of Prairie City Road and in a relatively small area within the Prairie City State Vehicular Recreational Area and range in thickness from 15 feet bgs to 70 feet bgs. Layers A and B are typically dry south of Prairie City Highway and east of Grant Line Road. Layers C and D are each approximately 20 to 50 feet thick in northern Zone 3 They increase in thickness in southern Zone 3. Layer C is over 100 feet thick in southern Zone 3 and Layer D ranges from 20 to 80 feet thick in this area. Layers E and F range in thickness from 20 to 60 feet and both layers have been encountered in southern Zone 3, but appear to pinch-out or on-lap onto the bedrock in the northern and northeastern portions of Zone 3.

Potentiometric surface maps indicate that groundwater from the Aerojet Site flows from the northeast and northwest towards the extraction wells located south of Prairie City Road. The hydraulic gradients in Zone 3 range from 0.004 ft/ft in Layer E to 0.019 ft/ft in Layer C. The most commonly observed pattern of groundwater flow is the convergence of groundwater flow paths from the northeast and northwest towards the central area of southern Zone 3.

COCs reported in Zone 3 groundwater samples at concentrations that exceeded their respective lowest potential chemical-specific ARAR include: 1,1-DCA; 1,1-DCE; 1,2-DCA; cis/trans-1,2-DCE; bromodichloromethane; carbon tetrachloride; Freon-113; TCE; 1,4-dioxane; aluminum; arsenic; iron; manganese; silver; diesel; kerosene; NDMA; nitrate; and perchlorate. TCE, perchlorate, and NDMA are the most widely distributed COCs and were reported throughout the PGOU with the highest concentrations detected near Gate 7. Figures 1-18 through 1-23 show the combined maximum extent of TCE, NDMA, and perchlorate reported above their respective screening levels in Layers A, B, C, D, E, and F, respectively.

1.3.4.4 Zone 4

Zone 4 is located in the northeastern portion of the Aerojet Site (Figure 1-2). It encompasses areas historically used for industrial manufacturing as well as approximately 373 acres of undeveloped land that was not used for industrial operations. Historical and recent operations upgradient of Zone 4 primarily supported the testing of liquid rocket engines in Sector A and solid rocket motors in Sector C.

Groundwater management Sectors A and C are located in the eastern and western portions of Zone 4, respectively. Existing remedial actions in Sector A include the GET A facility, which provides hydraulic containment along the northeastern portion of the Aerojet property boundary. Approximately 240 gpm of groundwater is extracted from 10 extraction wells in Sector A and following treatment, the groundwater is discharged to Rebel Hill Ditch and infiltrates into the dredge tailings south of GET A. There are no existing remedial actions in Sector C.

Delays in completion of the PGOU RI/FS prompted Aerojet and the Agencies to agree to a program whereby material modifications pursuant to Exhibit VI of the PCD (i.e., “early action commitments”) would be made to the existing GETs to enhance the current groundwater containment systems and be consistent with the remedy the Agencies will select for PGOU. Aerojet agreed and has implemented early action commitments to the existing GET A system consisting of the installation of seven new extraction wells and pipelines. In addition, treatment of the GET A water is being collocated to a new treatment facility at the current GET B treatment plant location. A pipeline to deliver the extracted water has been completed with completion of the treatment plant currently in progress.

The sediments beneath Zone 4 were divided into four hydrostratigraphic layers and include the Dredged Layer, Layers A and B, and bedrock. The Dredged Layer is present due to historical gold-dredging activities and is found throughout most of Sector C, the former Aerojet landfill and Area 46, and in the southwestern portion of Sector A. The Dredged Layer extends from the ground surface to approximate depths of 40 to 120 feet bgs. Layer A is present throughout Zone 4 and ranges from approximately 30 to 190 feet thick. Layer B is present beneath Layer A in Sector C and is at least 30 to 50 feet thick, but is absent to the east in Sector A. Bedrock outcrops are present at the eastern Aerojet property boundary near Alder Creek, and were reported to dip three to four degrees to the west under the surrounding sediments. The top of bedrock was encountered as deep as 170 ft bgs in Sector A; there are no wells screened in bedrock in Sector C.

Groundwater beneath Sector A flows to the north in Layer A and the Bedrock Layer. In Sector C, the groundwater flow is to the northwest and west in the Dredged Layer and Layers A and B. In the Dredged Layer, the hydraulic gradient averages approximately 0.012 ft/ft and increases to 0.020 ft/ft near the northern portion of the Aerojet Landfill. North of the landfill, it appears that groundwater migrates vertically and laterally into Layer A. In Layer A, groundwater flows to the north in Sector A with a hydraulic gradient of approximately 0.009 ft/ft. In Sector C, the hydraulic gradient is northwest at 0.009 ft/ft. Closer to Alder Creek, the hydraulic gradient is northwest with a magnitude of 0.019 ft/ft. Layer B is only present in the western portion of Sector C and the hydraulic gradient is generally to the northwest with an average magnitude of approximately 0.012 ft/ft.

COCs reported in Zone 4 groundwater samples during the RI sampling period at concentrations that exceeded their respective screening levels include: 1,1-DCA; 1,1-

DCE; 1,2-DCA; cis/trans-1,2-DCE; carbon tetrachloride; Freon-113; TCE; vinyl chloride; 1,4-dioxane; aluminum; arsenic; barium; beryllium; cadmium; chromium; cobalt; iron; lead; manganese; nickel; vanadium; NDMA; and perchlorate. TCE was the most common VOC detected and the sampling for metals was generally conducted on wells located around the perimeter of the former solid waste landfill. Figures 1-24 through 1-26 show the combined maximum extents of VOCs, NDMA, and perchlorate reported above their screening levels in each layer.

1.3.5 Site Conceptual Model

The overall Site Conceptual Model developed for the PGOU is presented on Figure 1-27 in the RI report. The Site Conceptual Model shows that the primary sources of chemicals to groundwater in the PGOU are associated with waste disposal facilities and include drums, storage tanks, ponds, and other waste disposal facilities. Deluge water from the rocket test stands in Zones 3 and 4 is also identified as a primary source. Chemicals were released to soils from the primary sources due to leaks, spills or standard waste management practices employed at the time. Some of these chemicals may have percolated through the vadose zone soils and into groundwater.

Chemicals in groundwater will migrate downgradient through the processes of advection and dispersion. The migration of chemicals in groundwater is influenced by the fate and transport characteristics of each chemical. Advection is probably the dominant process governing the fate and transport of contaminants in groundwater due to the relatively high groundwater velocities.

The fate and transport of chemicals in groundwater is also influenced by dispersive processes. The relative effects of molecular diffusion, mechanical dispersion, sorption, volatilization, and biological degradation on solvents, NDMA, perchlorate, metals, and 1.4-dioxane are summarized on the following chart:

	Dispersion Effects		Retardation		
COC	Molecular Diffusion	Mechanical Dispersion	Sorption	Volatilization	Biological Degradation
Solvents	√ √	√	√ √ √	√ √ √	√ √
Perchlorate	√ √ √	√ √ √	√ √ √	√	√ √
NDMA	√ √	√ √	√ √	√	√
Metals	√	√	√ √	√	√
1,4-Dioxane	√ √	√ √ √	√ √	√ √	√

The pathway for potential exposure to certain chemicals (i.e., VOCs) in the PGOU groundwater could occur due to volatilization of these chemicals from the groundwater and subsequent inhalation by residents or workers within the PGOU. Exposure to chemicals could also occur for residents or workers if groundwater is directly used as a source of domestic, agricultural, or industrial water supply through ingestion, inhalation, or dermal contact.

1.4 Baseline Risk Assessment

The following sections provide an executive summary of the baseline risk assessment (BLRA), Appendix E, that was prepared for the PGOU RI/FS.

1.4.1 Objective and Scope of Baseline Risk Assessment

The objective of this BLRA was to assess potential risks to human and ecological populations who may be exposed to chemicals present in groundwater within the PGOU under both current and future conditions. This BLRA utilized groundwater and surface water data presented in Appendix A (Zone 1 PGOU RI), Appendix B (Zone 2 PGOU RI), Appendix C (Zone 3 PGOU RI), and Appendix D (Zone 4 PGOU RI) to assess the potential risks to human and ecological receptors.

This BLRA consists of a human health risk assessment (HHRA) and a screening-level ecological risk assessment (SLERA) conducted in accordance with risk assessment methodologies developed by USEPA and DTSC and following the scope of work outlined in the Final Perimeter Groundwater Operable Unit Remedial Investigation/Feasibility Study Workplan (EMSI et al., 2002). The HHRA presents an evaluation of the hypothetical use of untreated groundwater for residential supply and the potential for migration of volatile organic compounds (VOCs) from groundwater into indoor air. The SLERA provides a preliminary characterization of potential risks to ecological receptors that may be exposed to chemicals in groundwater

1.4.2 Human Health Risk Assessment

Consistent with applicable guidance, the BLRA involved the following four steps:

1.4.2.1 Data Evaluation

The BLRA considered analytical results for all groundwater sampling conducted between January 2000 and June 2004 and supplemental data collected through November 2004. Solvents (including trichloroethene) and rocket fuel components (including perchlorate and N-nitrosodimethylamine [NDMA]) are the most widely distributed chemicals in groundwater within the PGOU. Other detected chemicals include tetrachloroethene (PCE); 1,2-dichloroethene (DCE); 1,1-DCE; and Freon 113.

In accordance with USEPA requirements, all groundwater data collected within the periods identified above were compiled, and the occurrence and distribution of each constituent was assessed. Screening for Constituents of Potential Concern (COPCs) was conducted based on a concentration-toxicity and frequency of detection evaluation. To screen for COPCs in a particular medium of interest, all samples for that medium were considered and the maximum concentration for each constituent was identified.

The following classes of chemicals were identified for groundwater and surface water:

- VOCs;
- Metals;
- SVOCs;
- Polychlorinated biphenyls (PCBs)/Aroclors;
- Pesticides; and
- Other constituents (e.g., perchlorate, NDMA).

Results of the concentration/toxicity screen and FOD analyses indicated that the following analytes were COPCs for groundwater in Zone 1:

- **VOCs:** 1,1,2,2-PCA; 1,1,2-TCA; 1,1-DCA; 1,1-DCE; 1,2-DCA; 1,2-DCE (total); benzene; BDCM; CCL; CF; cis-1,2-DCE; dibromochloromethane; Freon 113; methylene chloride; PCE; toluene; TCE; and VC.
- **SVOCs:** 1,4-Dioxane; n-buytlbenzenesulfonamide; and NDMA.
- **Other Organics:** Nitrate as NO_3, nitrite as NO_2, and perchlorate.
- **Metals:** Aluminum, barium, boron, hexavalent chromium, copper, iron, molybdenum, silver, and vanadium

Results of the concentration/toxicity screen and FOD analyses indicated that the following analytes were COPCs for Zone 2 groundwater:

- **VOCs:** 1,2-DCA; 1,2-DCE (total); CF; PCE; TCE; and VC.
- **Other Organics:** Nitrate as NO_3 and perchlorate.
- **Metals:** Copper, iron, manganese and vanadium.

Results of the concentration/toxicity screen and FOD analyses indicated that the following analytes were COPCs for groundwater in Zone 3:

- **VOCs:** 1,1-DCA; 1,1-DCE; 1,2-DCA; 1,2-DCE (total); carbon tetrachloride; CF; cis-1,2-DCE; Freon 113; methylene chloride; PCE; TCE; and VC.
- **SVOCs:** 1,4-Dioxane; 1-methyl-2-pyrrolidinone; dimethyl phthalate; and NDMA.
- **Other Organics:** Nitrate as NO_3, nitrite as NO_2, and perchlorate.
- **Metals:** Aluminum, iron, manganese, silver, vanadium, and zinc.

Results of the concentration/toxicity screen and FOD analyses indicated that the following analytes were COPCs for Zone 4 groundwater:

- **VOCs:** 1,1-DCA; 1,1-DCE; 1,2-DCA; 1,2-DCE (total); BDCM; carbon tetrachloride; CF; chloromethane, cis-1,2-DCE; Freon 113; methylene chloride; trans-1,2-DCE, Freon 11, PCE; TCE; and VC.

- **SVOCs:** 1,4-Dichlorobenzene; 1,4-Dioxane; and NDMA.
- **Other Organics:** Nitrate as NO_3, and perchlorate.
- **Metals:** Aluminum, barium, cadmium, cobalt, iron, lead, manganese, nickel, vanadium, and zinc.

Results of the concentration/toxicity screen and FOD analyses indicated that the following analytes were COPCs for surface water:

- **Metals/Inorganics:** Aluminum, arsenic, ammonia as nitrogen, cadmium, iron, lead, molybdenum, nitrate as nitrogen, selenium and vanadium.
- **Organics:** Chloroform, naphthalene and perchlorate.

1.4.2.2 Exposure Assessment

There is no known current use of groundwater for residential supply from unmonitored or untreated wells either at or beyond the property boundary within the PGOU. Additionally, future use of groundwater on the property is restricted and future use of groundwater beyond the property is managed by a special consultation zone. However, recognizing the CVR-RWQCB's designation of the PGOU as a potential drinking water source, this BLRA includes an analysis of the hypothetical use of untreated groundwater for residential water supply. This analysis considered hypothetical exposure to groundwater constituents via the following routes: ingestion, dermal contact, and inhalation of VOCs released during household non-ingestion use (i.e., showering, cooking, laundering, and dishwashing)..

Based on the hydrostratigraphic data and the detection of COPCs, the discharge of groundwater to surface water in Alder Creek and Administration Ditches is considered a potentially complete pathway in this HHRA. However, exposures to constituents in Alder Creek and Administration Ditches are expected to be negligible and limited to occasional dermal contact under a recreational scenario which was evaluated in the HHRA.

1.4.2.3 Toxicity Assessment

Consistent with regulatory guidance, the noncarcinogenic effects of the COPCs were assessed by comparing the calculated chemical intakes with USEPA reference doses. Evaluation of potential cancer risk utilized slope factors published by USEPA and Cal-EPA's Office of Environmental Health Hazard Assessment. This HHRA evaluated petroleum hydrocarbon mixtures through quantitative evaluation of the risks associated with exposure to petroleum constituents such as benzene, toluene, ethylbenzene, and xylenes (BTEX) and polynuclear aromatic hydrocarbons (PAHs).

1.4.2.4 Risk Characterization

Based on the risk analysis, the hypothetical use of untreated groundwater for residential water supply could result in unacceptable levels of risk. In addition, the HHRA identified potential locations in Zone 1, 2 and 4 where risks associated with the hypothetical use of land for either residential or commercial use could result in risks greater than the de minimus risk of 1×10^{-6} due to vapor migration from groundwater. The locations within Zone 1 are in the American River parkway, in open land areas without commercial or residential buildings or along a roadway. In Zone 2, the location is within the Aerojet plant, along Old White Rock Road, and not within an area of either an existing or planned building. In Zone 4 the locations are either within the existing, inactive solid waste landfill or in areas planned for open space development. In considering these findings, two points deserve emphasis:

First, there is no current or likely future use of untreated groundwater for residential water supply. Second, this HRA incorporated a number of conservative assumptions to guard against the underestimation of risks. The uncertainties in risk assessment can be grouped into four main categories and include environmental sampling and analysis, fate and transport modeling, assumptions concerning exposure scenarios and toxicity data and dose response extrapolations. A qualitative discussion of the uncertainties can be found in Section 2.6 of Appendix E, the BLRA.

1.4.3 Screening Level Ecological Risk Assessment

The results of the PGOU RI indicated that Alder Creek in Zone 4 PGOU is the only surface water feature that supports ecological receptors that could potentially receive discharge from PGOU groundwater. The analysis of surface water samples collected from Alder Creek as part of the RI detected trace concentrations of acetone, chloromethane, naphthalene, perchlorate, NDMA, and various inorganic constituents. Screening of these detected constituents against conservative ecological screening levels identified barium, boron, cadmium, manganese, and selenium as COPCs. Further evaluation indicated that the presence of those metals in Alder Creek did not appear to be site related and/or did not pose a potential risk to aquatic receptors. Additionally, none of the primary groundwater COPCs (i.e. TCE, perchlorate and NDMA) exceeded screening levels in surface water samples. Thus the screen results indicate that adverse ecological effects are not expected to occur associated with potential groundwater discharge to surface water.

A bioassessment of Alder Creek was also performed to further evaluate the potential effects on biota from the discharge of impacted groundwater in Zone 4 PGOU. The bioassessment involved the collection, identification, and comparison of benthic macroinvertebrates (BMI) at three locations along Alder Creek. The bioassessment found that, in general, the BMI communities at the three locations were not substantially different and did not indicate a potential for site related impact. Minor variations in the BMI communities appear likely due to physical characteristics of the stream such as shading and sediment compaction.

The results of the screening and bioassessment identified no specific, site-related impacts and therefore no further sampling or ecological risk assessment was recommended.

2 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This section includes discussions of RAOs, potential ARARs, general response actions (GRAs) that will satisfy the RAOs, and identification and screening of technology types and process options.

2.1 Remedial Action Objectives

The initial step in identifying remedial alternatives in the FS is to formulate RAOs. RAOs are media-specific goals designed to protect human health and the environment. RAOs specify the contaminants and media of interest, exposure pathways, and remediation goals that permit a range of alternatives to be developed on the basis of chemical-specific ARARs and site-specific risk-related factors.

As discussed previously, the only media currently of concern for Part 1 of the PGOU RI/FS is groundwater. The identified chemicals of concern include chlorinated VOCs, perchlorate, NDMA, and 1,4-dioxane. There is no known current use of groundwater for residential supply from unmonitored or untreated wells either at the property boundary or beyond the property boundary within the PGOU. Groundwater on Aerojet is not used for any purposes, and future groundwater use is encumbered by environmental restrictions. Future groundwater use within the PGOU and not within the Aerojet property boundary is regulated under Sacramento County Ordinance. The Sacramento County Environmental Management Department manages a "Consultation Zone" that requires all parties to consult with the RWQCB-CVR prior to drilling a well within a 2,500-foot distance from chemicals in groundwater around the Aerojet Site. Additionally, the future use of groundwater both at and beyond the property boundary is heavily monitored because of the presence of COCs in the groundwater associated with past practices by Aerojet, McDonald Douglas (IRCTS site), and the Air Force (Mather Air Force Base), among others. Recognizing the CVRWQCB's designation of groundwater beneath the PGOU as a potential drinking water source, the BLRA included analysis of the hypothetical use of untreated groundwater for residential water supply. Although there is no current or likely future use of untreated groundwater for residential water supply, the risk characterization analysis in the BLRA indicates that the hypothetical use of untreated groundwater for residential water supply may result in unacceptable levels of risk.

The overall goal of any remedial alternative is to protect human health and the environment. In order to achieve this goal for the PGOU, the following preliminary RAOs were identified by Aerojet in the PGOU RI/FS Work Plan:

- Protect human health and the environment from exposure to contaminated groundwater;

- Minimize offsite migration of chemicals where practicable to protect long term beneficial uses;

- Reduce contaminant concentrations in already contaminated groundwater in an efficient cost-effective manner; and

- Protect public drinking water wells and provide treatment or alternate supply for those drinking water wells that have been or potentially may become impacted by chemicals at unacceptable levels.

The following are additional preliminary RAOs identified by the Agencies in their comments on the PGOU RI/FS Work Plan:

- Achieve containment of the contaminated groundwater to minimize future migration of contaminants until cleanup is achieved;

- Restore groundwater within the PGOU to beneficial uses, to the extent technically practicable.

2.2 Potential ARARs

Section 121(d) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 U.S.C. Section 9621, states that remedial actions on CERCLA sites must attain (or justify the waiver of) any federal or more stringent State environmental standards, requirements, criteria, or limitations that are ARARs. Applicable requirements are those cleanup standards, criteria, or limitations promulgated under federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or State law that while not applicable, address problems or situations sufficiently similar to the circumstances of the proposed response action and are well-suited to the conditions of the particular site.

Pursuant to EPA guidance, ARARs generally are classified into three categories: chemical-specific, location-specific, and action-specific requirements. Chemical-specific ARARs include those laws and requirements that regulate the release to the environment of materials possessing certain chemical or physical characteristics or containing specified chemical compounds. These requirements generally set numerical health- or risk-based concentration limits or discharge limitations for specific hazardous substances. Location-specific ARARs are those requirements that relate to the geographical or physical position of the site, rather than the nature of the COCs or the proposed site remedial actions. Action-specific ARARs are requirements that define acceptable handling, treatment, and disposal procedures for hazardous substances.

A requirement may not meet the definition of an ARAR, but still may be useful in assessing whether to take action at a site or to what degree action is necessary. This can be particularly true when there are no ARARs for a site, action, or contaminant. Such requirements are called to-be-considered (TBC) criteria. TBC criteria are nonpromulgated advisories or guidance issued by a federal or State government that are not legally binding, but that may provide useful information or recommended procedures for remedial action. Although TBCs do not have the status of ARARs, they are considered together with ARARs to establish the required level of cleanup for protection of human health or the environment. The critical difference between a TBC and an ARAR is that one is not required to comply with or meet a TBC when deciding on a remedial action. However, should a TBC be established as a cleanup standard in the ROD, then the TBC effectively produces the same results as an ARAR.

For a description of specific potential ARARs in connection with the PGOU, refer to Appendix F. The specific potential ARARs in Appendix F respond to the Agencies' comments on the Draft PGOU RI/FS.

2.3 Identification of General Response Actions, Technologies, and Process Options

In this section GRAs, technologies, and process options are described and an overview of the process used to identify and screen technologies is provided. The overview is followed by a detailed discussion of the GRAs, and the identification and screening of technology types and possible process options.

2.3.1 General Response Actions

After RAOs are established for a site or OU, media-specific GRAs are developed to satisfy the RAOs. The RAOs for the PGOU FS were described previously in this section. On the basis of the current understanding of the COCs and environmental conditions associated with the PGOU, the GRAs that could be implemented to achieve these RAOs include the following:

- No-Action: No attempt is made to satisfy the RAOs and no remedial measures are implemented. No-Action is required for consideration by the NCP as a basis against which the other alternatives are compared;

- Institutional controls: Non-engineering methods by which access to contaminated groundwater is physically restricted or regulated, and/or contamination is monitored;

- Monitoring;

- Domestic and water supply wellhead treatment;

- Containment of groundwater: Actions that result in contaminated groundwater being contained, thereby minimizing or eliminating the migration of COCs and preventing exposure to contamination. Groundwater containment has a corollary benefit of some mass removal, although mass removal is not the primary objective;

- Treatment of groundwater; and

- Management/reuse of treated groundwater.

A summary of these GRAs is illustrated in Figure 2-1.

2.3.2 Technologies and Process Options

For each GRA, broad technology groups and specific process options that could be used to implement these actions are identified. Technologies refer to general categories (e.g., chemical treatment or biological treatment). Process options refer to the specific processes within each technology type (USEPA, 1988a). As discussed in Section 4, the No-Action GRA is included to provide a reference with which to compare the other alternatives that are developed.

Evaluation of potentially applicable technology types and process options is a key step in the FS process. The criteria for identifying potentially applicable technologies are provided in EPA guidance (EPA, 1988a) and in the NCP (EPA, 1990a). A strong statutory preference for remedies that are reliable and provide long-term protection is identified in Section 121 of CERCLA, as amended. The primary requirements for a final remedy are that it be both protective of human health and the environment and cost effective. Hence, candidate technologies and process options need to be capable of satisfying these key factors. A summary of potentially applicable remedial technology types and process options is illustrated in Figure 2-1.

2.4 Technical Implementablity Screening of Groundwater Remediation Technologies and Process Options

The universe of potentially applicable technology types and process options applicable to each identified general response action are initially reduced by evaluating the options with respect to technical implementability.

USEPA presumptive remedy guidance (Presumptive Remedies: Policies and Procedures; USEPA, 1993a) was used where appropriate to identify technologies and process options. Presumptive technologies were used to select ex-situ groundwater treatment process options. Eight presumptive technologies are identified in EPA's guidance document *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (EPA, 1996c.) Four of these technologies are applicable to organic contaminants (air stripping, granular activated carbon, chemical/ultraviolet oxidation, and aerobic biological reactors). When the presumptive technologies are used to treat dissolved contaminants in extracted groundwater, site-specific identification and screening of alternatives is not required. The basis for eliminating these steps is provided in the guidance listed above and EPA's *Analysis of Remedy Selection Experience for Ground Water Treatment Technologies at CERCLA Sites, Draft Final* (USEPA, 1996b). All of the presumptive technologies are well understood and have been used for many years for water, wastewater, and groundwater treatment.

In accordance with USEPA guidance (USEPA, 1988a), technologies and process options for the groundwater response actions were identified and screened for technical implementability. Screening results are summarized on Figure 2-1.

Process options for groundwater remediation that require excavation to groundwater, placement of a physical barrier in groundwater, or phytoremediation were not considered because of the depth to groundwater, the vertical depth of existing or potential occurrences of COCs, and the difficulty of constructing a long trench. These include all of the process options associated with interceptor trench subsurface drains; vertical physical barriers such as slurry walls and jet grouting, HDPE curtain walls, and reactive in-situ metals walls; and air sparging. Air sparging was also eliminated because two of the COCs, perchlorate and NDMA, are not removed by this process.

Presumptive process options for ex-situ treatment of dissolved contaminants in groundwater were identified in USEPA's *Final Guidance: Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (USEPA, 1996c). Screening and evaluation of the presumptive process options is not required. However, the presumptive process options were screened to provide a comparison with other process options that were identified. Several of the presumptive process options (e.g., precipitation, electrochemical processes, and aeration) were screened out because they are not applicable to the COCs relative to the PGOU.

Several other process options were eliminated in the technical implementability screening process. Membrane separation will remove the COCs, but was not considered because of the large flowrate of reject or concentrate sidestream anticipated to be generated (up to 10 percent of the groundwater to-be-treated flowrate). Electrochemical processes and aeration of metals were eliminated because they are not applicable for the COCs. Aerobic bioreactors have limited effectiveness for chlorinated VOCs and anaerobic bioreactors are difficult to implement and thus were screened out. Deep well injection of treated groundwater was eliminated because the permeability of the deeper groundwater units is not expected to be great enough to support this process option.

With the exception of horizontal extraction wells and several innovative process options, the majority of the process options retained as a result of the technical implementability screening have been or are currently being used at the Aerojet Sacramento facility. Aerojet continues to evaluate innovative treatment process options for treatment of chemicals, including VOCs, NDMA and perchlorate. For example, Aerojet has demonstrated that the biological reduction process will remove perchlorate from groundwater using either an aboveground-reactor or in-situ configuration. Aerojet continues to evaluate (including bench and pilot scale testing) innovative technologies for the management and treatment of contaminated groundwater and is currently piloting the in-situ biological reduction process for both perchlorate and VOCs removal.

The process options that were retained following the technical implementability screening are as follows. Additional innovative technologies may be appropriate for addition and selection in the future.

General Response Action	Remedial Technology	Process Options
Monitoring	Monitoring	• Groundwater monitoring
Institutional Controls	Proprietary Controls	• Deed restrictions • Deed notices • Easements • Covenants
	Governmental Controls	• Groundwater use restrictions • Advisories
Domestic and Water Supply Wellhead Treatment	Wellhead treatment	• Home carbon treatment unit (domestic) • LPGAC, ion exchange, UV/oxidation for water supply wellheads
Monitored Natural Attenuation	Monitoring/ Verification	• Groundwater monitoring

General Response Action	Remedial Technology	Process Options
Containment	Hydraulic Barriers	• Vertical extraction wells • Recharge wells
Collection	Groundwater Extraction	• Vertical extraction wells
In-situ Treatment	Stripping	• In-well aeration/stripping (for VOCs)
	Chemical Treatment	• In-well oxidation
	Biological Treatment	• Enhanced biological reduction
Liquid Phase Treatment	Ex-situ Physical/Chemical Treatment	• LPGAC • Air stripping • Filtration • Ion exchange • UV/oxidation, HiPOx • pH adjustment

	Ex-situ Biological Treatment	• Cometabolic bioreactors (biological reduction)
Vapor Phase Treatment for Air Stripping Offgas	Ex-situ Physical/ Chemical Treatment	• Direct discharge • VPGAC • Catalytic oxidation • Thermal oxidation
Disposition of Treated Groundwater	Management/Reuse of Treated Groundwater	• Direct potable water supply • Indirect potable water supply • Non-potable water reuse • Streamflow augmentation • Groundwater recharge

2.5 Evaluation of Retained Process Options

Technologies and process options considered to be technically implementable are evaluated in greater detail on the basis of effectiveness, implementability (both technical and administrative), and relative cost as defined by the following factors:

- Effectiveness - in terms of protecting human health and the environment in both the short term and the long term;

- Implementability - in terms of technical feasibility, resource availability, and administrative feasibility; and

- Cost - in a comparative manner (i.e., low, moderate, or high) for technologies of similar performance and/or implementability.

These evaluation criteria are applied only to the GRAs and technologies being evaluated for the PGOU and not to possible combinations of these technologies and process options that might be combined to form remedial alternatives.

Technologies and process options that are not effective in protecting human health and the environment, that cannot be implemented because of the physical characteristics of the site or COCs, or that have a cost that is an order of magnitude greater than a similar technology are eliminated during this phase of the screening. In accordance with USEPA guidance (1988a), effectiveness is the major emphasis of this screening evaluation. Less weight is given to cost and implementability. The technologies and process options that are retained after the effectiveness, implementability, and cost screenings are assembled into a range of remedial alternatives in Section 4.

The evaluation of groundwater remediation process options for effectiveness, implementability, and cost is presented on Figure 2-2 and is discussed in the following sections organized by general response actions. For some technologies, more than one process option was retained. Examples of multiple process options potentially applicable for the PGOU that were retained and were used to assemble alternatives are as follows:

Remedial Technology	Process Options Retained
Hydraulic barriers and groundwater extraction	• Vertical extraction wells • Horizontal extraction wells
Liquid phase treatment for removal of VOCs	• LPGAC • Air stripping • UV/oxidation; HiPOx
Liquid phase treatment for removal of perchlorate	• Ex-situ biological reduction • Ion exchange • In-situ biological reduction
Vapor phase treatment for air stripping offgas	• Direct discharge • VPGAC • Catalytic oxidation • Thermal oxidation
Management/reuse of treated groundwater	• Direct potable water supply • Indirect potable water supply • Non-potable water reuse • Streamflow augmentation • Groundwater recharge

In accordance with USEPA guidance (1988a), representative process options are selected to simplify the development and evaluation of alternatives. However, the specific process option used to implement a remedial action may not be selected until the remedial design phase. Selection of a representative process option does not preclude the application of other retained process options at the site.

2.5.1 Institutional Controls

The institutional controls process options are nonengineering methods by which federal, state, and local governments or private parties can prevent or limit access to affected environmental media and are applicable in conjunction with other response actions. Institutional controls do not reduce contaminant mobility, toxicity, or volume, but they can reduce the potential for exposure to contaminated material. Institutional control measures that apply solely to groundwater, such as groundwater restrictions, may be used to prohibit or limit the drilling of new wells or prohibit the temporary use of existing wells. While implementation of these process options alone may not attain the RAOs, they will most likely be necessary to maintain the integrity of any active remediation system that may be selected and will therefore be considered in combination with other process options during the development of alternatives.

Land use restrictions may take the form of governmental controls (e.g., zoning, well construction and groundwater use restrictions, and groundwater use advisories) and proprietary controls (restrictions on land use through the use of deed restrictions, easements, covenants, and reversionary interests).

On the basis of effectiveness, implementability, and cost, institutional controls have been retained.

Onsite Institutional Controls. Propriety controls that can be implemented on the Aerojet property include restrictions on land use including restricting the use of groundwater and restricting recharge through impoundments, deed restrictions, easements, covenants and reversionary interests. There are deed restrictions currently on the Aerojet Site through PCD Paragraph 11 and on lands no longer part of the Aerojet Superfund Site through environmental restrictions

Offsite Institutional Controls. Offsite institutional controls can include propriety controls such as land purchase and restrictions on land use through the use of easements. Governmental controls can include groundwater use notices/restrictions and advisories, well construction restrictions, zoning, and tailored ordinances.

A covenant is a legal, written instrument attached to the property deed that is used to record land use restrictions. The covenant may take the form of easements, restrictions, and servitudes as described below:

- Easements allow access to property, for example, so operation, maintenance, and monitoring can be performed;

- Restrictions such as deed or access restrictions are specific provisions that apply to the use of property; for example, notifying of the potential that groundwater may be contaminated or restrictions on the use of groundwater for certain purposes; and

- Servitudes are specific provisions that apply to the property owner and either oblige or restrict the owner from certain uses of the property that would impair an established easement.

As shown on Figure 2-2, institutional controls were not eliminated during the evaluation of groundwater technologies and process options.

Sacramento County has established a Consultation Zone in its well drilling ordinance. Title 6, Chapter 6.28.00 of the ordinance requires: "any application for a well permit within 2000 feet of a known contaminant plume is subject to special review by appropriate regulatory agencies, including but not limited to the Sacramento County

Environmental Management Department and the California Regional Water Quality Control Board, Central Valley Region, to ensure that public health and groundwater quality are protected."

Descriptions of the institutional controls and the respective enforcement and monitoring activities to be included in each remedial alternative are provided in Section 4.

2.5.2 Monitoring

Groundwater monitoring is a process option that is expected to be a component of each remedial alternative in Section 4. Groundwater monitoring may serve the purpose of evaluating the migration of COCs and, depending upon the remedial alternative selected, to evaluate the effectiveness of any hydraulic containment and of any treatment processes. Groundwater monitoring is integral to monitored natural attenuation, which may be part of a selected remedial alternative.

2.5.3 Domestic Wellhead and Water Supply Wellhead Treatment

Domestic wellhead treatment is a process option that would involve installation of a home carbon treatment (for VOCs removal) unit on the water piping from a domestic well after the piping enters the respective dwelling unit. Water supply wellhead treatment would involve installation of the appropriate treatment technology at the wellhead location to remove any COC prior the water being introduced to the municipal or private water distribution system. Technologies that have been approved by the California Department of Health Services (DHS) for use in this application include LPGAC for removal of VOCs and other organics; ion exchange for removal of nitrate, perchlorate, and other inorganics; and chemical oxidation (e.g., ozone, hydrogen peroxide) and/or UV/chemical oxidation for disinfection and removal of certain organics not removed by LPGAC (e.g., NDMA and 1,4-dioxane).

2.5.4 Monitored Natural Attenuation

Monitored natural attenuation refers to the reliance on natural attenuation processes to achieve site-specific remediation objectives within a timeframe that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of 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. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, or destruction of contaminants (USEPA, 1999).

2.5.5 Groundwater Containment and Collection

Extraction wells were selected as a representative process option for the potential containment and collection response actions. This process option involves drilling vertical extraction wells that are screened within the hydrogeologic layer where contamination is known to exist or is projected to be present based on modeling. The wells are pumped and a hydraulic barrier is established to control contaminant migration. If contaminants are present in the groundwater, they are physically removed with the groundwater. Public water supply wells can also serve the function of extraction wells for a hydraulic barrier.

2.5.6 In-situ Treatment

All in-situ treatment process options were eliminated during the evaluation process, with the exception of in-well stripping, in-well oxidation, and enhanced biological reduction innovative process options. While the in-well stripping and in-well oxidation in-situ treatment process options only remove VOCs and other organics (in-well oxidation), they were retained after the evaluation because of their potential application with alternatives that might involve groundwater containment or collection using vertical wells. When assembling alternatives that might involve extraction of groundwater using vertical wells, from a groundwater treatment perspective it may be desirable to remove VOCs and other organics at the extraction well rather than after the groundwater is blended with groundwater from one or more other wells that may or may not contain VOCs or other organics. Limited operational and cost information is available for these process options. Because of the limited cost and performance data available at this time, a representative in-situ treatment process was not selected and the process option is not included in the developed alternatives. However, these innovative process options are not precluded from being implemented during remedial design of any selected remedy in the future if information becomes available to suggest that the technology can achieve significant savings in cost or time to achieve RAOs.

Treatability testing of the in-situ enhanced biological reduction innovative process option is currently being conducted by Aerojet for removal of perchlorate and VOCs.

Within the context of this PGOU FS, innovative process options that were retained, but not selected as representative process options, will be considered relative to the representative process option on a case-by-case basis during the remedial design phase as these technologies become more developed and sufficient information regarding cost and performance is available.

2.5.7 Liquid Phase Treatment

For ex-situ treatment of groundwater, LPGAC, air stripping, UV irradiation/oxidation, ion exchange, and biological reduction were selected as representative process options. These technologies have all been used historically to treat water from water supply wells or are currently used at the Aerojet GET treatment facilities to treat contaminated groundwater.

<u>LPGAC.</u> LPGAC is a commonly used method of removing VOCs and other organics. Activated carbon, when contacted with water containing organic material, will remove the organic compounds selectively by a combination of adsorption of the less polar molecules, filtration of the larger particles, and partial deposition of colloidal material on the exterior surface of the activated carbon. The extent of removal of soluble organics by adsorption depends on the diffusion of the particle to the external surface of the carbon and diffusion within the porous adsorbent.

Activated carbon is generally considered to consist of rigid clusters of microcrystallites, with each microcrystallite made up of a stack of graphitic planes. Each carbon atom within a particular plane is bonded to four adjacent carbon atoms, with carbon atoms at the edges of the graphitic planes having highly reactive (active) radical sites. At these sites, which consist of a heterogeneous mix of basal planes and microcrystallite edges, adsorption takes place. The adsorbent capacity of the carbon is reached when the active sites have been filled. As these sites fill, sorption equilibrium is approached, and effluent quality deteriorates to an unacceptable level. Then, the carbon is considered spent and removed for regeneration, typically to a reactivation furnace. Most carbon-adsorption systems utilize granular activated carbon (GAC) in flow-through column reactors which can be employed as an upflow-countercurrent type operated with packed or expanded carbon beds or as an upflow or downflow fixed-bed unit having two or three columns in series.

<u>Air Stripping.</u> Air stripping is currently used at GETs A, B, D, ARGET, and E/F as the main process to remove VOCs (GET D) or as a VOC-removal polishing step subsequent to UV/oxidation (GETs A, B, ARGET, and E/F).

Air stripping is a physical unit process in which dissolved molecules are transferred from a liquid, such as groundwater, into a flowing gas or vapor stream, such as air. The driving force for mass transfer is provided by the concentration gradient between the liquid and gas phases, with solute molecules moving from the liquid to the gas until equilibrium is reached. The governing equilibrium relationship is Henry's Law. VOCs in groundwater having Henry's Law constants above 10 atmospheres (atm) are readily strippable at ambient temperatures. The economic viability of the conventional air stripping process is, however, limited to the VOCs whose Henry's Law constants are more than about 100 atm.

The most common configuration for application of air stripping to groundwater treatment for removal of VOCs is the counter current packed tower air stripper. In countercurrent packed towers, packing materials are used which provide high void volumes and high surface area. The water flows downward by gravity and air is forced upward. The untreated water is usually distributed on the top of the packing with sprays or distribution trays and the air is blown through the tower in forced or induced draft. This design results in continuous and thorough contact of the liquid with the gas and minimizes the thickness of the water layer on the packing, promoting efficient mass transfer. For removal of volatile organic compounds from groundwater, it is economically desirable to operate packed columns with a maximum water flow rate and with the minimum volume of air necessary to achieve the desired concentration of organics in the treated water.

Depending on the air quality requirements where air stripping is to be employed, offgas emissions from the air stripper may require treatment. The process options for air stripper offgas treatment are discussed later in this section.

Filtration. This process option is employed to remove particulates that may be generated by other processes and need to be removed prior to the groundwater undergoing treatment by another process or prior to management/reuse of the treated groundwater. There are many common configurations of filters available including dual-media gravity and pressure filters, continuous upflow sand filters, and in-line bag filters. The configuration of filter is selected based on the specific filter application.

UV/oxidation. UV/oxidation is a generic name for a family of advanced oxidation technologies (AOT) that use ultraviolet light either alone or in conjunction with standard oxidants such as hydrogen peroxide or ozone to achieve greatly increased treatment performance over that obtained with either hydrogen peroxide or ozone alone. The most common UV/oxidation process is the use of UV with hydrogen peroxide. Ultraviolet light is used to split the hydrogen peroxide molecule, producing very reactive hydroxyl radicals (OH^-). These hydroxyl radicals then quickly react with organic contaminants in the water, eventually breaking them down into carbon dioxide and water. UV/oxidation is currently being used at GET facilities to remove NDMA, VOCs and 1,4 dioxane.

Other AOTs are commercially available that produce hydroxyl radicals without the presence of UV light. An example includes the HiPOx technology which uses hydrogen peroxide in conjunction with ozone to oxidize organic compounds. A full-scale pilot test was recently conducted at the ARGET treatment facility using the HiPOx technology. Test results showed removal of chlorinated ethylenes to below 0.5 ug/L and 1,4-dioxane to below 3 ug/L.

Biological Reduction. The biological reduction process is currently used at the GETs E/F treatment facility to remove perchlorate from GETs E and F groundwater. This technology can be described as a biological reduction process using a fixed-film bioreactor. A fixed-film of biomass is attached to granular activated carbon operated as a fluidized bed (GAC/FB). Groundwater, amended with an organic substrate (e.g., ethanol) and nutrients (nitrogen and phosphorus) is introduced into the influent stream. As groundwater passes through the system, the microorganisms derive energy from the oxidation of the organic substrate, simultaneously destroying the perchlorate, reducing it to chloride and oxygen. In a fluidized-bed bioreactor, flocculated organisms are suspended by drag forces exerted by the rising liquid. By balancing operating conditions and organism characteristics, the flocs are retained in the bioreactor while the medium flows through it continuously. Perchlorate reduction is similar to nitrate reduction. The energy-generated portion of the denitrification reaction with ethanol as the organic substrate (neglecting cell synthesis) is:

$$5C_2H_5OH + 12NO_3^- + 12H^+ \rightarrow 10CO_2 + 6N_2 + 21H_2O$$

The similar reaction for perchlorate during the biological reduction process is:

$$2C_2H_5OH + 4ClO_4^- + 8H^+ \rightarrow 4CO_2 + 4Cl^- + 10H_2O$$

Note that nitrate and perchlorate are completely destroyed, and the carbon substrate (ethanol) is oxidized by bacteria. The end products for the process are biomass (sludge), carbon dioxide, water, chloride, and nitrogen (HLA, 1998). The biomass is typically discharged to a POTW or dewatered and disposed in a non-hazardous landfill.

Ion Exchange. Perchlorate and other anionic COCs in groundwater are effectively removed by ion exchange, a process where contaminant anions are exchanged and replaced by an innocuous anion, typically chloride. Ion exchange is an effective method for many groundwater treatment applications due to its efficiency in removing contaminants present in varying concentrations at relatively low costs. Most of the ion exchange resins manufactured are used for water treatment and strong-base anionic resins have been used to remove nitrates from drinking water for several years. Although ion exchange technology is well-known, the effectiveness of an ion exchange process depends, among other factors, on the operational configuration of the process. Key parameters that determine the efficiency and impact the economics of an ion exchange process are treatment ratio and the volume of regeneration waste generated. Treatment ratio refers to the volume of feed water that can be treated before breakthrough of the contaminant(s) is obtained. Regeneration waste volume refers to the volume of waste generated by the ion exchange process while regenerating the ion exchange resin saturated with contaminants. An effective ion exchange process is one that achieves high treatment ratios while producing low regeneration waste volume.

Several ion exchange equipment designs are currently employed including relatively simple fixed bed downflow or upflow contactor systems that can be operated in either concurrent or countercurrent (service flow in the direction opposite to the regeneration), continuous moving bed systems, and continuous multi-port rotating distributor systems.

Aerojet is currently piloting the ion exchange process using fixed bed contactor pairs operated in series for removal of perchlorate at the GET D and GET B facilities. Spent ion exchange media is not regenerated on-site, but is removed from the contactors and replaced with regenerated media by the ion exchange vendor. Several resins with high capacities for perchlorate are also being evaluated.

2.5.8 Vapor Phase Treatment for Air Stripping Offgas

Vapor-phase treatment refers to process options to remove VOCs in air stripper offgas in the event that concentrations of contaminants in the offgas warrant emission control. Direct discharge, VPGAC, catalytic oxidation, and thermal oxidation were selected as representative vapor-phase treatment process options.

VPGAC. GAC is the most common method of vapor phase treatment for removal of VOCs from air stripper gas. VPGAC is popular for several reasons, including its relative ease of implementation and operation, its reputation as a commonly-used treatment, its ability to be regenerated for repeated use, and its applicability to a wide range of contaminants at a wide range of flow rates. As described for the LPGAC process, VPGAC contactors are provided in standard prefabricated units that can contain up to 20,000 pounds of activated carbon. VPGAC contactors are typically operated in series and, when loaded to breakthrough with VOCs, the GAC is either replaced or regenerated on-site using a steam-based desorbing system. The costs are associated with concentrations in the emissions and the volume of air required to be treated.

The adsorption capacity of the carbon depends on several factors, including influent vapor temperature and relative humidity and, most importantly, the influent VOC types and concentrations. Isotherms, which show the mass of contaminants that can be adsorbed per unit mass of carbon, are available to predict the contaminant-specific adsorption capacity for a specific type of carbon.

Direct and Flameless Thermal Oxidation. In this offgas treatment process, vapors from the air stripping process are pre-heated and then heated to a high temperature (typically greater than 1,400^{o}F) in a combustion chamber, destroying the contaminant vapors. If thermal oxidation is used to treat a vapor stream containing chlorinated VOCs, depending on the concentrations of the VOCs in the vapor stream, a scrubbing system may be required downstream of the oxidizer to neutralize hydrochloric acid that is generated in the process.

Catalytic Oxidation. Catalytic oxidation is a variation of the thermal oxidation process which uses catalysts to increase the oxidation rate of contaminant vapors at lower temperature than conventional thermal oxidation processes. A catalytic oxidation process always requires a lower oxidation temperature [less than 1000^{o}F] than thermal oxidation. The products of combustion of a catalytic oxidation reaction are the same as those of thermal oxidation and may require a downstream scrubber. The heat of oxidation liberated by catalytic oxidation is the same as that of a thermal oxidation. Catalysts are used to increase the oxidation rate at lower temperatures. The advantages of catalytic oxidation over thermal are the lower fuel requirement because of the lower operating temperature and less severe service requirement for materials of construction.

2.5.9 Disposition of Treated Groundwater

Several possible process options have been identified for management and/or possible reuse of untreated or treated groundwater produced by any hydraulic containment or groundwater collection/treatment alternatives. There are several water resource management opportunities and actions that are available in or near the PGOU in connection with this OU. Regional and local water resource planning includes consideration of the water flows in the American River and the Folsom South Canal, as well as the current and projected future potable and nonpotable water demands of existing development in Sacramento County and various planned development areas in the eastern and southern portions of the County. Quantities of untreated or treated groundwater on an average annual basis that are currently or potentially available vary for the remedial alternatives described in Section 4. There also may be desirable combinations of the following management/reuse options, as matched to a given remedial alternative.

Possible process options for management or reuse of treated groundwater include the following. At present, the streamflow augmentation and recharge options are being used to manage treated groundwater from the GET facilities at Aerojet's Sacramento site.

Direct Potable Water Supply. Treated groundwater can be made available to meet urban water supply needs. It can be provided directly under one or more alternatives to local water supplies to a point of use within a water distribution system or directly with wellhead treatment. It can also be provided directly through regional surface water treatment facilities processing treated ground water to meet requirements of DHS. This reuse to provide a potable supply can be implemented if DHS approves the use of treated groundwater for potable use.

Indirect Potable Supply. Indirect potable water use can be achieved through treatment and discharge to surface waters, to the Folsom South Canal, or both. This indirect use would include full water treatment at the point of use by a responsible utility. The treated groundwater could be integrated with proposed regional water supply plans of Sacramento County or residential and commercial development plans in the Eastern Sacramento County area. These development plans include Douglas/Sunrise, the villages of Zinfandel and Rio del Oro, Lewis Homes at Mather, or other proposed developments in the area that are projected to require new water supplies or will have increased water demand.

These growing potable demands can be met through treatment of water from the American River watershed delivered through the Folsom South Canal, but such deliveries are currently inconsistent with the policies of the Water Forum and Sacramento County, which require that water delivered from the American River be diverted at its mouth or from the Sacramento River. Since flows in the American River and, potentially, the Folsom South Canal can be augmented by approved surface discharges under one or more of the alternatives in the OU, a similar amount of water could be diverted from the system without compromising the local policies with regard to water use.

The use of this water would be subject to conveyance approvals by the USBR that could be acquired in part to offset any lost groundwater extraction capacity of existing customers. In addition, an evaluation of potential impacts to more senior or environmental rights and the environmental consequences of the discharge along the River between the Nimbus Reservoir and the point of treated groundwater discharge would also need to be performed to ensure no adverse impact. Using the treated groundwater in a manner that assists in meeting the growing potable and non-potable water needs in eastern Sacramento County would be consistent with the County policies regarding American River flow management. This approach would allow remediation action efforts to be conducted in concert with water management objectives and provide economic benefits using the most efficient water resource management system possible.

Non-Potable Water Use. Another groundwater use option would be to supply water for Aerojet's operations, irrigation of golf courses, parks, open space, and residential areas, or other areas currently proposed for development south and west of the PGOU. Sacramento has a County policy to install dual systems where economically feasible. These systems can provide different qualities of water from various sources to meet different levels of public health protection.

Aerojet operates and maintains a non-potable industrial water system at its Sacramento facility that is comprised of water distribution piping throughout the property, elevated water storage tanks to provide sufficient water pressure within the system, and fire hydrants. Water from the system is used in the various manufacturing processes and serves as the primary source of water that is available for fire suppression. The current source of water for the industrial water system is untreated surface water that is provided to Aerojet by the City of Folsom. Treated groundwater could be used as the source of water for the Aerojet industrial water system in lieu of the untreated surface water.

Treated water could be delivered directly from the OU facilities into a non-potable reuse system to be used for irrigation, provided that a dual piping system was constructed as part of all new developments that could be economically served. Permitting conditions for this source of non-potable water should be less stringent than water for potable uses and from wastewater sources.

Streamflow Augmentation. The discharge of treated water to surface waters directly or indirectly entering the American River can provide instream and downstream benefits. These discharges would be managed through an existing or new NPDES discharge. One possible process option for the management of treated water would be to discharge the treated water to the American River through the existing Buffalo Creek outlet or via Alder Creek. The discharge of treated water would need to meet all surface and receiving water requirements. Discharge to the American River would provide for enhancing streamflow for fish or downstream users. Discharge of treated water to the American River also represents an option anticipated to require the least amount of water delivery obligations, including operation and maintenance costs.

Discharge to the American River may be deemed an "off-property" action and therefore may require permitting through the NPDES program, or possibly the State regulatory activities. The flows in the American River are managed by the BOR under permits issued by the State that have been subject to recent judicial review. State permits may be necessary to divert water that has been discharged to the American River as part of remedial action. It is also possible that water discharged to the River could be resold downstream under a water marketing/transfer proposal yet to be developed. The extent of federal and state permitting required for long-term augmentation of American River flows depends upon the proposed program and the beneficial use of such waters.

<u>Groundwater Recharge.</u> The groundwater resource underlying the region is replenished on an annual basis and generally flows from east to west or southwest. While local extraction may affect the performance of nearby remedial extraction facilities, the long-term yield of the basin is unaffected by the extraction and/or recharge of the quantities of water described in this report. In addition, recharge of the treated water could return water to the basin.

<u>Satisfying Varying Demands.</u> The various remedial alternatives would supply treated groundwater at a steady annual rate. It is likely that the most beneficial uses would accept water at seasonally varying rates. Accommodating this seasonal variation can be accomplished by:

- Varying the operation of extraction and treatment facilities within acceptable limits;
- Discharging increasing quantities of water in the winter months to surface waters for streamflow augmentation or downstream use;
- Providing a combination of recharge and surface water use that optimizes investments and costs; and
- Designing the use facilities to provide for local storage to meet peak demands.

One or more of these options could be employed to optimize the remediation and delivery performance.

Incorporation of the management of the treated groundwater into the overall water supply plans for the eastern portion of the County could be used to minimize potential investment by Sacramento County and would delay if not eliminate the need for a new major Sacramento River diversion and accompanying treatment and pumping facilities at least for service to the portions of eastern Sacramento County that are farthest from the river. It would allow for staged development of water supply facilities meeting all public health and environmental requirements. All costs above the basic remedial action cost would become part of the new development financing program with potentially significant cost savings to both the remediation and development efforts.

Given the benefits of a coordinated approach to the wholesale water supply and development of eastern Sacramento County in conjunction with the requirements and potential beneficial uses associated with groundwater treatment at the Site, all of the possible water management/reuse process options will be retained for consideration in the OU FS. This will allow all of the interested parties to provide input on the possible alternatives for management/reuse of treated groundwater.

3 DESCRIPTION AND EFFECTIVENESS OF CURRENT REMEDIAL ACTIONS

Several Interim Action remedial systems located within the PGOU and Aerojet site were installed and are currently operated and maintained by Aerojet to prevent the continued offsite migration of chemicals in groundwater at the boundary of the Aerojet Site or to collect off-site contaminated groundwater. These Interim Actions include the GET D and ARGET systems in Zone 1, GET E/F in Zone 2 (included in OU-3), GET B in Zone 3, and GET A in Zone 4. The locations of these Interim Actions are shown on Figure 3-1. A description, history, and evaluation of the effectiveness of each of these GET systems are provided in the following sections.

3.1 Zone 1

The two interim action remedial systems in Zone 1 are the GET D and ARGET groundwater extraction and treatment systems located on- and off-site, respectively (Figure 3-1).

3.1.1 GET D Description and History

GET D was originally constructed in 1981 to hydraulically contain groundwater at the Sector D site perimeter using 24 groundwater extraction wells and six treated groundwater recharge wells. Extraction and recharge well numbers, design flows, and actual flows are provided on the table titled "Current Extraction and Recharge Well Information" in Appendix G. Additional information regarding the well construction is provided in the "Facility Report – GET D System" (Aerojet, 1995), which is also included in Appendix G.

Extracted groundwater is conveyed from the extraction wells to the GET D treatment facility that is located on-property, as shown on Figure 3-1 and in the process flow schematic for GET D (Figure 3-2). Groundwater from the extraction wells is pumped to the GET D treatment area and blended in a 20,000 gallon surge tank prior to treatment. The current combined groundwater flowrate from the GET D extraction wells averages approximately 860 gpm.

The original treatment facilities installed in 1981 at GET D consists of air stripping (two pairs of packed column, counter-current towers) for VOCs removal, addition of carbon dioxide for pH adjustment, and bag filtration. The air stripping system has a hydraulic capacity of 1,400 gpm, given the VOC removal design requirements provided in the "Facility Report – GET D System" contained in Appendix G. Design information for the carbon dioxide feed system and other equipment and appurtenances at the GET D treatment facility are also included in the Facility Report.

An air stripper offgas emissions treatment system consisting of two granular activated carbon beds and a steam-based solvent recovery system was also installed in 1981. The system has never been used because the emissions concentrations from the air stripping process have always been low enough to not warrant emissions control.

Ion exchange contactors for removal of perchlorate were added to the downstream end of the treatment train in August 2002. The contactors are operated in series and have a hydraulic and treatment capacity of 1,200 gpm. Treated water from GET D is recharged through a series of six recharge wells located southwest of the extraction wells (Figure 3-1) at depths ranging from 80 to 160 ft bgs. A process flow schematic for the GET D system is included as Figure 3-2.

Effluent requirements for all the GET treatment systems are contained in Exhibit VI of the PCD and are as follows:

Parameter	Monthly Average (ug/L)	Daily Maximum (ug/L)
TCE	2	4
PCE	2	4
1,1,1-TCA	2	4
Freon-12	2	4
1,1-DCE	2	4
trans-1,2-DCE	2	4
1,2-DCA	1	2
Chloroform	5	10
Vinyl Chloride	1	2
NDMA	0.02	0.02

3.1.2 GET D Treatment Effectiveness

Evaluation of the effectiveness of the treatment processes with respect to removing the COCs is provided in the table titled "GET D Process Performance Data" included in Appendix G. Available analytical results for the various sample locations within the treatment facility (see Figure 3-2 for sample locations) for the time period from January 2002 through November 2003 are included on the table in Appendix G. Comparison of influent and effluent data for the entire facility and each unit process (where available) are included on the tables. Removal percentages are also calculated for the various COCs. As indicated on the "GET D Process Performance Data" table, total VOCs and perchlorate are consistently removed to 0.25 and 1.0 ug/L, respectively.

3.1.3 ARGET Description and History

Prior to the 2007-2009 modifications, the ARGET hydraulic containment system containred 18 extraction wells on the north and south sides of the American River (Figure

3-1) including six wells screened in Layer C, two screened in Layers C and D, six screened in Layer D, one screened in Layers D and E, and two screened in Layer E only. Extraction well numbers, screened layer information, design flows, and actual flows are provided on the table titled "Current Extraction and Recharge Well Information" in Appendix G. Additional information regarding the well construction is provided in the "Operation and Maintenance Plan for the American River Groundwater Extraction and Treatment Facility" (Aerojet, 1998a, and 2000). A process flow schematic for the ARGET groundwater extraction and treatment facilities (Figure 3-3) shows the location of the respective extraction wells relative to the American River. The combined groundwater flowrate from the ARGET hydraulic containment wells is currently approximately 2,400 gpm. Approximately 560 gpm is contributed by the wells located on the southeast side of the American River (Fish Hatchery wells) and approximately 1,840 gpm from all of the other wells.

Groundwater extracted from well 1156, located on the north side of the American River, is treated via a LPGAC contactor, which has a hydraulic capacity of 150 gpm. The treated groundwater from well 1156 is discharged to the Fish Pond at Sailor Bar Park.

Extracted groundwater is conveyed from the extraction wells to the ARGET treatment facility that is located on Aerojet's property, as shown on Figure 3-1. Groundwater from the wells located on the north side of the American River is conveyed under the river via a 16-inch diameter pipeline. After the river the pipeline diameter increase to 20-inches to accommodate the increased flow from wells located on the southwest side of the river. A separate secondary-contained 10-inch diameter pipeline conveys untreated groundwater from wells 4325, 4330, and 4335.

The process flow schematic for the ARGET system (Figure 3-3) shows the unit processes employed at the facility and the treatment sequences for the two flowstreams prior to 2007-2009. Groundwater from wells 4325, 4330, and 4335 flows into a 40,000 gallon influent tank and is then pretreated via the HiPOx process which replaced the UV/chemical oxidation process for removal of 1,4-dioxane and most VOCs. Following pretreatment, the groundwater from extraction wells 4325, 4330, and 4335 is combined with groundwater from the other 15 extraction wells and passed through a single packed column air stripper for removal of the remaining VOCs. The treated water from the ARGET treatment facility is discharged to Buffalo Creek under an NPDES permit. Effluent discharge limitations for the ARGET groundwater treatment facility are included in Table F-3. The NPDES permit CA0083861 for GET E/F is included in Appendix G.

The ARGET treatment facility was designed to accommodate a total flow rate of 3,445 gpm, 785 gpm from the Fish Hatchery wells and 2,660 gpm from wells located to the north of the American River and southwest of the River. The air stripping system has a hydraulic capacity of 3,800 gpm, given the VOC removal design requirements provided in the "Operation and Maintenance Plan for the American River Groundwater Extraction and Treatment Facility". The UV/oxidation reactors include six Calgon 30 kilowatt lamps and were designed to accommodate a flowrate of 1,500 gpm.

3.1.4 ARGET Treatment Effectiveness

Evaluation of the effectiveness of the treatment processes with respect to removing the COCs is provided in the table titled “ARGET Process Performance Data” included in Appendix G. Available analytical results for the various sample locations within the treatment facility (see Figure 3-3 for sample locations) for the time period from September 2002 through November 2003 are included on the table in Appendix G. Comparison of influent and effluent data for the entire facility and each unit process (where available) are included on the tables. Removal percentages are also calculated for the various COCs. As indicated on the “ARGET Process Performance Data” table, total VOCs are consistently removed by the UV/oxidation pretreatment and air stripping processes to 0.25 ug/L. Several comparisons are provided in the “ARGET Process Performance Data”table: Fish Hatchery wells influent/plant effluent (sample locations 7065/7069); pretreated Fish Hatchery wells and flow from north and southwest of the River/plant effluent (7068/7069); and, flow from north and southwest of the River/plant effluent (7067/7069).

Estimated concentrations of 1,4-dioxane below the Method 8270C reporting limit (10 µg/l) are consistently observed in treatment influent samples collected downstream (sample location 7065) from the Fish Hatchery extraction wells. Two samples (sample location 7065) collected in March 2003 and June 2003 reported 1,4-dioxane at 11µg/l. 1,4-dioxane is not observed in samples collected from the American River (sample locations 7070/7071) or treatment effluent samples (sample location 7069) either above the reporting limit (10 µg/l) or as estimated concentrations.

3.1.5 Hydraulic Containment Effectiveness – Zone 1

The hydraulic containment of the GET D and ARGET extraction systems was assessed by evaluating water levels, chemical distribution maps, chemical concentration trends, and by conducting groundwater flow simulations. These data were used primarily to identify areas where additional or modified groundwater extraction may be necessary to achieve RAOs for hydraulic containment in Zone 1. Depictions of the hydraulic containment provided by the GET D and ARGET extraction systems are provided in Figures H2-7, H2-8, and H2-9 (Layers C, D, and E, respectively), which show the existing Zone 1 hydraulic containment zone derived from particle tracking analyses conducted in conjunction with groundwater modeling simulations (Appendix H) overlaid with an outline of the maximum extent of contamination in all layers.

The GET D extraction system provides hydraulic containment in Layers B, C, D, and E near the northwestern Aerojet property boundary, downgradient of source areas in Areas 20, 49, and the Central Disposal Area. Modeling simulations and chemical distribution data indicate that the entire GET D extraction and recharge systems are unnecessary for achieving hydraulic containment because chemicals are present downgradient beyond the capture area of the GET D extraction wells. Continued operation of some GET D extraction wells may benefit downgradient hydraulic containment by reducing the mass of chemicals that would otherwise migrate downgradient.

The ARGET extraction system is located downgradient of GET D and was constructed to provide hydraulic containment for COCs present in Layers C, D, and E on the north and south sides of the American River. Some TCE is present northwest of the downgradient ARGET extraction wells and groundwater flow simulations suggest that this TCE will not be hydraulically contained.

On the south side of the American River, ARGET extraction wells are located near the leading edge of TCE in Layers C, D, and E. The Layer E wells recently began operating and long term water level and chemical concentration trends will be determined. Potentiometric surface maps and groundwater modeling simulations suggest that these wells should contain the downgradient extent of TCE, just south of the American River.

Groundwater flow simulations show that TCE and perchlorate present south of the southwestern ARGET extraction wells will not be contained by the ARGET system. These chemicals are present in a continuous area in Layers C and D, extending from the GET D recharge wells to the east to approximately Sunrise Boulevard to the west. Extraction wells being installed as part of the remedial action currently being implemented for the WGOU (OU-3) will address the downgradient containment of TCE and perchlorate in this area.

3.1.6 Other Historical Remedial Efforts in Zone 1

Several smaller remedial efforts have been completed at a few source areas and for some groundwater in Zone 1. A free-product recovery system was installed in Area 20 to remove diesel fuel downgradient of Sites 3D/52D in the early 1980's. The system is no longer operating. Some perchlorate and TCE in groundwater downgradient of the CDA were removed during two pilot tests conducted to evaluate enhanced intrinsic bioremediation in 2000 and 2001, respectively (GeoSyntec, 2001).

3.2 Zone 2

Existing groundwater extraction and treatment systems in Zone 2 on the Aerojet site include the GET E groundwater extraction wells, the GET F extraction wells, and the GET E/F groundwater treatment facility (Figure 3-1). These systems provide containment of groundwater upgradient of the western boundary of the Site and were included as part of the remedial action selected for WGOU. Separately Aerojet has prepared and submitted documents regarding the WGOU, which provide the extent of capture for that operable unit.

A process flow schematic for the GET E/F system is included as Figure 3-4. Effluent discharge limitations for the GET E/F groundwater treatment facility are included in Table F-3. The NPDES permit, CA0083861, is included in Appendix G.

3.3 Zone 3

The interim action remedial system located in the southeastern section of the Aerojet Site in Zone 3 (Figure 3-1) is the GET B groundwater extraction and treatment system (Aerojet, 2000).

3.3.1 GET B Description and History

GET B was placed into operation in September 1986 pumping groundwater from off-property extraction wells 1198, 4080, 4085, and 4090. In 1988 extraction wells 4095, 4195, and 4215 were added (wells 4095 and 4195 replaced 1198). Offsite extraction well 4303 and onsite wells 98, 4011, and 4304 were installed in 1995. Offsite extraction wells 4460, 4465, 4410, 4400, and 4405 and onsite extraction wells 4475 and 4480 were added in 1998. Prior to 2007-2009 the total number of operational extraction wells associated with GET B was 21, ranging in depth from 115 to 260 feet. Two of these wells are screened in Layer B (Wells 98 and 4304) while the remainder (Wells 4480, 4475, 4011, 4215, 4195, 4095, 4080, 4085, 4090, 4405, 4303, 4450, 4455, 4495, 4400, 4460, 4570, 4565, 4575, and 4410) are screened in both Layers C and D. Extraction well numbers, design flows, and actual flows are provided on the table titled "Current Extraction and Recharge Well Information" in Appendix G. Additional information regarding the well construction is provided in the "Facility Report – GET B System" (Aerojet, 2002b), which is also included Appendix G.

Groundwater from wells located to the south in Sector B (southern wells) is conveyed to the GET B treatment facility via an 18-inch pipeline, while groundwater from the wells located immediately south of White Rock Road (northern wells) flows through a 14-inch diameter pipeline. Groundwater from the WRND Interim Action (extraction wells 4505, 4510, 4515, 4520, and 4525) is also directed to the GET B treatment facility via an 8-inch diameter pipeline for VOCs removal. Current combined influent flowrate to the GET B treatment facility averages approximately 1,240 gpm, with approximately 390 gpm contributed by the northern wells and approximately 850 gpm from the southern wells. Extraction well, piping, and the GET B treatment facility locations are shown on Figure 3-1. A process flow schematic for GET B is included as Figure 3-5).

The GET B treatment facility was designed to remove NDMA and VOCs and originally consisted of a 10-acre solar UV treatment pond, a chemical feed system, two induced draft cross-current air stripping columns operated in series, and an effluent infiltration area. The effluent infiltration area is located along Rebel Hill Ditch.

The GET B treatment facility was redesigned to consist of two treatment trains, the North System and the South System and was operated in this manner during 1998. Groundwater from the northern extraction wells was pretreated via the UV/oxidation process prior to air stripping for removal of NDMA and most VOCs. In the South system, flow from the southern wells was pumped directly to the southern air stripper for

VOCs removal. Treated effluent from both systems was combined and discharged to a common infiltration area, which then drains into Rebel Hill Ditch.

The UV/oxidation system is designed to achieve an effluent water quality of less than 0.020 ug/L of NDMA at a maximum of influent concentration of 40 ug/L NDMA at a maximum flow rate of 1,750 gpm. (Hydraulically, the UV/oxidation system can accommodate 3,500 gpm) It currently consists of seven Calgon 90 kilowatt (KW) UV/chemical oxidation reactors operated in parallel. Each 90 KW reactor consists of 3, 30 KW reactors in a series configuration. Both packed tower counter-current air stripping towers are designed to accommodate 2,000 gpm hydraulic capacity. Additional air stripping design information with respect to COCs is included in the "Facility Report – GET B System" included in Appendix G. Design information for the hydrogen peroxide feed system associated with the UV/oxidation process and other equipment and appurtenances at the GET B treatment facility are also included in the Facility Report.

The process configuration at the GET B treatment facility was modified to reflect the sequence or treatment depicted in the current process flow schematic (Figure 3-5). The ion exchange process for perchlorate removal was installed in January 2004. The ion exchange contactors are operated in series and have a hydraulic capacity of 2,000 gpm. Currently, groundwater from both the northern and southern wells is collected in the sump of one of the air strippers, which serves as an influent equalization tank. From there, groundwater is pumped through bag filters, ion exchange contactors for perchlorate removal, UV/oxidation reactors for NDMA removal and pretreatment for removal of VOCs, and air stripping for removal of any remaining VOCs.

Effluent requirements are listed previously in Section 3.1.1.

3.3.2 GET B Treatment Effectiveness

Evaluation of the effectiveness of the treatment processes with respect to removing the COCs is provided in the table titled "GET B Process Performance Data" included in Appendix G. Available analytical results for the various sample locations within the treatment facility (see Figure 3-5 for sample locations) for the time period from September 2002 through November 2003 are included on the table in Appendix G. Comparison of influent and effluent data for the entire facility and each unit process (where available) are included on the tables. Removal percentages are also calculated for the various COCs. As indicated on the "GET B Process Performance Data" table, total VOCs are consistently removed to 0.25 ug/L and NDMA is consistently removed to below 0.012 ug/L for the time period analyzed. Long-term performance information with respect to the ion exchange system for perchlorate removal is not yet available.

3.3.3 Hydraulic Containment Effectiveness – Zone 3

The GET B system is designed to provide hydraulic containment of VOCs, NDMA, and perchlorate present beneath portions of Zone 3 in Layers B, C, D, E, and F. This section addresses the areas where data suggest that hydraulic containment of groundwater containing these chemicals may not be sufficient for achieving RAOs. Water levels, chemical concentration trends, and computer modeling were used as tools to evaluate the GET B hydraulic containment. These data suggest that there are two general areas in Zone 3 that may require additional groundwater extraction to meet RAOs for hydraulic containment. Depictions of the hydraulic containment provided by the GET B extraction system are provided in Figures H4-3, H4-4, and H4-5 (Layers B, C, and D, respectively), which show the existing Zone 3 hydraulic containment zone derived from particle tracking analyses conducted in conjunction with groundwater modeling simulations (Appendix H) overlaid with an outline of the maximum extent of contamination in all layers.

Potentiometric surface maps show that the overall groundwater flow direction in Zone 3 is towards the south, and that groundwater converges towards the central portion of Zone 3 from the northeast and northwest. In general, hydraulic containment is focused on Layers C, D, E, and F, as Layers A and B are either unsaturated or absent in the downgradient southern areas of Zone 3.

The first area where hydraulic containment does not appear complete is located near the downgradient southern extent of chemicals in groundwater. An east-west oriented line of extraction wells is intended to hydraulically contain the downgradient extent of COCs in Layers C and D; however, it appears that COCs were present downgradient of the southern extraction wells prior to their initial operation. Water level data and groundwater flow simulations suggest that COCs already present south of these wells are not hydraulically contained. In addition, groundwater flow simulations suggest that hydraulic containment may not be complete just west of the southern-most extraction wells.

The second area where hydraulic containment may not be complete is in Layers E and F, between White Rock Road and the southern Aerojet property boundary. Groundwater containing TCE, perchlorate, and NDMA was present south of Layer E and F extraction wells 4475 and 4480 prior to their initial operation and these chemicals are not hydraulically contained south of White Rock Road. Monitor well 30338-30339 was installed to delineate the southeastern extent of COCs in Layers E and F.

There is no existing hydraulic containment system specifically addressing perchlorate reported in Layer A/B groundwater beneath potential source areas in the Prairie City Off-Highway Vehicular Park (Area 39). This area is included in the Boundary Operable Unit. The monitor wells in this area are screened in very low permeability sediments that are often dry and may be perched above the regional water table. Hydraulic containment of groundwater in this area is impractical as the wells are often dry or bail dry during sampling and would not likely produce sustainable quantities of water. In addition, potentiometric surface maps suggest that if groundwater from this area does percolate into underlying Layer C, it should flow west towards the southern GET B extraction wells.

3.4 Zone 4

The interim action remedial system located in the northeastern section of the Aerojet Site in Zone 4 (Figure 3-1) is the GET A groundwater extraction and treatment system (Aerojet, 1997).

3.4.1 GET A Description and History

GET A was placed into operation in July 1986 (extraction wells 4100, 4105, 4110, 4115, 4120, 4125, and 4130) with an initial flow of 360 gpm to contain and treat chemicals in on-site Layer A groundwater, downgradient of Management Areas 30, 31, and 32. In February 1995, extraction wells 4012 and 4013 were added to also intercept contaminated groundwater near a suspected source. In 1997, extraction well 4500 was installed to replace extraction well 4115 and well 4430 was constructed, bringing the number of operational extraction wells to 10. In 2007-2008 seven additional extraction wells were installed. The extraction wells are screened in Layer A and range in depth from 67 to 150 feet, except for 1 new extraction well, screened in Layer B. Locations of the wells and treatment facility prior to 2007-2009 are shown on Figure 3-1. Current combined flow from the wells averages approximately 250 gpm. Extraction well numbers, design flows, and actual flows are provided on the table titled "Current Extraction and Recharge Well Information" in Appendix G. Additional information regarding the well construction is provided in the "Facility Report – GET A System" (Aerojet, 1997), which is also included Appendix G.

The GET A treatment facility originally consisted of a 1.5-acre solar UV treatment pond, a chemical feed system, one induced draft cross-current air stripping column, and an effluent infiltration area. The effluent infiltration area is located along Rebel Hill Ditch.

The current treatment system consists of one 90 KW Calgon UV/chemical oxidation reactor (the 90 KW reactor consists of 3, 30 KW reactors in a series configuration) and one counter-current packed tower air stripper for VOCs removal. A process flow schematic for the GET A system is included as Figure 3-6. The air stripping system has a hydraulic capacity of 400 gpm and a process capacity of 340 gpm given the VOC removal design requirements provided in the "Facility Report – GET A System" contained in Appendix G. Design information for the hydrogen peroxide feed system associated with the UV/oxidation process and other equipment and appurtenances at the GET A treatment facility are also included in the Facility Report.

Effluent requirements are listed previously in Section 3.1.1.

3.4.2 GET A Treatment Effectiveness

Evaluation of the effectiveness of the treatment processes with respect to removing the COCs is provided in the table titled "GET A Process Performance Data" included in Appendix G. Available analytical results for the various sample locations within the treatment facility (see Figure 3-6 for sample locations) for the time period from September 2002 through November 2003 are included on the table in Appendix G. Comparison of influent and effluent data for the entire facility and each unit process (where available) are included on the tables. Removal percentages are also calculated for the various COCs. As indicated on the "GET A Process Performance Data" table, total VOCs are consistently removed to below 3.3 ug/L by the UV/oxidation process and to 0.25 ug/L after the air stripper prior to discharge. NDMA is consistently removed to below 0.012 ug/L for the time period analyzed.

3.4.3 Hydraulic Containment Effectiveness – Zone 4

The GET A system is designed to provide hydraulic containment of VOCs and NDMA present beneath portions of Zone 4 in Layer A. Multiple lines of evidence were reviewed to evaluate the effectiveness of hydraulic containment of GET A, although more detailed analysis typically necessary to demonstrate hydraulic containment was unnecessary for this evaluation and comparison of remedial alternatives. For the purposes of this FS, the analysis focuses on areas where the hydraulic containment provided by GET A may not be sufficient for achieving RAOs. A depiction of the hydraulic containment provided by the GET A extraction system is provided in Figure H5-4, which shows the existing Zone 4 hydraulic containment zone in Layer A derived from particle tracking analyses conducted in conjunction with groundwater modeling simulations (Appendix H) overlaid with an outline of the maximum extent of contamination in all layers.

Potentiometric surface maps indicate that the predominant groundwater flow direction in Zone 4 is to the north-northwest. The GET A extraction system intercepts groundwater migrating from potential source areas located upgradient in Zone 4. Chemical distribution maps and water level data suggest that the northern GET A extraction wells have provided effective hydraulic containment of groundwater originating at the potential source areas. However, these same data also show that TCE and NDMA are present sidegradient (west and northwest) of the GET A extraction wells. The contoured potentiometric surface suggests that the area of hydraulic containment provided by GET A extends approximately 800 feet west of the western-most GET A extraction well. This observation is consistent with increasing chemical concentrations observed in several monitor wells in the areas, and with particle tracking analyses conducted in conjunction with groundwater modeling simulations (Appendix H).

4 DEVELOPMENT AND SCREENING OF ALTERNATIVES

4.1 Introduction

This section describes the remedial alternatives assembled from the technologies and process options retained in Section 2. Often, a large number of remedial alternatives are screened against the criteria of overall effectiveness in meeting the RAOs, implementability, and cost in order to screen out certain alternatives, thereby allowing the more detailed evaluation (in Section 5) to be undertaken with a reduced number of alternatives. Here, given the limited remedial actions that are potentially viable for the groundwater concerns in Zones 1 through 4, the number of alternatives assembled are a manageable number, and additional screening to eliminate alternatives was not required. All of the alternatives have been carried forward to the detailed analysis presented in Section 5.

This OU FS is evaluating a remedial action for groundwater for each of the Zones included within the PGOU. It does not evaluate source control measures for specific onsite source areas. As discussed in Section 2, the following preliminary RAOs were identified by Aerojet in the PGOU RI/FS Work Plan:

- Protect human health and the environment from exposure to contaminated groundwater;
- Minimize offsite migration of chemicals where practicable to protect long term beneficial uses;
- Reduce contaminant concentrations in already contaminated groundwater in an efficient cost-effective manner; and
- Protect public drinking water wells and provide treatment or alternate supply for those drinking water wells that have been or potentially may become impacted by chemicals at unacceptable levels.

The following are additional preliminary RAOs identified by the Agencies in their comments on the PGOU RI/FS Work Plan:

- Achieve containment of the contaminated groundwater to minimize future migration of contaminants until cleanup is achieved;
- Restore groundwater within the PGOU to beneficial uses, to the extent technically practicable.

The NCP (EPA, 1990a) requires that, at a minimum, the following alternatives be considered during development of remedial alternatives:

- A No-Action alternative;
- A limited number of remedial alternatives that attain site-specific remediation levels within different restoration time periods using one or more technologies; and
- Alternatives that include innovative treatment technologies, if those technologies offer the potential for comparable or superior performance or implementability, fewer or less adverse impacts than other available approaches, or lower costs for levels of performance similar to that of demonstrated treatment technologies.

Using the technologies and representative process options retained in Section 2 and considering the specific RAOs developed for the PGOU as well as the alternatives required to be considered by the NCP, remedial alternatives were developed as described in the following sections.

4.2 Listing of Alternatives

A listing of the remedial alternatives that are described in Section 4 is as follows:

4.2.1 Zone 1 (Sector D and ARSA)

Alternative Z1-1: No Action with Groundwater Monitoring

Alternative Z1-2: Contain and Remediate Zone 1 Groundwater

Alternative Z1-3: Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

4.2.2 Zone 2

Alternative Z2-1: No Action with Groundwater Monitoring

Alternative Z2-2: Contain and Remediate Zone 2 Groundwater

Alternative Z2-3: Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

4.2.3 Zone 3 (Area 39 and Sector B)

Alternative Z3-1: No Action with Groundwater Monitoring

Alternative Z3-2: Contain and Remediate Zone 3 Groundwater

Alternative Z3-3: Contain, Remediate, and Remove Additional Mass from Zone 3 Groundwater

4.2.4 Zone 4 (Sector A and Sector C)

Alternative Z4-1: No Action with Groundwater Monitoring

Alternative Z4-2: Contain and Remediate Zone 4 Groundwater

Alternative Z4-3: Contain, Remediate, and Remove Additional Mass from Zone 4 Groundwater

Each of the alternatives is described in the following sections. More detailed information is further provided in Section 5 where each alternative is evaluated against the NCP criteria. All alternatives include groundwater monitoring. In addition, all of the alternatives include institutional controls in the form of deed restrictions, which include restrictions on the use of groundwater and are currently on the Aerojet Site through the Partial Consent Decree Paragraph 11, or on lands removed from the Superfund site through the Environmental Restrictions of the 2002 Stipulation and Order Modifying the Partial Consent. There are also restrictions through off-property governmental institutional control; namely, Sacramento County's Consultation Zone Ordinance and DHS oversight over public drinking water systems.

The detailed description and conceptual design of each of the alternatives described below was based upon the results of the RI (Appendices A through D) and the results of FS-level numerical groundwater flow models for each Zone. Descriptions of the models, discussion of model calibration, and the approach/results of the various model simulations for the alternatives described in this section are summarized in Appendix H.

The detailed descriptions and conceptual designs included in this section are FS-level evaluations that provide an adequate basis for evaluation of alternatives. However, it is anticipated that there may be changes to the representative process options during the period of evaluation of this FS and through any remedy design. For example, there may be developments in treatment technologies that will meet performance standards more efficiently, at a lower cost, or in such a manner that less treatment residuals are generated. Additional evaluation of design of any remedy, including new extraction well or treatment facility location, actual treatment technologies and the optimal sequence and configuration of these treatment technologies, and the option or options that will be employed for management/reuse of treated groundwater will be further evaluated in any remedial design activity.

Additionally, preparation of the PGOU RI/FS has occurred over a multi-year timeframe. Accordingly, the current RI/FS report may not reflect the latest data for the site; however, the most recent data supports the overall interpretation of the site conceptual model. In addition, the FS-level evaluations provided in this report are adequate for selection of remedy. The most current site data will be evaluated as part of design and implementation of the selected remedy and should account for any changes between completion of the RI/FS report and implementation of remedy.

4.3 Description of Alternatives

4.3.1 Zone 1 (Sector D and ARSA)

4.3.1.1 Alternative Z1-1: No Action with Groundwater Monitoring

Alternative Z1-1 (No Action) is included as required by the NCP to serve as a baseline for comparison of the other alternatives. For this alternative, the GET D and ARGET groundwater extraction, treatment, treated groundwater recharge facilities (GET D), and treated groundwater discharge facilities would be terminated and no further remedial activities would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Zone 1.

4.3.1.2 Alternative Z1-2: Contain and Remediate Zone 1 Groundwater

Alternative Z1-2 involves the continued operation of the existing ARSA off-property hydraulic barrier and Fish Hatchery wells, including eight existing extraction wells: 4302, 4325, 4330, 4335, 4380, 4580, 4585, and 4620. Existing GET D extraction well 4035 would continue to operate. Recharge of treated GET D groundwater would cease. Existing GET D recharge wells 5020 and 5105 would be converted to extraction wells. In addition, two new extraction wells completed in Layer C and two new extraction wells completed in Layer D would be constructed. One Layer C and one Layer D well would be located north of the American River to address COCs that have apparently migrated northwest downgradient of existing ARSA extraction well 4620. A pair of Layer C and D wells would be constructed to near the west end of the abandoned GET D recharge field to contain groundwater in this area. Operation of this hydraulic barrier would contain the Zone 1 groundwater within the PGOU and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of the groundwater.

With the exception of existing GET D extraction well 4035, the results of the FS-level groundwater flow model (Appendix H) show that all other GET D extraction wells and all recharge wells would be unnecessary to contain Zone 1 groundwater. The existing GET D groundwater treatment facilities would be demolished as the GET D facility is more than 27 years old and would require replacement to continue operating. All groundwater would be treated at the existing ARGET groundwater treatment facility. The estimated groundwater flowrate under Alternative Z1-2 is approximately 3,560 gpm.

A conceptual depiction of the facilities that would comprise Alternative Z1-2 is contained on Figure 4-1. More detailed discussion of the modeling and assumptions made are contained in Appendix H. Table 4-1 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of the COCs under Alternative Z1-2. As shown on Table 4-1, groundwater from all hydraulic barrier extraction wells is anticipated to contain VOCs that will require removal at the existing ARGET treatment facility. Groundwater from existing and proposed extraction wells located south of the American River and the Fish Hatchery wells (4325, 4330, and 4335) are anticipated to contain perchlorate.

Groundwater from existing and proposed extraction wells located south of the American River and the Fish Hatchery wells (4325, 4330, and 4335) would be conveyed to the ARGET treatment facility via the existing 10-inch secondary-contained polyethylene pipe and pretreated for removal of perchlorate, 1,4-dioxane, and most VOCs. The existing GET D recharge piping would be utilized to route groundwater flow from wells 4035, 5020, and 5105 in Sector D to connect with the existing 10-inch diameter ARGET influent pipeline that currently carries untreated groundwater from extraction wells 4325, 4330, and 4335. A section of new 8-inch buried piping constructed on Aerojet property would be needed to extend the existing recharge piping from the approximate location of existing recharge well 5030 to the existing 10-inch diameter ARGET influent pipeline. The modeled flowrate from these wells is estimated to be approximately 1,120 gpm. This pretreated groundwater would be blended with groundwater from extraction wells located north of the American River (approximately 2,440 gpm conveyed via existing 20-inch pipeline) and directed through the air stripping process for remaining VOCs removal.

As depicted on the process flow schematic for the ARGET treatment facility (Figure 3-3), the facility was constructed to provide for pretreatment of groundwater conveyed via the 10-inch secondary-contained pipeline. Ion exchange contactors would be installed upstream of the existing UV/oxidation facilities for removal of perchlorate. The existing UV/oxidation pretreatment capacity is rated at approximately 1,500 gpm, therefore no expansion of the UV/oxidation process at the ARGET treatment facility would be necessary. Likewise, since the hydraulic design capacity of the existing air stripping process is rated at 3,800 gpm, no expansion of the air stripping process at the ARGET treatment facility would be necessary to accommodate the estimated flow of 3,560 gpm from Alternative Z1-2.

As an alternative to routing flow from new hydraulic containment wells C1 and D1 located north of the American River (Figure 4-1) to the ARGET facility for treatment, the approximately 1,100 gpm flow could be directed to a location adjacent to Fair Oaks Water District well 1047. A treatment facility consisting of new LPGAC contactors would be constructed at this location. VOCs would be removed via the LPGAC process and treated groundwater would be either discharged to the storm sewer system or used by the Fair Oaks Water District.

Alternative Z1-2 also includes groundwater monitoring. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 1. Samples would also be collected to evaluate the performance of the unit processes at the ARGET treatment facility and as required to monitor the effluent discharge to Buffalo Creek.

In addition, Alternative Z1-2 would include institutional controls in the form of off-property governmental institutional control; namely, Sacramento County's Consultation Zone Ordinance and DHS oversight over public drinking water systems that requires reporting of contaminants to DHS and which establishes obligations on water purveyors to provide potable water supplies to their customers.

TCE and perchlorate present in groundwater near the former GET D recharge wells northwest of the intersection of the Folsom South Canal and Highway 50 appears to be contiguous with the TCE and perchlorate present in the WGOU east of Sunrise Boulevard. Hydraulic containment for this area is being addressed as part of the WGOU (OU-3) remedy.

4.3.1.3 Alternative Z1-3: Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

Alternative Z1-3 would include operation of the hydraulic barrier and the same components as Alternative Z1-2, with the addition of existing groundwater extraction wells 4220 and 4320 to provide additional mass removal. Alternative Z1-3 is included because the NCP requires that "*A limited number of remedial alternatives that attain site-specific remediation levels within different restoration time periods using one or more technologies* …." be considered during development of remedial alternatives. Use of existing GET D extraction wells 4035, 4220, and 4320 as mass removal wells under this Alternative Z1-3 is proposed as these wells are estimated to contain the highest concentrations of VOCs and perchlorate and have the highest modeled flowrates of all existing GET D extraction wells. In addition, in their comments (Specific Comment 52.) on the February 19, 2004 Draft PGOU FS, the Agencies specified that these three wells be operated as mass removal wells.

As under Alternative Z1-2, all groundwater would be routed to and treated at the existing ARGET groundwater treatment facility. The estimated groundwater flowrate under Alternative Z1-3 is approximately 3,900 gpm. Approximately 1,460 gpm would be contributed from the existing and proposed extraction wells located south of the American River and the Fish Hatchery wells. The existing GET D recharge piping would be used to convey untreated groundwater, as described under Alternative Z1-2. The remaining approximately 2,440 gpm would be contributed from extraction wells located north of the American River.

Like Alternative Z1-2, Alternative Z1-3 could include the alternative routing of flow from new hydraulic containment wells C1 and D1 located north of the American River to the Fair Oaks Water District well 1047 location for treatment.

Under Alternative Z1-3, ion exchange contactors would be added at the ARGET treatment facility to provide pretreatment for perchlorate removal of the estimated 1,460 gpm that would be delivered to the facility via the 10-inch secondary-contained polyethylene pipe. The existing UV/oxidation facilities would have sufficient capacity to provide VOCs and 1,4-dioxane removal prior to air stripping. Based on Aerojet's operating experience with the air stripping process at other GET treatment facilities, it is anticipated that the existing facilities can accommodate the estimated flow of 3,900 gpm and no expansion of the air stripping process at the ARGET treatment facility would be necessary.

A conceptual depiction of the facilities that would comprise Alternative Z1-3 is contained on Figure 4-2. Modeled locations of the extraction wells relative to the COC plumes are provided in Appendix H. More detailed discussion of the modeling and assumptions made are contained in Appendix H. Table 4-2 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of the COCs under Alternative Z1-3.

It is estimated that the addition of the mass removal wells would increase the mass of TCE removed by 6 percent and increase the mass of perchlorate removed by approximately 75 percent, as compared to the mass of these COCs estimated to be removed by Alternative Z1-2.

The monitoring and institutional control components described under Alternative Z1-2 would also be included. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment and mass removal in Zone 1. Monitoring of the ARGET treatment process performance and effluent quality would also be conducted.

4.3.2 Zone 2

4.3.2.1 Alternative Z2-1: No Action with Groundwater Monitoring

Alternative Z2-1 (No Action) is included as required by the NCP to serve as a baseline for comparison of the other alternative for Sector G. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Sector G.

As discussed previously, groundwater remedies are planned near or downgradient of the PGOU Zone 2 on the IRCTS, and at the former WRND. Additionally, potential remedies are being pilot tested and are likely in source areas upgradient of the PGOU. The groundwater remedies to be evaluated downgradient of Zone 2 include the Western Non-Aerospace Non-Industrial Area (WNN) in-situ biological reduction process, currently being piloted, and a groundwater extraction and treatment system along a portion of the WNN easement. Additionally, the DTSC has indicated it will require source control within IRCTS and mid-plume control for IRCTS, probably within the WNN easement.

At the WRND, an existing shallow groundwater extraction system is located north of White Rock Road in Layer B and additional extraction wells are proposed to address groundwater in Layers C and D south of White Rock Road (EMSI et.al., 2001). A pilot test is being conducted upgradient of the PGOU at the Hogout Facility to assess the performance of the in-situ bioremediation technology for removal of TCE and perchlorate in the vadose zone and in groundwater. If the in-situ bioremediation pilot testing is successful, this process could provide source control for those areas that appear to be contributing the majority of chemicals detected in Zone 2 groundwater.

4.3.2.2 Alternative Z2-2: Contain and Remediate Zone 2 Groundwater

Alternative Z2-2 would involve the construction of three groundwater extraction wells constructed within Layer C to contain Zone 2 groundwater from migrating further on the IRCTS property. The modeled locations of the extraction wells are shown on Figure 4-3. The extraction well locations, and estimated pumping rates are based on the FS-level groundwater flow modeling presented in Appendix H. More detailed discussion of the modeling and assumptions made are contained in Appendix H. Table 4-3 lists the extraction wells, anticipated pumping rates, and the estimated influent concentrations of the COCs under Alternative Z2-2. Total depths and screened interval lengths/depth for the proposed extraction wells would be determined during well construction. Capture zones anticipated for each extraction well are provided with the modeling results in Appendix H. Modeling results indicate that a sufficient downward gradient would be created by the extraction wells completed in Layer C to contain groundwater from Layer B.

The downgradient extraction well locations in Zone 2 are based on the objective of providing hydraulic containment of COCs originating on the Aerojet Site. The extraction wells are located in the approximate areas where TCE concentrations in groundwater attenuate to less than 50 µg/L, before increasing to greater than 50 µg/L farther downgradient. The increasing TCE concentrations downgradient of the proposed extraction well locations are believed to indicate that sources on the IRCTS are contributing to groundwater impacts. These sources are being addressed under the remedial programs under development for the IRCTS. The actual location of the groundwater extraction wells would be based upon a combination of factors, including design/construction constraints and projected future land use, and may not result in the placement of the hydraulic barrier at the exact locations shown on Figure 4-3.

From the FS-level model, it is estimated that the combined flow of extracted groundwater under Alternative Z2-2 would be approximately 1,400 gpm and contain concentrations of VOCs and perchlorate, as summarized on Table 4-3. Under Alternative Z2-2, groundwater would be piped to the GET E/F treatment facility (as conceptually depicted on Figure 4-3) for removal of VOCs and perchlorate. The existing FBR facilities at the GET E/F treatment facility would be expanded to accommodate the added flow anticipated to contain perchlorate. Two spare (240 kw capacity each) UV/oxidation reactors obtained from another project are currently stored at the GET E/F facility. To address pretreatment for VOCs removal prior to air stripping polishing, one of these reactors would be rehabilitated and placed on-line. Following UV/oxidation pretreatment, air stripping would be used to remove remaining VOCs. An additional air stripping column would be added to the GET E/F treatment facility to accommodate the additional modeled flow of 1,400 gpm from Zone 2.

Alternative Z2-2 also recognizes that groundwater remedies are planned at the former WRND and that a feasibility study for groundwater on the IRCTS is in process. Additionally, potential remedies are being pilot-tested in source areas upgradient of the PGOU. The groundwater remedies to be evaluated on the IRCTS include the WNN in-situ biological reduction, currently being piloted, and groundwater extraction along a portion of the WNN easement with treatment at various locations. Additionally, the DTSC has indicated it will require on-site plume control for IRCTS, probably within the WNN easement.

Alternative Z2-2 would also include groundwater monitoring and institutional control components in the form of the restrictions on use and transfer of land as provided in Paragraph 11 of the PCD, as well as the County ordinance and DHS oversight described under Alternative Z1-2. The monitoring program would include the extraction wells and sufficient monitor wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 2. Monitoring of the process performance and effluent quality of the GET E/F treatment facility where Zone 2 groundwater would be treated would also be conducted.

4.3.2.3 Alternative Z2-3: Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

Alternative Z2-3 would include operation of the hydraulic barrier and the same components as Alternative Z2-2, with the addition of groundwater extraction well 4420 to provide additional mass removal. A conceptual depiction showing modeled new hydraulic containment wells and mass removal wells is provided as Figure 4-4. The estimated groundwater flowrate under Alternative Z2-3 is approximately 1,550 gpm.

The discussion of conveyance and treatment of the modeled approximately 1,400 gpm from the three Zone 2 containment wells would also apply to this alternative. Hydraulic and process capacity design would be based on the estimated flowrates and influent chemistry provided in Table 4-4.

As depicted on Figure 4-4, groundwater from mass removal well 4420 would be conveyed to the GET B treatment facility for removal of VOCs and perchlorate. Approximately 150 gpm of additional UV/oxidation and perchlorate removal capacity at the GET B treatment facility would be necessary to accommodate the flow from the Zone 2 mass removal well. Additional UV/oxidation treatment capacity would be needed for pretreatment of VOCs. Depending on the alternative selected for Zone 3, additional ion exchange capacity may be needed at the GET B treatment facility to address the groundwater flow from mass removal well 4420.

It is estimated that the addition of the mass removal well would increase the mass of TCE and perchlorate removed by 50 and 95 percent, respectively, as compared to the mass of these COCs estimated to be removed by Alternative Z2-2.

Alternative Z2-3 would also include a monitoring program and institutional controls, as described previously under Alternative Z2-2.

4.3.3 Zone 3 (Sector B)

4.3.3.1 Alternative Z3-1: No Action with Groundwater Monitoring

Alternative Z3-1 (No Action) is included as required by the NCP to serve as a baseline for comparison of the other alternatives. For this alternative, the GET B groundwater extraction, treatment, and treated groundwater discharge facilities would be terminated and no further remedial activities would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Sector B.

4.3.3.2 Alternative Z3-2: Contain and Remediate Zone 3 Groundwater

Alternative Z3-2 involves the continued operation of existing hydraulic barrier extraction well 4570. Alternative Z3-2 also includes the addition of 12 new hydraulic containment wells. Based on the FS-level modeling results, three new extraction wells are proposed to be installed in each of Layers C, D, E, and F. Modeled locations of the extraction wells relative to the COC plumes are shown on the conceptual depiction on Figure 4-5. Operation of this hydraulic barrier would contain the Sector B groundwater within the PGOU and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of the groundwater. The extraction well locations and estimated pumping rates are based on the FS-level groundwater flow modeling presented in Appendix H. Capture zones anticipated for each extraction well and more detailed discussion of the modeling and assumptions made are contained in Appendix H.

Groundwater from Zone 3 would continue to be treated at the GET B groundwater treatment facility. The estimated groundwater flowrate under Alternative Z3-2 for the one existing and 12 new hydraulic containment wells is approximately 1,850 gpm. While WRND extraction wells 4505, 4510, 4515, 4520, and 4525 are regulated under CRWQCB-CVR CAO No. 96-150 and are not integral to providing hydraulic containment of Zone 3 groundwater, groundwater from these wells (approximately 50 gpm) has been and will continue under this alternative to be treated at the GET B facility. The estimated combined flowrate from the Zone 3 and WRND extraction wells is 1,900 gpm.

Table 4-5 lists the extraction wells, anticipated modeled pumping rates, and the estimated influent concentrations of the COCs under Alternative Z3-2. Total depths and screened interval lengths/depth for the existing well are provided on Table 4-5 while total depths and screened interval lengths/depth for the proposed extraction wells would be determined during well construction. The actual location of the hydraulic containment wells would be based upon a combination of factors, including design and construction constraints (e.g., locations of existing piping, pipeline corridors, rights-of-way), and may not result in the placement of the hydraulic barrier at the exact locations shown on Figure 4-5 or downgradient of the leading edge of the plume.

As shown on Table 4-5, groundwater from the hydraulic barrier extraction wells is anticipated to contain VOCs, perchlorate, and NDMA that will require removal at the existing GET B treatment facility. The GET B treatment facility currently employs the ion exchange process for perchlorate removal, UV/oxidation for NDMA removal and pretreatment for VOCs removal, and air stripping for removal of VOCs remaining subsequent to the UV/oxidation. To accommodate the modeled flowrate of approximately 1,900 under this alternative, the following modifications to the GET B treatment facility would be necessary. Treated effluent could continue to be discharged to Rebel Hill Ditch or used as a source of non-potable water for the industrial water system that serves the Aerojet Sacramento facilities. If the treated effluent from GET B were to serve as the primary source of non-potable water for the industrial water system and the GET B effluent flow is greater than the industrial water demand, excess flow would be discharged to the Rebel Hill Ditch.

- For perchlorate removal, since the existing ion exchange system has a maximum hydraulic capacity of 2,000 gpm, no additional ion exchange facilities would be necessary. Alternatively, a new fluidized bed biological reduction reactor system, sized to accommodate approximately 1,900 gpm would be constructed.

- The existing UV/oxidation system is sized to accommodate a flow of 1,500 gpm; to remove NDMA from 15 ug/L to less than 0.0013 ug/l; and to remove TCE from 60 ug/L, 1,1-DCE from 7 ug/L, 1,1-DCE (cis/trans) from 5 ug/L, and carbon tetrachloride from 0.50 ug/L to less than 0.50 ug/l. Approximately 400 gpm of additional capacity, designed to similar criteria as the existing system, would be needed. The UV/oxidation system would be designed to remove sufficient VOCs such that offgas treatment for the air stripping process would not be required. The existing pre-engineered metal building would be expanded to accommodate the additional UV/oxidation capacity.

- Two air strippers exist at the GET B treatment facility, each with a capacity of 2,000 gpm. One of the air strippers is currently used as an influent equalization tank. To accommodate the estimated ultimate influent flow of approximately 1,900 gpm, the configuration of the existing air strippers and GET B treatment train could remain as is.

Alternative Z3-2 also includes groundwater monitoring. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 3. Samples would also be collected to evaluate the performance of the unit processes at the GET B treatment facility and as required to monitor the effluent discharge to Rebel Hill Ditch.

In addition, Alternative Z3-2 would include institutional controls in the form of deed restrictions currently on the Aerojet Site through PCD Paragraph 11, restricting the use of groundwater. Offsite governmental institutional control; namely, Sacramento County's Consultation Zone Ordinance and DHS oversight over public drinking water systems that requires reporting of contaminants to DHS and which establishes obligations on water purveyors to provide potable water supplies to their customers, are also included under Alternative Z3-2.

4.3.3.3 Alternative Z3-3: Contain, Remediate, and Remove Additional Mass from Zone 3 Groundwater

Alternative Z3-3 would involve the operation of a hydraulic barrier similar to the barrier discussed for Alternative Z3-2. The hydraulic barrier would consist of existing extraction well 4570 and the addition of 12 new hydraulic containment wells, as discussed for Alternative Z3-2. In addition, Alternative Z3-3 would include the following six existing groundwater extraction wells to provide additional mass removal: 4011, 4303, 4405, 4450, 4475, and 4480. Modeled locations of the hydraulic containment wells relative to the COC plumes as well as the locations of the existing mass removal wells are shown on the conceptual depiction on Figure 4-6. The estimated groundwater flowrate under Alternative Z3-3 is approximately 2,560 gpm, with approximately 650 gpm being contributed from the mass removal wells.

It is estimated that the addition of the mass removal wells would double the mass of NDMA removed and increase the mass of TCE and perchlorate removed by 84 and 23 percent, respectively, as compared to the mass of these COCs estimated to be removed by Alternative Z3-2.

The new extraction well locations and estimated pumping rates are based on the FS-level groundwater flow modeling presented in Appendix H. Modeled locations of the extraction wells relative to the COC plumes are provided in Appendix H. More detailed discussion of the modeling and assumptions made are contained in Appendix H. Table 4-6 lists the existing extraction wells and their characteristics (total depths and screened interval lengths/depths), anticipated pumping rates for both the existing and proposed new hydraulic containment and mass removal wells, and the estimated influent concentrations of the COCs under Alternative Z3-3.

Groundwater from Zone 3 would continue to be treated at the GET B groundwater treatment facility. As in Alternative Z3-2, flow from WRND extraction wells 4505, 4510, 4515, 4520, and 4525 would be included as a component of the estimated 2,560 gpm groundwater flowrate for treatment at the GET B facility.

As shown on Table 4-6, groundwater from the hydraulic barrier and mass removal extraction wells is anticipated to contain VOCs, perchlorate, and NDMA that will require removal at the existing GET B treatment facility. Modifications to the existing UV/oxidation system would be necessary to increase the capacity from 1,500 gpm to the approximate estimated flowrate of 2,560 gpm. Likewise, a pair of ion exchange contactors would need to be added to accommodate flow above the existing capacity of 2,000 gpm. The existing air stripping capacity would be adequate to address the anticipated influent flowrate and water quality. However, the current treatment process configuration would need to be modified such that the air stripper that is being used as an influent equalization tank be placed back into service as an air stripper. The UV/oxidation process would be designed to remove sufficient VOCs such that offgas treatment for the air stripping process would not be required. Alternatively for perchlorate removal, a FBR reactor biological reduction system could be constructed.

Alternative Z3-3 would also include a groundwater monitoring program and institutional controls similar to Alternative Z3-2.

4.3.4 Zone 4 (Sector A and Sector C)

4.3.4.1 Alternative Z4-1: No Action with Groundwater Monitoring

Alternative Z4-1 (No Action) is included as required by the NCP to serve as a baseline for comparison of the other alternatives. For this alternative, the GET A extraction, treatment, and treated groundwater discharge facilities would be terminated and no further groundwater containment remedial activities in Sector A would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Sectors A and C.

4.3.4.2 Alternative Z4-2: Contain and Remediate Zone 4 Groundwater

Alternative Z4-2 involves the continued operation of the existing GET A onsite hydraulic barrier, including seven existing extraction wells: 4100, 4105, 4110, 4120, 4125, 4130, and 4500. It also includes the addition of seven new hydraulic containment wells to address VOCs and NDMA in Sector A and Sector C groundwater. Modeled locations of the hydraulic containment wells relative to the COC plumes are shown on the conceptual depiction on Figure 4-7. Operation of this hydraulic barrier would contain the Sector A and Sector C groundwater onsite within Zone 4 and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of groundwater. The estimated groundwater flowrate under Alternative Z4-2 is approximately 640 gpm, with approximately 430 gpm being contributed by the new containment wells.

The hydraulic containment well locations and estimated pumping rates are based on the FS-level groundwater flow modeling presented in Appendix H. Capture zones anticipated for each extraction well and more detailed discussion of the modeling and assumptions made are contained in Appendix H. Table 4-7 lists the extraction wells, anticipated modeled pumping rates, and the estimated influent concentrations of the COCs under Alternative Z4-2. Total depths and screened interval lengths/depths for existing wells are provided on Table 4-7 while total depths and screened interval lengths/depth for the proposed extraction wells would be determined during well construction. As indicated on Table 4-7, six of the proposed wells would be screened in Layer A and one would be screened in Layer B. The actual location of the proposed hydraulic containment wells would be based upon a combination of factors, including design and construction constraints, and may not result in the placement of the hydraulic barrier at the exact locations shown on Figure 4-7 or downgradient of the leading edge of the plume. New piping would also be necessary to convey groundwater from the proposed hydraulic containment wells to treatment.

As shown on Table 4-7, groundwater from the existing and new hydraulic barrier extraction wells is anticipated to contain VOCs and NDMA that will require removal at the existing GET A groundwater treatment facility or at a new facility. In addition, groundwater from the new hydraulic containment wells is anticipated to contain perchlorate. Under Alternative Z4-2, groundwater from the new hydraulic containment wells would be conveyed to treatment via a pipeline separate from the pipeline that conveys groundwater from the existing extraction wells. Conveyance of groundwater that contains perchlorate in a separate pipeline will allow pretreatment for perchlorate removal at the treatment facility prior to this flow being combined with flow from the existing extraction wells and subsequently treated for NDMA and VOCs removal.

If a new facility were to be constructed, it would probably be located in the vicinity of Alder Creek, near the proposed hydraulic containment wells. The new facility would be sized to either treat that portion of groundwater from the proposed hydraulic containment wells, with the remaining flow treated at GET A, or all of the groundwater from Zone 4 would be treated at the new facility.

Treatment processes necessary to remove COCs from Zone 4 groundwater include ion exchange for perchlorate removal, UV/oxidation for NDMA removal and pretreatment of VOCs, and air stripping for removal of any VOCs remaining after UV/oxidation pretreatment. If the GET A facility would be used to treat the entire estimated flow of approximately 640 gpm, ion exchange pretreatment facilities sized for approximately 430 gpm and additional UV/oxidation and air stripping capacity would be required. The current UV/oxidation process and air stripping processes only have a hydraulic capacity of 400 gpm. One or more UV/oxidation reactors (and associated hydrogen peroxide feed system capacity, if needed) would be added to accommodate the additional flow and be designed to remove NDMA and pretreat VOCs to current required levels. The additional UV/oxidation capacity would be designed to remove sufficient VOCs such that offgas treatment for the air stripping process would not be required. With respect to air stripping, either a second counter-current packed tower would be added to provide two air stripping towers operated in parallel or a new tower, sized to accommodate the entire flow, would be installed. Treated effluent could continue to be discharged to Rebel Hill Ditch or used as a source of non-potable water for the industrial water system that serves the Aerojet Sacramento facilities. If the treated effluent from GET A were to serve as the primary source of non-potable water for the industrial water system and the effluent flow from GET A is greater than the industrial water demand, excess flow would be discharged to the Rebel Hill Ditch.

If a new treatment facility were to be constructed at the location discussed above, ion exchange, UV/oxidation, and air stripping processes would be provided and housed in a building constructed of materials that would be compatible with anticipated future land use. Use of a low-profile stacked tray air stripper would be considered during remedial design. Treated groundwater from a new treatment facility would be discharged to Alder Creek under an NPDES permit or used as a source of non-potable water for the industrial water system that serves the Aerojet Sacramento facilities.

Alternative Z4-2 also includes groundwater monitoring. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 4. Samples would also be collected to evaluate the performance of the unit processes at the GET A and/or new treatment facility and as required to monitor the effluent discharge(s).

Alternative Z4-2 would also include institutional controls in the form of deed restrictions currently on the Aerojet Site through the Partial Consent Decree Paragraph 11, or on lands removed from the Superfund site through the Environmental Restrictions of the 2002 Stipulation and Order Modifying the Partial Consent. There are also restrictions through off-property governmental institutional control; namely, Sacramento County's Consultation Zone Ordinance and DHS oversight over public drinking water systems.

4.3.4.3 Alternative Z4-3: Contain, Remediate, and Remove Additional Mass from Zone 4 Groundwater

Alternative Z4-3 would include operation of the hydraulic barrier and the same components as Alternative Z4-2, with the addition of the following three existing groundwater extraction wells to provide additional mass removal: 4012, 4013, and 4430. A conceptual depiction showing existing containment wells, modeled new hydraulic containment wells, and mass removal wells is provided as Figure 4-8. The estimated groundwater flowrate under Alternative Z4-3 is approximately 670 gpm.

The discussion of treatment facility location, required treatment processes, existing GET A process capacity, and necessary additional treatment capacity provided for Alternative Z4-2 would also apply to this alternative. Since the additional mass removal wells are anticipated to include perchlorate and would be conveyed to the GET A treatment facility via an existing pipeline that is separate from the pipeline that conveys groundwater from the existing containment wells, groundwater from the new containment wells and the existing mass removal wells would be combined at the GET A facility prior to pretreatment for perchlorate removal via ion exchange. Hydraulic and process capacity design would be based on the estimated flowrates and influent chemistry provided in Table 4-8. Approximately 450 gpm would undergo pretreatment for perchlorate removal while the entire flow of approximately 670 gpm would be treated via the UV/oxidation and air stripping processes for NDMA and VOCs removal.

It is estimated that the addition of the mass removal wells would more than double the mass of TCE removed and increase the mass of perchlorate and NDMA removed by 24 and 11 percent, respectively, as compared to the mass of these COCs estimated to be removed by Alternative Z4-2.

Alternative Z4-2 would also include a monitoring program and institutional controls, as described previously under Alternative Z4-2.

5 DETAILED ANALYSIS OF ALTERNATIVES

In this section, the 12 alternatives developed in Section 4 are subjected to detailed analysis. The purpose of this detailed analysis is to provide sufficient information to allow for comparisons among the alternatives based on the standard criteria specified in the NCP.

The detailed evaluation of final alternatives for a remedial action is a two-stage process. During the first stage of evaluation, each of the alternatives is assessed against the individual criteria. This first-stage evaluation of the final remedial action alternatives for the PGOU FS is presented in this section; the evaluation is based on the conceptual descriptions of the final alternatives provided in Section 4. For the second stage of the evaluation process, the criteria are grouped into a tiered system to reflect their interrelationships and different levels of significance. During this second-stage evaluation, the alternatives are initially evaluated according to the threshold criteria, which must be met, and then compared with each other to identify relative advantages and disadvantages and trade-offs among the different balancing criteria. The purpose of the comparative analysis is to provide information for a balanced remedy selection. The second-stage evaluation of final remedial action alternatives is presented in Section 6.

The nine NCP evaluation criteria include:

Threshold Criteria:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs

Primary Balancing Criteria:

- Long-Term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume through Treatment
- Short-Term Effectiveness
- Implementability
- Cost

Modifying Criteria:

- State Acceptance
- Community Acceptance

The NCP [40 CFR Section 300.430(e)(9)(iii)] categorizes these nine criteria into three groups: threshold criteria, primary balancing criteria, and 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 (unless a waiver is obtained).

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 alternative 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 proposed plan.

Modifying criteria are generally evaluated after public comment on the OU RI/FS and the Proposed Plan. Accordingly, only the seven threshold and primary balancing criteria are used in the detailed analysis phase. The following sections provide descriptions of the evaluation criteria and the items considered when assessing alternatives with respect to each criterion.

5.1 Description of Evaluation Criteria

5.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion assesses how each alternative provides and maintains adequate protection of human health and the environment. Alternatives are assessed to determine whether they can adequately protect human health and the environment from unacceptable risks posed by contaminants present at the site, 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, institutional controls, or other remedial activities. The considerations evaluated during the analysis of each alternative for overall protection of human health and the environment are presented in below:

Protection of human health:

- Likelihood that the alternative reduces risk to human health to below risk-based levels.

Protection of the environment:

- Likelihood that the alternative reduces the threat to unaffected groundwater by minimizing migration of contaminants. As discussed in the BLRA, there are no completed exposure pathways to groundwater for ecological receptors.

5.1.2 Compliance with ARARs

This evaluation criterion is used to evaluate if each alternative would attain federal and State ARARs, or whether invoking waivers to specific ARARs is adequately justified. Other information, such as advisories, criteria, or guidance, is considered where appropriate during the ARARs analysis. The considerations evaluated during the analysis of the ARARs applicable to each alternative are presented below. Potential action-, location-, and chemical-specific ARARs for the alternatives presented in this FS are identified in Appendix F.

Chemical-specific ARARs:

- Likelihood that the alternative will achieve compliance with chemical-specific ARARs (e.g., MCLs) within a reasonable period of time.
- If it appears that compliance with chemical-specific ARARs will not be achieved, then evaluation of whether a waiver is appropriate.

Location-specific ARARs:

- Determination of whether any location-specific ARARs (e.g., whether facilities will be located in a floodplain and preservation of wetlands) apply to the alternative.
- Likelihood that the alternative will achieve compliance with the location-specific ARAR.
- Evaluation of whether a waiver is appropriate if the location-specific ARAR cannot be met.

Action-specific ARARs:

- Likelihood that the alternative will achieve compliance with action-specific ARARs (e.g., new source air emission rules).
- Evaluation of whether a waiver is appropriate if the action-specific ARAR cannot be met.

Other criteria and guidance:

- Likelihood that the alternative will achieve compliance with other criteria, such as risk-based criteria.

5.1.3 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 action imposed by the alternative. The primary components of this criterion are the magnitude of residual risk remaining at the site after remedial objectives 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 alternative for long-term effectiveness and permanence are presented below. The components addressed for each alternative are described in more detail in the following subsections.

Magnitude of residual risks:

- Identity of remaining risks (risks from treatment residuals) as well as risks from untreated residual contamination.
- Magnitude of the remaining risks.

Adequacy and reliability of controls:

- Likelihood that the technologies will meet required process efficiencies or performance specifications.
- Type and degree of long-term management required.
- Long-term monitoring requirements.
- O&M functions that must be performed.
- Difficulties and uncertainties associated with long-term O&M functions.
- 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.
- Uncertainties associated with land disposal of residuals and untreated wastes.

5.1.3.1 Magnitude of Residual Risk

The magnitude of residual risk at the end of remedial activities is measured by numerical standards, or the volume or concentration of COCs remaining. The characteristics of the residuals remaining are also evaluated, considering their volume, toxicity, and mobility.

5.1.3.2 Adequacy and Reliability of Controls

The adequacy and reliability of controls that are used to either manage treatment residuals or untreated materials that remain after attaining numerical limitations are evaluated. This criterion includes an assessment of containment systems and institutional controls to evaluate the degree of confidence that they adequately handle potential problems and provide sufficient protection. The criterion also addresses long-term reliability, the need for long-term management and monitoring, and the potential need to replace technical components of the alternative.

5.1.4 Reduction of Toxicity, Mobility or Volume through Treatment

This evaluation criterion addresses the anticipated performance of the treatment technologies employed by each alternative in permanently and significantly reducing toxicity, mobility, and/or volume of COCs associated with the OU. The NCP prefers remedial actions 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 alternative for reduction of toxicity, mobility, or volume of COCs present at a given site are presented below:

Treatment process and remedy:

- Likelihood that the treatment process addresses the principal threat.
- Special requirements for the treatment process.

Relative amount of hazardous material destroyed or treated:

- Portion (mass) of COC that is destroyed.
- Portion (mass) of COC that is treated.

Reduction in toxicity, mobility, or volume:

- Extent that the total mass of COCs is reduced.
- Extent that the mobility of COCs is reduced.
- Extent that the volume of COCs is reduced.

Irreversibility of treatment:

- Degree that the effects of the treatment are irreversible.

Type and quantity of residuals remaining following treatment:

- 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.

5.1.5 Short-Term Effectiveness

Short-term effectiveness considers the effect of each remedial alternative on the protection of human health and the environment during the construction and implementation phase. The short-term effectiveness evaluation only addresses protection prior to meeting the RAOs. The considerations evaluated during the analysis of each alternative for short-term effectiveness are presented below:

Protection of the community during any remedial action:

- 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 remedial actions:

- Risks to the workers that must be addressed.
- How the risks will be addressed and mitigated and the effectiveness and reliability of measures to be taken.
- Remaining risks that cannot be readily controlled.

Environmental impacts of any remedial action:

- Environmental impacts that are expected with the construction and implementation of the alternative.
- Mitigation measures that are available and their reliability to minimize potential impacts.
- Impacts that cannot be avoided, should the alternative be implemented.

Time until RAOs are achieved:

- Time to achieve protection against the threats being addressed.
- Time until any remaining threats are addressed.
- Time until RAOs are achieved.

The times until RAOs are achieved for TCE, NDMA and perchlorate were estimated to compare the short-term effectiveness of each remedial alternative. These estimates were not prepared to represent actual cleanup times but rather for the comparison of the alternatives to one another. The comparative time estimates are based on calculating the estimated number of pore volumes necessary to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria, and then multiplying the number of pore volumes by the time estimated for one pore volume flush through each hydrostratigraphic layer.

The number of pore volumes were estimated based on the following equation (EPA, 1988c):

$$NPV = -R\ln(C_{wt}/C_{wo})$$

where,

NPV = Number of pore volumes

R = Chemical specific retardation factor

C_{wt} = Chemical-specific ARAR or risk-based criteria

C_{wo} = Initial chemical concentration

Cleanup levels of 5, 0.0017, and 4 ug/L, and retardation factors of 2.1, 1.6, and 1.0, were applied for TCE, NDMA, and perchlorate, respectively. The initial chemical concentrations were estimated from chemical distribution maps. The time for each pore volume flush was based on particle tracking simulations conducted using the groundwater flow models developed for each zone (Appendix H). The time until RAOs are achieved is then calculated by multiplying the time for each single pore volume flush by the number of pore volumes. The results of the calculations for each alternative are provided in Table 5-1.

5.1.6 Implementability

Implementability evaluates the technical feasibility and administrative feasibility (i.e., the ease or difficulty) of implementing each alternative and the availability of required services and materials during its implementation. The following considerations are evaluated during the analysis of each alternative for implementability:

<u>Technical Feasibility</u>

Ability to construct and operate the technology:

- Difficulties associated with the construction.
- Uncertainties associated with the construction.

Reliability of the technology:

- Likelihood that technical problems will lead to schedule delays.

Ease of undertaking additional remedial action:

- Likely future remedial actions that may be anticipated.
- Difficulty implementing additional remedial actions.

Monitoring considerations with respect to effectiveness of the remedy:

- Migration or exposure pathways that cannot be monitored adequately.
- Risks of exposure, should the monitoring be insufficient to detect failure.

Administrative Feasibility

Coordination with other agencies:

- Steps required to coordinate with regulatory agencies to implement any remedy.
- Steps required to establish long-term or future coordination among agencies.
- Ease of obtaining permits for off-property 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 technologies:

- Whether technologies under consideration are generally available and sufficiently demonstrated.

- Further field applications needed to demonstrate that the technologies may be used full-scale to treat COCs.
- When technology should be available for full-scale use.
- Whether more than one vendor will be available to provide a competitive bid.

5.1.7 Cost

The estimated costs are presented within the +50%/-30% accuracy range stated in RI/FS guidance (USEPA, 1988a). The cost sensitivity analysis represents an evaluation of how sensitive the cost of a given project is to changes in parameters that are not known with certainty.

Capital and O&M costs were prepared using February 2005 dollars. In preparing the capital and O&M cost estimates, contingency allowances of 15 percent and 10 percent, respectively, were included to address unforeseen circumstances such as the ability to estimate the scope of any remedial alternative at this stage of the FS, the ability to predict the schedule for implementation of a remedy, the ability to estimate costs of treatment technologies for removal of certain COCs, uncertainties associated with the provisional reference dose for perchlorate, and unresolved issues with respect to management of treated groundwater in concert with overall regional water management objectives. With respect to the present worth cost analyses, in accordance with current EPA guidance (EPA, 1988a and 2000), a discount rate of 7 percent (before taxes and after inflation) and a 30 year period of performance for costing purposes were assumed.

In their comments on the draft FS report, the Agencies requested that supplemental non-discounted constant dollar cost estimates to remedy completion be provided since the remedy durations are estimated to be beyond 30 years. Supplemental non-discounted constant dollar cost estimates were developed using the capital replacement criteria as follows:

- Equipment that includes rotating parts (e.g., extraction well pumps, transfer pumps, and flow meters) would be replaced every 10 years;

- All other extraction well and treatment equipment would be replaced every 20 years;

- Buildings, concrete structures, extraction well construction and casing, and access roads would be replaced on a frequency of approximately every 50 years; and

- Approximately every 100 years, buried piping and conduit would be replaced.

5.1.8 State Acceptance

This criterion involves technical and administrative concerns that the State may communicate in its comments concerning each alternative.

5.1.9 Community Acceptance

The preferred alternative(s) for this OU will be presented to the public in a Proposed Plan, which will provide a brief summary of all of the alternatives studied in the detailed analysis of alternatives section of the FS. In accordance with the NCP, the public will have an opportunity to review and comment on the selected remedial alternative(s) presented in the Proposed Plan. The public's comments will be addressed in the responsiveness summary and ROD for the PGOU.

5.2 Results of the Detailed Analysis of Alternatives

The following sections present the detailed analysis of the 12 remedial alternatives using the seven threshold and primary balancing criteria.

A numerical groundwater model was used to assist in evaluating the alternatives with respect to the NCP threshold criteria (protectiveness and compliance with ARARs). The model simulated groundwater flow and estimated advective migration of dissolved COCs and was used to evaluate the relative merits of the remedial alternatives subsequently described in this section. The groundwater model used to evaluate the remedial alternatives was based on the final site conceptual model as presented in the RI (Appendices A through D). A description of the groundwater model used is presented in Appendix H.

Groundwater flow was simulated using MODFLOW, a modular three-dimensional flow model developed by the United States Geological Survey (USGS). A particle-tracking model, MODPATH, was used to evaluate advective contaminant migration for each of the remedial alternatives as described in Appendix H. This objective was achieved by starting particles and allowing them to migrate with the advective groundwater flow.

These evaluation results are used to compare and contrast the relative merits of each of the remedial alternatives. Analyses were performed to evaluate whether model results were sensitive to uncertainties in various input parameters. These analyses are presented in Appendix H.

5.2.1 Alternative Z1-1: No Action with Groundwater Monitoring

This section presents the detailed analysis of the No Action alternative for Zone 1, which serves as the baseline for comparison of the effectiveness of the other two alternatives for Zone 1. Under No Action, the GET D and ARGET groundwater extraction, treatment, and treated groundwater recharge facilities would be terminated and no further remedial activities would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Zone 1. Also, no institutional controls would be implemented under the No Action alternative.

5.2.1.1 Overall Protection of Human Health and Environment

Contaminated groundwater is not prevented from migrating further and affecting other groundwater resources. Except to the extent that preexisting institutional controls exist to prevent exposure, the No Action alternative does not eliminate, reduce, or control the potential consumption of groundwater containing site-related constituents at levels above risk-based criteria. The No Action alternative (as evaluated in the BLRA) assumes that persons will be supplied water containing site-related constituents above risk-based levels either by private or public water providers or through use of individual domestic wells. Therefore, in theory, and for purposes of comparison to the other alternatives, the No Action alternative is assumed to provide inadequate protection to human health and the environment.

In actuality, public water purveyors take action to monitor and shut down wells that they or DHS consider to be inappropriate for service to customers. Further, the Sacramento County Consultation Zone ordinance would restrict access to groundwater. Consequently, although for purposes of this FS it is assumed that the No Action alternative does not include any active or passive means to eliminate, reduce, or control the pathway by which persons could be exposed to contaminated drinking water, there are controls outside the scope of this FS that would eliminate, restrict, or control potential use of contaminated drinking water.

Under the No Action alternative, the existing GET D and ARGET facilities would be terminated. Therefore, the No Action alternative would not minimize or control migration of COCs and would not limit further migration of impacted groundwater downgradient. To the extent that it would be practicable to return the regional aquifer to its beneficial uses through cost-effective remediation, the No Action alternative would not achieve the goal of returning the regional aquifer to its expected beneficial use.

As there are no active remediation measures included in the No Action alternative, it does not pose any unacceptable short-term risks or other adverse impacts beyond its theoretical failure to eliminate the use of contaminated groundwater.

5.2.1.2 Compliance with ARARs

Chemical-specific ARARs will not be met within a reasonable time frame.

Location- and action-specific ARARs do not apply to the No Action alternative.

5.2.1.3 Long-Term Effectiveness and Permanence

All current and potential future risks remain. Untreated residual COCs in groundwater would pose a risk if the residential well or water supply pathways become complete.

Risks posed by COCs in groundwater are expected to gradually decrease as contaminant concentrations decrease over time through physical dilution by dispersion and diffusion of all COCs and possibly through biodegradation of VOCs or perchlorate.

5.2.1.4 Reduction of Toxicity, Mobility, and Volume through Treatment

The No Action alternative would not provide any reduction in toxicity beyond the natural attenuation of COCs that may occur in the groundwater environment. There would be no reduction of mobility and volume through treatment because no treatment technologies would be employed. Therefore, the No Action alternative would not address the statutory preference for treatment as a principal element. No treatment residuals would be generated.

5.2.1.5 Short-Term Effectiveness

Because no remedial action would be taken under the No Action alternative, no short-term risks to the community or to workers as a result of implementing the action would occur. Similarly, no environmental impact from construction activities would occur.

The RAO for protection of beneficial uses would not met by the No Action alternative as it does not minimize downgradient migration and there are alternatives that appear to be practicable that do so.

5.2.1.6 Implementability

As no active or passive remedial technologies would be implemented under the No Action alternative, there are no implementability concerns or issues associated with the No Action alternative. There are no impediments to implementing the No Action alternative.

5.2.1.7 Costs

Because the No Action alternative only includes groundwater monitoring, it is ranked as the least costly alternative. The annual O&M costs and 30 year present worth costs associated with implementing Alternative Z1-1 are as follows. A present worth summary is included in Appendix I.

Estimated annual monitoring costs:	$147,000
Estimated 30-year present worth costs:	$1,850,000

5.2.2 Alternative Z1-2: Contain and Remediate Zone 1 Groundwater

Alternative Z1-2 involves the continued operation of and downgradient expansion of the ARSA hydraulic barrier, intended to contain the plume and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of the groundwater. Along the GET D boundary containment system, groundwater modeling indicates that the boundary containment system could continue to be effective by continued operation of GET D extraction well 4035, discontinuing use of the GET D recharge field and conversion of recharge wells 5105 and 5020 to extraction wells, installation of one Layer C and one Layer D well north of the American River, and installation of a pair of new extraction wells in Layers C and D near the western end of the recharge field (Figure 4-1). A capture zone map for Alternative Z1-2 is included in Appendix H. All groundwater would be treated at an expanded ARGET groundwater treatment facility. (Alternatively, groundwater from the new extraction wells north of the American River could be treated at a location adjacent to Fair Oaks Water District well 1047.) The existing GET D groundwater treatment facilities would be demolished.

To provide further protection, Alternative Z1-2 also includes institutional controls (DHS oversight of public drinking water systems and the County Consultation Zone Ordinance). In addition, groundwater monitoring is a component of Alternative Z1-2. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 1 as well as the performance of the ARGET treatment facility.

5.2.2.1 Overall Protection of Human Health and Environment

The hydraulic barrier and monitoring that would be implemented as part of Alternative Z1-2 would prevent potential exposure. Existing institutional controls (DHS permitting of public water purveyors and the County Consultation Zone ordinance) would provide additional protection to prevent exposure due to COCs in groundwater. Therefore, Alternative Z1-2 would be protective of human health and the environment.

Alternative Z1-2 would minimize the continued migration of COCs through operation of the ARSA hydraulic boundary. Alternative Z1-2 could eventually result in the restoration of the currently contaminated portion of the aquifer. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, the extent and time of restoration is uncertain.

Alternative Z1-2 relies on institutional controls to restrict the use of untreated water from existing public and private water purveyor wells downgradient of the hydraulic barrier and to restrict the potential for future installation of additional public or private water supply wells in the impacted area.

As the active remediation measures included in Alternative Z1-2 are based on standard, accepted treatment practices, this alternative does not pose any unacceptable short-term risks or other adverse impacts.

5.2.2.2 Compliance with ARARs

All ARARs that pertain to the protection of groundwater resources and the cleanup of releases will be met by Alternative Z1-2. Contaminated groundwater drawn from the extraction wells will be treated prior to management/reuse to concentrations that meet cleanup standards based on chemical-specific ARARs (*e.g.,* California MCLs, Proposition 65) where in effect, and otherwise, based on risk-based criteria as informed by TBCs. Over the long term, this alternative will provide a permanent solution by removing COCs from groundwater to concentrations below risk-based criteria and chemical-specific ARARs.

The extraction and conveyance facilities and ARGET treatment facilities will continue to be operated in a manner designed to comply with all location- and action-specific ARARs.

5.2.2.3 Long-Term Effectiveness and Permanence

Alternative Z1-2 provides effective long-term control of COC plumes through extraction and treatment of groundwater using proven or innovative technologies. Over the long term, this alternative would provide a permanent solution by removing COCs from groundwater to below risk-based criteria and chemical-specific ARARs.

Residual risk would remain in certain portions of the groundwater until all of the groundwater containing COCs has been removed by the extraction wells and has been replaced by natural and/or artificial recharge of uncontaminated water. This risk would be managed through the Sacramento County Consultation Zone well drilling ordinance and the DHS requirement that water supply wells be shut down if certain concentrations of COCs are detected.

With respect to adequacy and reliability of controls, all of the technologies and associated equipment and monitoring facilities proposed for this alternative are proven and reliable. The monitor wells, monitoring equipment, extraction wells and pumps, conveyance piping, transfer pumping, treatment processes for removal of the COCs, treated water management facilities, and associated instrumentation and control systems are common, well established, remedy components that have been implemented at the Aerojet Sacramento Site and numerous other sites. The likelihood is high that containment and treatment performance specifications will be met. Equipment and spare parts are readily available. O&M functions should be routine. There are no uncertainties associated with addressing any treatment residuals generated from this remedial alternative.

5.2.2.4 Reduction of Toxicity, Mobility and Volume through Treatment

For Alternative Z1-2, the ARSA containment system would continue to be operated as discussed in Section 3 and a revised GET D containment system would be operated, capturing the COCs and preventing them from migrating, reducing the toxicity, mobility, and volume of the COCs.

Groundwater would be conveyed to the ARGET treatment facility. The treatment processes currently employed at the ARGET facility (Figure 3-3) and the proposed ion exchange facilities for perchlorate removal would be used to reduce the toxicity and volume of the COCs. Any VOCs and 1,4-dioxane would be destroyed via these processes, which are irreversible. Perchlorate would be retained on ion exchange media, which would subsequently be regenerated. Use of these treatment processes would satisfy the statutory preference for treatment as a principal element of the remedial action.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping process, which based on the design intent and verified through operating experience at several GET facilities, will be below chemical-specific ARARs and risk-based criteria. Exhausted ion exchange resin would be regenerated by the vendor. The spent resin, as characterized in 2002-3 at GET D, is non-hazardous.

5.2.2.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be minimal during demolition of the GET D treatment facility. This construction activity would occur on Aerojet property. Workers would be adequately protected during construction by adhering to OSHA practices. Workers would also be protected while operating and maintaining facilities by adhering to appropriate health and safety procedures.

Since there are no water supply wells in the vicinity of the ARSA hydraulic containment wells, the effect on existing water supply wells of water table drawdown resulting from operation of the existing extraction wells under Alternative Z1-2 was not evaluated. In addition, Aerojet understands that the future owner of the treated groundwater intends to use the water in the general area thereby offsetting the potential effects of groundwater pumping for municipal supplies.

Environmental Impacts. There are no adverse environmental impacts anticipated to be associated with this alternative.

Time until Response Objectives are Achieved. Minimizing further migration of COCs to downgradient areas is already being achieved by the existing ARSA and GET D containment systems. Alternative Z1-2 could eventually result in the restoration of the currently contaminated portion of the regional aquifer. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, it is uncertain how much restoration will occur and over what period.

Estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria for TCE, NDMA, and perchlorate were calculated using the assumptions and pore volumes/one pore volume flush through each hydrostratigraphic layer methodology discussed in Section 5.1.5. The results of these estimates are included in Table 5-1. For alternative Z1-2, the longest time until response objectives are achieved is estimated to be 151 years, with the chemical driver being TCE.

5.2.2.6 Implementability

The primary technical feasibility issue associated with constructing Alternative Z1-2 will be to establish the hydraulic barrier, given the difficulties of siting extraction wells and pipelines and the complexity of the hydrogeology. This difficulty is partially managed by phasing of well construction and pump testing to allow more detailed understanding of aquifer characteristics and chemical distribution. In addition, monitoring of COC plume capture may indicate that adequate capture is not being maintained by a particular extraction well.

There are technical and administrative difficulties associated with the construction of the portion of the hydraulic barrier not within land owned by Aerojet, including siting and construction of wells and conveyance pipeline. The majority of construction would occur on County Park property and within roads in the Fair Oaks neighborhood north of the County Park, which would involve securing the necessary easements required to place the extraction wells and route conveyance piping from the extraction wells to the ARGET treatment facility. It will be desirable to locate extraction wells in areas where access can be maintained for future servicing/rehabilitation. Piping and electrical conduit or overhead electrical power wiring will have to be routed so as not to interfere with any current use of and anticipated future development of the property. Potential delays in the start of implementation of this remedial alternative could result because of these issues.

With respect to administrative feasibility issues, ongoing operation and maintenance requirements within the areas of land not owned by Aerojet would continue to involve coordination with local agencies. For example, ongoing coordination will be needed for access to monitoring wells and there may be need for management of waters used for well rehabilitation.

5.2.2.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z1-2, are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$2,200,000
Estimated annual monitoring costs:	$180,000
Estimated annual O&M costs:	$720,000
Estimated 30-year present worth costs:	$13,400,000

Based on the estimated time of 151 years until RAOs are achieved (see Section 5.2.2.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z1-2 is $147,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

If groundwater from proposed extraction wells located north of the American River were treated at a location adjacent to Well 1047, estimated costs for Alternative Z1-2 would be as follows:

Capital costs:	$3,500,000
Annual monitoring costs:	$180,000
Annual O&M costs:	$720,000
30-year present worth costs:	$14,600,000
Non-discounted constant dollar costs:	$152,000,000

5.2.3 Alternative Z1-3: Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

Alternative Z1-3 would include operation of and modifications to the hydraulic barrier and the same components as Alternative Z1-2, with the additional operation of selected existing GET D groundwater extraction wells to provide additional mass removal. Alternative Z1-3 would also include the addition of perchlorate removal capability at the ARGET treatment facility. A map showing the capture zone for this alternative is included in Appendix H. The discussion below does not repeat the substance of the discussion as to Alternative Z1-2, but simply notes any differences between the two alternatives resulting from the addition of the mass removal wells.

5.2.3.1 Overall Protection of Human Health and Environment

Alternative Z1-3 would be equally as protective as Alternative Z1-2.

5.2.3.2 Compliance with ARARs

Alternative Z1-3 would provide the same level of compliance with ARARs as Alternative Z1-2.

5.2.3.3 Long-Term Effectiveness and Permanence

With the exception that there would be more mass of chemicals extracted, Alternative Z1-3 would provide the same level of long-term effectiveness and permanence as Alternative Z1-2.

5.2.3.4 Reduction of Toxicity, Mobility and Volume through Treatment

Because of the additional mass removal and perchlorate removal components, the reduction of toxicity, mobility, or volume through treatment for Alternative Z1-3 would be increased over that of Alternative Z1-2.

Residuals remaining after treatment would be the same as those under Alternative Z1-2. More volume/mass of residuals would be generated under Alternative Z1-3 than under Alternative Z1-2.

5.2.3.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be similar to Alternative Z1-2.

Environmental Impacts. Same as Alternative Z1-2.

Time until Response Objectives are Achieved. Same as Alternative Z1-2, with the exception that the estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria would be different. The results of these estimates are included in Table 5-1. For alternative Z1-3, the longest time until response objectives are achieved is estimated to be 124 years, with the chemical driver being TCE.

5.2.3.6 Implementability

Same as Alternative Z1-2.

5.2.3.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z1-3 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$2,200,000
Estimated annual monitoring costs:	$200,000
Estimated annual O&M costs:	$870,000
Estimated 30-year present worth costs:	$15,500,000

Based on the estimated time of 124 years until RAOs are achieved (see Section 5.2.3.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z1-3 is $142,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

If groundwater from proposed extraction wells located north of the American River were treated at a location adjacent to Well 1047, estimated costs for Alternative Z1-3 would be as follows:

Capital costs:	$3,500,000
Annual monitoring costs:	$200,000
Annual O&M costs:	$870,000
30-year present worth costs:	$16,700,000
Non-discounted constant dollar costs:	$178,000,000

5.2.4 Alternative Z2-1: No Action with Groundwater Monitoring

For the No Action alternative in Zone 2 (Alternative Z2-1) there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Zone 2. The No Action alternative for Zone 2 serves as the baseline for comparison of the effectiveness of the other alternative for Zone 2.

5.2.4.1 Overall Protection of Human Health and Environment

Contaminated groundwater is not prevented from migrating further and affecting other groundwater resources. Except to the extent that preexisting institutional controls exist to prevent exposure, the No Action alternative does not eliminate, reduce, or control the potential consumption of groundwater containing site-related constituents at levels above risk-based criteria. The No Action alternative (as evaluated in the BLRA) assumes that persons will be supplied water containing site-related constituents above risk-based levels either by private or public water providers or through use of individual domestic wells. Therefore, in theory, and for purposes of comparison to the other alternatives, the No Action alternative is assumed to provide inadequate protection to human health and the environment.

In actuality, public water purveyors take action to monitor and shut down wells that they or DHS consider to be inappropriate for service to customers. Further, the Sacramento County Consultation Zone ordinance would restrict access to groundwater. Consequently, although for purposes of this FS it is assumed that the No Action alternative does not include any active or passive means to eliminate, reduce, or control the pathway by which persons could be exposed to contaminated drinking water, there are controls outside the scope of this FS that would eliminate, restrict, or control potential use of contaminated drinking water.

The No Action alternative would not minimize or control migration of COCs and would not limit further migration of impacted groundwater downgradient. To the extent that it would be practicable to return the regional aquifer to its beneficial uses through cost-effective remediation, the No Action alternative would not achieve the goal of returning the regional aquifer to its expected beneficial use.

As there are no active remediation measures included in the No Action alternative, it does not pose any unacceptable short-term risks or other adverse impacts beyond its theoretical failure to eliminate the use of contaminated groundwater.

5.2.4.2 Compliance with ARARs

Chemical-specific ARARs will not be met within a reasonable time frame.

Location- and action-specific ARARs do not apply to the No Action alternative.

5.2.4.3 Long-Term Effectiveness and Permanence

All current and potential future risks remain. Untreated residual COCs in groundwater would pose a risk if the residential well or water supply pathways become complete.

Risks posed by COCs in groundwater are expected to gradually decrease as contaminant concentrations decrease over time through physical dilution by dispersion and diffusion of all COCs and possibly through biodegradation of any VOCs or perchlorate.

5.2.4.4 Reduction of Toxicity, Mobility and Volume through Treatment

The No Action alternative would not provide any reduction in toxicity beyond the natural attenuation of COCs that may occur in the groundwater environment. There would be no reduction of mobility and volume through treatment because no treatment technologies would be employed. Therefore, the No Action alternative would not address the statutory preference for treatment as a principal element. No treatment residuals would be generated.

5.2.4.5 Short-Term Effectiveness

Because no remedial action would be taken under the No Action alternative, no short-term risks to the community or to workers as a result of implementing the action would occur. Similarly, no environmental impact from construction activities would occur.

The RAO for protection of beneficial uses would not met by the No Action alternative as it does not minimize downgradient migration and there are alternatives that appear to be practicable that do so.

5.2.4.6 Implementability

As no active or passive remedial technologies would be implemented under the No Action alternative, there are no implementability concerns or issues associated with the No Action alternative. There are no impediments to implementing the No Action alternative.

5.2.4.7 Costs

Because the No Action alternative only includes groundwater monitoring, it is ranked as the least costly alternative. The annual O&M costs and 30 year present worth costs associated with implementing Alternative Z2-1 are as follows. A present worth summary is included in Appendix I.

Estimated annual monitoring costs:	$36,000
Estimated 30-year present worth costs:	$480,000

5.2.5 Alternative Z2-2: Contain and Remediate Zone 2 Groundwater

Alternative Z2-2 would involve the construction of three groundwater extraction wells on the IRCTS property to contain Zone 2 groundwater originating on the Aerojet Site and prevent it from migrating further downgradient. Groundwater would be piped to the GET E/F treatment facility for removal of VOCs and perchlorate.

Alternative Z2-2 also recognizes that groundwater remedies are planned at the former WRND and that a feasibility study for groundwater on the IRCTS is in process. Additionally, potential remedies are being pilot tested in source areas upgradient of the PGOU. The groundwater remedies to be evaluated on the IRCTS include the WNN in-situ biological reduction, currently being piloted, and groundwater extraction along a portion of the WNN easement with treatment at various locations. Additionally, the DTSC has indicated it will require on-site plume control for IRCTS, probably within the WNN easement.

Alternative Z2-2 would also include groundwater monitoring and institutional control components in the form of the restrictions on use and transfer of land as provided in Paragraph 11 of the PCD, as well as the County ordinance and DHS oversight described under Alternative Z1-2. The monitoring program would include the extraction wells and sufficient monitor wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 2. Monitoring of the process performance and effluent quality of the GET E/F treatment facility would also be conducted.

5.2.5.1 Overall Protection of Human Health and Environment

Existing institutional controls (DHS permitting of public water purveyors and the County Consultation Zone ordinance) provide adequate protection to prevent exposure due to COCs in groundwater. The hydraulic barrier and the monitoring that would be required would provide an additional level of protection to prevent potential exposure. Therefore, Alternative Z2-2 is protective of human health and the environment.

Alternative Z2-2 would minimize migration of COCs through operation of the containment extraction wells. Alternative Z2-2 could eventually result in the restoration of the currently contaminated portion of the aquifer in the vicinity and upgradient of the extraction wells. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, the extent and time of restoration is uncertain.

Alternative Z2-2 relies on institutional controls to restrict the use of untreated water from existing private water wells downgradient of the hydraulic barrier and to restrict the potential for future installation of additional public or private water supply wells in the impacted area.

The active remediation measures included under Alternative Z2-2 are based on standard, accepted treatment practices. Therefore, this alternative does not pose any unacceptable short-term risks or other adverse impacts.

5.2.5.2 Compliance with ARARs

All ARARs that pertain to the protection of groundwater resources and the cleanup of releases will be met by Alternative Z2-2. Groundwater drawn from the extraction wells will be treated prior to management/reuse to concentrations that meet cleanup standards based on chemical-specific ARARs (*e.g.,* California MCLs, Proposition 65) where in effect, and otherwise, based on risk-based criteria as informed by TBCs. Over the long term, this alternative will provide a permanent solution by removing COCs from groundwater to concentrations below risk-based criteria and chemical-specific ARARs.

The new groundwater extraction and conveyance facilities and existing GET B treatment facilities will continue to be operated in a manner designed to comply with all location- and action-specific ARARs.

5.2.5.3 Long-Term Effectiveness and Permanence

Alternative Z2-2 provides effective long-term control of COC plumes through extraction and treatment of groundwater using proven or innovative technologies. Over the long term, this alternative would provide a permanent solution by removing COCs from groundwater to below risk-based criteria and chemical-specific ARARs.

Residual risk would remain in certain portions of the groundwater until all of the groundwater containing COCs has been removed by the extraction wells and has been replaced by natural and/or artificial recharge of uncontaminated water. This risk would be managed through the Sacramento County Consultation Zone well drilling ordinance and the DHS requirement that water supply wells be shut down if certain concentrations of COCs are detected.

With respect to adequacy and reliability of controls, all of the technologies and associated equipment and monitoring facilities proposed for this alternative are proven and reliable. The monitor wells, monitoring equipment, extraction wells and pumps, conveyance piping, transfer pumping, treatment processes for removal of the COCs at GET E/F, treated water management facilities, and associated instrumentation and control systems are common, well established, remedy components that have been implemented at the Aerojet Sacramento Site and numerous other sites. The likelihood is high that containment and treatment performance specifications will be met. Equipment and spare parts are readily available. O&M functions should be routine. There are no uncertainties associated with addressing any treatment residuals generated from this remedial alternative.

5.2.5.4 Reduction of Toxicity, Mobility and Volume through Treatment

For Alternative Z2-2, the Zone 2 containment system described in Section 4 would capture the COCs and prevent them from migrating, reducing the toxicity, mobility, and volume of the COCs.

Groundwater would be conveyed to the GET E/F treatment facility. The treatment processes currently employed at the GET E/F facility (Figure 3-4) would be used to reduce the toxicity and volume of the COCs. Any VOCs and perchlorate would be destroyed via these processes, which are irreversible. Use of these treatment processes would satisfy the statutory preference for treatment as a principal element of the remedial action.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping process which are expected to be below chemical-specific ARARs and risk-based criteria. Residuals would also include the minor volume of non-hazardous organic sludge that would be generated by the biological reduction process for perchlorate removal at the GET E/F treatment facility. The sludge would be discharged to a sanitary sewer or dewatered and disposed in a non-hazardous landfill.

5.2.5.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be minimal during construction of new containment wells and associated conveyance piping. These construction activities would occur on Aerojet and Boeing property. Workers would be adequately protected during construction by adhering to OSHA practices. Workers would also be protected while operating and maintaining facilities by adhering to appropriate health and safety procedures.

Since there are no water supply wells in the vicinity of the Zone 2 hydraulic containment wells, the effect on existing water supply wells of water table drawdown resulting from operation of the proposed extraction wells under Alternative Z2-2 was not evaluated. In addition, Aerojet understands that the owner of the treated groundwater intends to use the water in the general area thereby offsetting the potential effects of groundwater pumping for municipal supplies.

Environmental Impacts. There are no adverse environmental impacts anticipated to be associated with this alternative.

Time until Response Objectives are Achieved. Minimizing further migration of COCs to downgradient areas would be achieved immediately after the containment extraction wells become operational. Estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria for TCE and perchlorate were calculated using the assumptions and pore volumes/one pore volume flush through each hydrostratigraphic layer methodology discussed in Section 5.1.5. The results of these estimates are included in Table 5-1. For alternative Z2-2, the longest time until response objectives are achieved is estimated to be 232 years, with the chemical driver being TCE.

5.2.5.6 Implementability

The primary technical feasibility issue associated with constructing Alternative Z2-2 will be to establish the hydraulic barrier, given the difficulties of siting extraction wells and pipelines and the complexity of the hydrogeology. This difficulty is partially managed by phasing of well construction and pump testing to allow more detailed understanding of aquifer characteristics and chemical distribution. In addition, monitoring of COC plume capture may indicate that adequate capture is not being maintained by a particular extraction well.

There are technical and administrative difficulties associated with the construction of the hydraulic barrier not within land owned by Aerojet, including siting and construction of wells and conveyance pipeline. The majority of construction would occur on IRCTS property, which would involve securing the necessary easements required to place the extraction wells and route conveyance piping from the extraction wells to the GET E/F treatment facility. It will be desirable to locate extraction wells in areas where access can be maintained for future servicing/rehabilitation. Piping and electrical conduit or overhead electrical power wiring will have to be routed so as not to interfere with any anticipated future development of the property. Potential delays in the start of implementation of this remedial alternative could result because of these issues.

With respect to administrative feasibility issues, ongoing operation and maintenance requirements within the areas of land not owned by Aerojet would continue to involve coordination with the adjacent landowner (currently Boeing). For example, ongoing coordination will be needed for access to monitoring wells and there may be need for management of waters used for well rehabilitation.

5.2.5.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z2-2 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$4,600,000
Estimated annual monitoring costs:	$40,000
Estimated annual O&M costs:	$490,000
Estimated 30-year present worth costs:	$11,200,000

Based on the estimated time of 232 years until RAOs are achieved (see Section 5.2.5.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z2-2 is $167,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

5.2.6 Alternative Z2-3: Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

Alternative Z2-3 would involve three groundwater extraction wells to contain Zone 2 groundwater with conveyance to and treatment of groundwater at the GET E/F facility described under Alternative Z2-2. The mass removal component of this alternative would include operation of existing extraction well 4420. Groundwater from the mass removal well would be piped to the GET B treatment facility for removal of VOCs and perchlorate. Alternative Z2-3 would also include groundwater monitoring and the institutional control components described under Alternative Z1-2.

A map showing the capture zone for this alternative is included in Appendix H. The discussion below does not repeat the substance of the discussion as to Alternative Z2-2, but simply notes any differences between the two alternatives resulting from the addition of the mass removal wells.

5.2.6.1 Overall Protection of Human Health and Environment

Alternative Z2-3 would be equally as protective as Alternative Z2-2.

5.2.6.2 Compliance with ARARs

Alternative Z2-3 would provide the same level of compliance with ARARs as Alternative Z2-2.

5.2.6.3 Long-Term Effectiveness and Permanence

With the exception that there would be more mass of chemicals extracted, Alternative Z2-3 would provide the same level of long-term effectiveness and permanence as Alternative Z2-2.

5.2.6.4 Reduction of Toxicity, Mobility and Volume through Treatment

Because of the additional mass removal, the reduction of toxicity, mobility, or volume through treatment for Alternative Z2-3 would be increased over that of Alternative Z2-2.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping processes at GET E/F and GET B, which are expected to be below chemical-specific ARARs and risk-based criteria. Residuals would also include those from the perchlorate removal process employed at the GET E/F and GET B treatment facilities, i.e., the minor volume of non-hazardous organic sludge that would be generated by the biological reduction process and exhausted ion exchange resin. The sludge would be discharged to a sanitary sewer or dewatered and disposed in a non-hazardous landfill. Exhausted ion exchange resin would be regenerated by the vendor.

More volume/mass of residuals would be generated under Alternative Z2-3 than under Alternative Z2-2.

5.2.6.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be similar to Alternative Z2-2 with the exception that construction would involve additional activities: new lengths conveyance pipeline and expansion of capacity at the GET B treatment facility.

Environmental Impacts. Same as Alternative Z2-2.

Time until Response Objectives are Achieved. Same as Alternative Z2-2, with the exception that the estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria would be different. The results of these estimates are included in Table 5-1. For alternative Z2-3, the longest time until response objectives are achieved is estimated to be 131 years, with the chemical driver being TCE.

5.2.6.6 Implementability

Same as Alternative Z2-2.

5.2.6.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z2-3 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$5,300,000
Estimated annual monitoring costs:	$44,000
Estimated annual O&M costs:	$560,000
Estimated 30-year present worth costs:	$12,800,000

Based on the estimated time of 131 years until RAOs are achieved (see Section 5.2.6.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z2-3 is $105,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

5.2.7 Alternative Z3-1: No Action with Groundwater Monitoring

This section presents the detailed analysis of the No Action alternative for Zone 3, which serves as the baseline for comparison of the effectiveness of the other two alternatives for Zone 3. Under No Action, the GET B groundwater extraction, treatment, and treated groundwater discharge facilities would be terminated and no further remedial activities would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Zone 3. Also, no institutional controls would be implemented under the No Action alternative.

5.2.7.1 Overall Protection of Human Health and Environment

Contaminated groundwater is not prevented from migrating further and affecting other groundwater resources. Except to the extent that preexisting institutional controls exist to prevent exposure, the No Action alternative does not eliminate, reduce, or control the potential consumption of groundwater containing site-related constituents at levels above risk-based criteria. The No Action alternative (as evaluated in the BLRA) assumes that persons will be supplied water containing site-related constituents above risk-based levels either by private or public water providers or through use of individual domestic wells. Therefore, in theory, and for purposes of comparison to the other alternatives, the No Action alternative is assumed to provide inadequate protection to human health and the environment.

In actuality, public water purveyors take action to monitor and shut down wells that they or DHS consider to be inappropriate for service to customers. Further, the Sacramento County Consultation Zone ordinance would restrict access to groundwater. Consequently, although for purposes of this FS it is assumed that the No Action alternative does not include any active or passive means to eliminate, reduce, or control the pathway by which persons could be exposed to contaminated drinking water, there are controls outside the scope of this FS that would eliminate, restrict, or control potential use of contaminated drinking water.

Under the No Action alternative, the existing GET B facilities would be terminated. Therefore, the No Action alternative would not minimize or control migration of COCs and would not limit further migration of impacted groundwater downgradient. To the extent that it would be practicable to return the regional aquifer to its beneficial uses through cost-effective remediation, the No Action alternative would not achieve the goal of returning the regional aquifer to its expected beneficial use.

As there are no active remediation measures included in the No Action alternative, it does not pose any unacceptable short-term risks or other adverse impacts beyond its theoretical failure to eliminate the use of contaminated groundwater.

5.2.7.2 Compliance with ARARs

Chemical-specific ARARs will not be met within a reasonable time frame.

Location- and action-specific ARARs do not apply to the No Action alternative.

5.2.7.3 Long-Term Effectiveness and Permanence

All current and potential future risks remain. Untreated residual COCs in groundwater would pose a risk if the residential well or water supply pathways become complete.

Risks posed by COCs in groundwater are expected to gradually decrease as contaminant concentrations decrease over time through physical dilution by dispersion and diffusion of all COCs and possibly through biodegradation of VOCs or perchlorate.

5.2.7.4 Reduction of Toxicity, Mobility and Volume through Treatment

The No Action alternative would not provide any reduction in toxicity beyond the natural attenuation of COCs that may occur in the groundwater environment. There would be no reduction of mobility and volume through treatment because no treatment technologies would be employed. Therefore, the No Action alternative would not address the statutory preference for treatment as a principal element. No treatment residuals would be generated.

5.2.7.5 Short-Term Effectiveness

Because no remedial action would be taken under the No Action alternative, no short-term risks to the community or to workers as a result of implementing the action would occur. Similarly, no environmental impact from construction activities would occur.

The RAO for protection of beneficial uses would not met by the No Action alternative as it does not minimize downgradient migration and there are alternatives that appear to be practicable that do so.

5.2.7.6 Implementability

As no active or passive remedial technologies would be implemented under the No Action alternative, there are no implementability concerns or issues associated with the No Action alternative. There are no impediments to implementing the No Action alternative.

5.2.7.7 Costs

Because the No Action alternative only includes groundwater monitoring, it is ranked as the least costly alternative. The annual O&M costs and 30 year present worth costs associated with implementing Alternative Z3-1 are as follows. A present worth summary is included in Appendix I.

Estimated annual monitoring costs:	$157,000
Estimated 30-year present worth costs:	$1,980,000

5.2.8 Alternative Z3-2: Contain and Remediate Zone 3 Groundwater

Alternative Z3-2 involves the continued operation of existing hydraulic barrier extraction well 4570 and the additional operation of 12 new hydraulic containment wells. Based on the FS-level modeling results, three new extraction wells are proposed to be installed in each of Layers C, D, E, and F. Operation of the hydraulic barrier would contain the Sector B groundwater within the PGOU and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of the groundwater. A capture zone map for Alternative Z3-2 is included in Appendix H. Groundwater from Zone 3 would continue to be treated at the GET B groundwater treatment facility.

Alternative Z3-2 also includes groundwater monitoring and institutional controls in the form of deed restrictions currently on the Aerojet Site through PCD Paragraph 11. For the land not owned by Aerojet, governmental institutional control; namely, Sacramento County's Consultation Zone Ordinance and DHS oversight over public drinking water systems that requires reporting of contaminants to DHS would be included.

5.2.8.1 Overall Protection of Human Health and Environment

Existing institutional controls (DHS permitting of public water purveyors and the County Consultation Zone ordinance) provide adequate protection to prevent exposure due to COCs in groundwater. The hydraulic barrier and the monitoring that would be required would provide an additional level of protection to prevent potential exposure. Therefore, Alternative Z3-2 is protective of human health and the environment.

Alternative Z3-2 would minimize migration of COCs through operation of the modified hydraulic boundary. Alternative Z3-2 could eventually result in the restoration of the currently contaminated portion of the aquifer. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, the extent and time of restoration is uncertain.

Alternative Z3-2 relies on the remedial design as well as institutional controls to restrict the use of untreated water from existing public and private water wells downgradient of the hydraulic barrier and to restrict the potential for future installation of additional public or private water supply wells in the impacted area.

As the active remediation measures included in this Alternative Z3-2 are based on standard, accepted treatment practices, this alternative does not pose any unacceptable short-term risks or other adverse impacts.

5.2.8.2 Compliance with ARARs

All ARARs that pertain to the protection of groundwater resources and the cleanup of releases will be met by Alternative Z3-2. Groundwater drawn from the extraction wells will be treated prior to management/reuse to concentrations that meet cleanup standards based on chemical-specific ARARs (*e.g.,* California MCLs, Proposition 65) where in effect, and otherwise, based on risk-based criteria as informed by TBCs. Over the long term, this alternative will provide a permanent solution by removing COCs from groundwater to concentrations below risk-based criteria and chemical-specific ARARs.

The groundwater extraction and conveyance facilities and GET B treatment facilities will continue to be operated in a manner designed to comply with all location- and action-specific ARARs.

5.2.8.3 Long-Term Effectiveness and Permanence

Alternative Z3-2 provides effective long-term control of COC plumes through extraction and treatment of groundwater using proven technologies. Over the long term, this alternative would provide a permanent solution by removing COCs from groundwater to below risk-based criteria and chemical-specific ARARs.

Residual risk would remain in certain portions of groundwater until all of the groundwater containing COCs has been removed by the extraction wells and has been replaced by natural and/or artificial recharge of uncontaminated water. This risk would be managed through the Sacramento County Consultation Zone well drilling ordinance and the DHS requirement that water supply wells be shut down if certain concentrations of COCs are detected.

With respect to adequacy and reliability of controls, all of the technologies and associated equipment and monitoring facilities proposed for this alternative are proven and reliable. The monitor wells, monitoring equipment, extraction wells and pumps, conveyance piping, transfer pumping, treatment processes for removal of the COCs, treated water management facilities, and associated instrumentation and control systems are common, well established, remedy components that have been implemented at the Aerojet Sacramento Site and numerous other sites. The likelihood is high that containment and treatment performance specifications will be met. Equipment and spare parts are readily available. O&M functions should be routine. There are no uncertainties associated with addressing any treatment residuals generated from this remedial alternative.

5.2.8.4 Reduction of Toxicity, Mobility and Volume through Treatment

For Alternative Z3-2, the Zone 3 containment system would be operated as discussed in Section 4, capturing the COCs and preventing them from migrating, reducing the toxicity, mobility, and volume of the COCs.

Groundwater would continue to be conveyed to the GET B treatment facility. The treatment processes currently employed at the GET B facility (Figure 3-5) would be used to reduce the toxicity and volume of the COCs. Any VOCs, NDMA, and perchlorate would be destroyed via these processes, which are irreversible. Use of these treatment processes would satisfy the statutory preference for treatment as a principal element of the remedial action.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping process which are expected to be below chemical-specific ARARs and risk-based criteria. Residuals would also include exhausted ion exchange resin from the perchlorate removal process employed at the GET B treatment facility. Exhausted ion exchange resin would be regenerated by the vendor.

5.2.8.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be minimal during construction of additional containment wells and expansion of the GET B treatment facility. Workers would be adequately protected during construction by adhering to OSHA practices. Workers would also be protected while operating and maintaining facilities by adhering to appropriate health and safety procedures.

Environmental Impacts. There are no adverse environmental impacts anticipated to be associated with this alternative.

Time until Response Objectives are Achieved. Minimizing further migration of COCs to downgradient areas would be achieved immediately after the new containment extraction wells become operational. Estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria for TCE, NDMA and perchlorate were calculated using the assumptions and pore volumes/one pore volume flush through each hydrostratigraphic layer methodology discussed in Section 5.1.5. The results of these estimates are included in Table 5-1. For alternative Z3-2, the longest time until response objectives are achieved is estimated to be 327 years, with the chemical driver being NDMA.

5.2.8.6 Implementability

The primary technical feasibility issue associated with constructing Alternative Z3-2 will be to establish the hydraulic barrier, given the difficulties of siting extraction wells and pipelines and the complexity of the hydrogeology. This difficulty is partially managed by phasing of well construction and pump testing to allow more detailed understanding of aquifer characteristics and chemical distribution. In addition, monitoring of COC plume capture may indicate that adequate capture is not being maintained by a particular extraction well.

There are technical and administrative difficulties associated with the construction of the portion of the hydraulic barrier not within land owned by Aerojet, including siting and construction of wells and conveyance pipeline. The majority of construction would occur on property owned by Teichert Aggregates, which would involve securing the necessary easements required to place the extraction wells and route conveyance piping from the extraction wells to the GET B treatment facility. It will be desirable to locate extraction wells in areas where access can be maintained for future servicing/rehabilitation. Piping and electrical conduit or overhead electrical power wiring will have to be routed so as not to interfere with any current use of and anticipated future development of the property. Potential delays in the start of implementation of this remedial alternative could result because of these issues.

Ongoing operation, maintenance, and monitoring requirements in areas not owned by Aerojet would involve coordination with Teichert Aggregates. There may also be the need for management of waters used for well rehabilitation.

5.2.8.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z3-2 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$3,900,000
Estimated annual monitoring costs:	$170,000
Estimated annual O&M costs:	$990,000
Estimated 30-year present worth costs:	$18,300,000

Based on the estimated time of 327 years until RAOs are achieved (see Section 5.2.8.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z3-2 is $430,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

5.2.9 Alternative Z3-3: Contain, Remediate, and Remove Additional Mass from Zone 3 Groundwater

Alternative Z3-3 would include operation of the hydraulic barrier in a similar manner as Alternative Z3-2. Also, six existing groundwater extraction wells would be operated to provide additional mass removal.

In addition, Alternative Z3-3 would include a groundwater monitoring program and institutional controls similar to Alternative Z3-2.

The discussion below does not repeat the substance of the discussion as to Alternative Z3-2, but simply notes any differences between the two alternatives resulting from the addition of the mass removal wells.

5.2.9.1 Overall Protection of Human Health and Environment

Alternative Z3-3 would be equally protective as Alternative Z3-2.

5.2.9.2 Compliance with ARARs

Alternative Z3-3 would provide the same level of compliance with ARARs as Alternative Z3-2.

5.2.9.3 Long-Term Effectiveness and Permanence

With the exception that the rate of mass of chemicals extracted is higher, Alternative Z3-3 would provide the same level of long-term effectiveness and permanence as Alternative Z3-2.

5.2.9.4 Reduction of Toxicity, Mobility and Volume through Treatment

Because of the additional mass removal component, the reduction of toxicity, mobility, or volume through treatment for Alternative Z3-3 would be increased over that of Alternative Z3-2.

The same residuals would remain after treatment under Alternative Z3-3 as under Alternative Z3-2. More volume/mass of residuals would be generated under Alternative Z3-3.

5.2.9.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be similar to Alternative Z3-2.

Environmental Impacts. Same as Alternative Z3-2.

Time until Response Objectives are Achieved. Same as Alternative Z3-2, with the exception that the estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria would be different. The results of these estimates are included in Table 5-1. For alternative Z3-3, the longest time until response objectives are achieved is estimated to be 263 years, with the chemical driver being NDMA.

5.2.9.6 Implementability

Same as Alternative Z3-2.

5.2.9.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z3-3 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$4,900,000
Estimated annual monitoring costs:	$170,000
Estimated annual O&M costs:	$1,370,000
Estimated 30-year present worth costs:	$24,000,000

Based on the estimated time of 263 years until RAOs are achieved (see Section 5.2.9.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z3-3 is $459,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

5.2.10 Alternative Z4-1: No Action with Groundwater Monitoring

This section presents the detailed analysis of the No Action alternative for Zone 4, which serves as the baseline for comparison of the effectiveness of the other two alternatives for Zone 4. Under No Action, the GET A groundwater extraction, treatment, and treated groundwater discharge facilities would be terminated and no further remedial activities would be implemented. For the No Action alternative there would be no active remediation of groundwater. Groundwater would be monitored under this alternative, including the lateral and vertical extent of the COCs within Zone 4. Also, no institutional controls would be implemented under the No Action alternative.

5.2.10.1 Overall Protection of Human Health and Environment

Contaminated groundwater is not prevented from migrating further and affecting other groundwater resources. Except to the extent that preexisting institutional controls exist to prevent exposure, the No Action alternative does not eliminate, reduce, or control the potential consumption of groundwater containing site-related constituents at levels above risk-based criteria. The No Action alternative (as evaluated in the BLRA) assumes that persons will be supplied water containing site-related constituents above risk-based levels either by private or public water providers or through use of individual domestic wells. Therefore, in theory, and for purposes of comparison to the other alternatives, the No Action alternative is assumed to provide inadequate protection to human health and the environment.

In actuality, public water purveyors take action to monitor and shut down wells that they or DHS consider to be inappropriate for service to customers. Further, the Sacramento County Consultation Zone ordinance would restrict access to groundwater. Consequently, although for purposes of this FS it is assumed that the No Action alternative does not include any active or passive means to eliminate, reduce, or control the pathway by which persons could be exposed to contaminated drinking water, there are controls outside the scope of this FS that would eliminate, restrict, or control potential use of contaminated drinking water.

Under the No Action alternative, the existing GET A facilities would be terminated. Therefore, the No Action alternative would not minimize or control migration of COCs and would not limit further migration of impacted groundwater downgradient. To the extent that it would be practicable to return the regional aquifer to its beneficial uses through cost-effective remediation, the No Action alternative would not achieve the goal of returning the regional aquifer to its expected beneficial use.

As there are no active remediation measures included in the No Action alternative, it does not pose any unacceptable short-term risks or other adverse impacts beyond its theoretical failure to eliminate the potential use of contaminated groundwater.

5.2.10.2 Compliance with ARARs

Chemical-specific ARARs will not be met within a reasonable time frame.

Location- and action-specific ARARs do not apply to the No Action alternative.

5.2.10.3 Long-Term Effectiveness and Permanence

All current and potential future risks remain. Untreated residual COCs in groundwater would pose a risk if the residential well or water supply pathways become complete.

Risks posed by COCs in groundwater are expected to gradually decrease as contaminant concentrations decrease over time through physical dilution by dispersion and diffusion of all COCs and possibly through biodegradation of VOCs.

5.2.10.4 Reduction of Toxicity, Mobility and Volume through Treatment

The No Action alternative would not provide any reduction in toxicity beyond the natural attenuation of COCs that may occur in the groundwater environment. There would be no reduction of mobility and volume through treatment because no treatment technologies would be employed. Therefore, the No Action alternative would not address the statutory preference for treatment as a principal element. No treatment residuals would be generated.

5.2.10.5 Short-Term Effectiveness

Because no remedial action would be taken under the No Action alternative, no short-term risks to the community or to workers as a result of implementing the action would occur. Similarly, no environmental impact from construction activities would occur.

The RAO for protection of beneficial uses would not be met by the No Action alternative as it does not minimize downgradient migration and there are alternatives that appear to be practicable that do so.

5.2.10.6 Implementability

As no active or passive remedial technologies would be implemented under the No Action alternative, there are no implementability concerns or issues associated with the No Action alternative. There are no impediments to implementing the No Action alternative.

5.2.10.7 Costs

Because the No Action alternative only includes groundwater monitoring, it is ranked as the least costly alternative. The annual O&M costs and 30 year present worth costs associated with implementing Alternative Z4-1 are as follows. A present worth summary is included in Appendix I.

Estimated annual monitoring costs:	$51,000
Estimated 30-year present worth costs:	$650,000

5.2.11 Alternative Z4-2: Contain and Remediate Zone 4 Groundwater

Alternative Z4-2 involves the continued operation of the GET A hydraulic barrier, intended to contain the plume and prevent further migration of COCs downgradient of the barrier in concentrations that would impair beneficial uses of the groundwater. It also includes the addition of seven new hydraulic containment wells to address VOCs and NDMA in Sector A and Sector C groundwater. A capture zone figure for Alternative Z4-2 is included in Appendix H.

Groundwater would continue to be treated at the GET A groundwater treatment facility, which would be expanded to accommodate the additional flow from the seven new hydraulic containment wells. Alternatively, either wellhead treatment (e.g., in-well stripping or oxidation) would be implemented or a new treatment facility would be located nearer the new extraction wells to accommodate groundwater from the wells.

Alternative Z4-2 also includes groundwater monitoring. The monitoring program would include the monitor and extraction wells, frequency of sampling, and analyses necessary to evaluate hydraulic containment in Zone 4. Samples would also be collected to evaluate the performance of the GET A treatment facility. In addition, deed restrictions and institutional controls on land not owned by Aerojet (DHS oversight of public drinking water systems and the County Consultation Zone Ordinance) are assumed.

5.2.11.1 Overall Protection of Human Health and Environment

Existing off-property institutional controls (DHS permitting of public water purveyors and the County Consultation Zone ordinance) and deed restrictions on the use of groundwater would provide adequate protection to prevent exposure due to COCs in groundwater. The hydraulic barrier and the monitoring that would be required would provide an additional level of protection to prevent potential exposure. Therefore, Alternative Z4-2 is protective of human health and the environment.

Alternative Z4-2 would eliminate the potential for continued migration of COCs through operation of the modified hydraulic boundary. Alternative Z4-2 could eventually result in the restoration of the aquifer. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, the extent and time of restoration over what period is uncertain.

Alternative Z4-2 relies on institutional controls to restrict the use of untreated water from any public and and/or private water wells downgradient of the hydraulic barrier and to restrict the potential for future installation of additional public or private water supply wells outside of the Aerojet property boundary.

The active remediation measures included under Alternative Z4-2 are based on standard, accepted treatment practices; therefore, this alternative does not pose any unacceptable short-term risks or other adverse impacts.

5.2.11.2 Compliance with ARARs

All ARARs that pertain to the protection of groundwater resources and the cleanup of releases will be met by Alternative Z4-2. Contaminated groundwater drawn from the containment extraction wells will be treated prior to management/reuse to concentrations that meet cleanup standards based on chemical-specific ARARs (*e.g.,* California MCLs, Proposition 65) where in effect, and otherwise, based on risk-based criteria as informed by TBCs. Over the long term, this alternative will provide a permanent solution by removing COCs from groundwater to concentrations below risk-based criteria and chemical-specific ARARs.

The existing and proposed new groundwater extraction and conveyance facilities and GET A treatment facilities will be operated in a manner designed to comply with all location- and action-specific ARARs.

5.2.11.3 Long-Term Effectiveness and Permanence

Alternative Z4-2 provides effective long-term control of the COC plumes through extraction and treatment of groundwater using proven technologies. Over the long term, this alternative would provide a permanent solution by removing COCs from groundwater to below risk-based criteria and chemical-specific ARARs.

Residual risk would remain in certain portions of the groundwater until all of the groundwater containing COCs has been removed by the extraction wells and has been replaced by natural and/or artificial recharge of uncontaminated water. This risk would be managed through the current deed restrictions limiting the use of groundwater.

With respect to adequacy and reliability of controls, all of the technologies and associated equipment and monitoring facilities proposed for this alternative are proven and reliable. The monitor wells, monitoring equipment, extraction wells and pumps, conveyance piping, transfer pumping, treatment processes for removal of the COCs, treated water management facilities, and associated instrumentation and control systems are common, well established, remedy components that have been implemented at the Aerojet Sacramento Site and numerous other sites. The likelihood is high that containment and treatment performance specifications will be met. Equipment and spare parts are readily available. O&M functions should be routine. There are no uncertainties associated with addressing any treatment residuals generated from this remedial alternative.

5.2.11.4 Reduction of Toxicity, Mobility and Volume through Treatment

For Alternative Z4-2, the Zone 4 containment system would be operated as discussed in Section 4, capturing the COCs and preventing them from migrating, reducing the toxicity, mobility, and volume of the COCs.

Groundwater would continue to be conveyed to the GET A treatment facility. The treatment processes currently employed at the GET A facility (Figure 3-6) would be used to reduce the toxicity and volume of the COCs. Any VOCs and NDMA would be destroyed via these processes, which are irreversible. Ion exchange facilities would be added to GET A for removal of perchlorate. Perchlorate would be retained on ion exchange media, which would subsequently be regenerated. Use of these treatment processes would satisfy the statutory preference for treatment as a principal element of the remedial action.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping process which are expected to be below chemical-specific ARARs and risk-based criteria. Residuals would also include exhausted ion exchange resin from the perchlorate removal process employed at the GET A treatment facility. Exhausted ion exchange resin would be regenerated by the vendor.

5.2.11.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be minimal during construction of additional containment wells and conveyance piping and expansion of the GET A treatment facility. These construction activities would occur on Aerojet property. Workers would be adequately protected during construction by adhering to OSHA practices. Workers would also be protected while operating and maintaining facilities by adhering to appropriate health and safety procedures.

This alternative will not have negative effects on groundwater levels because the extraction flow rates are relatively small and there are no water supply wells in the vicinity of the Zone 4 hydraulic containment wells.

Environmental Impacts. There are no adverse environmental impacts anticipated to be associated with this alternative.

Time until Response Objectives are Achieved. Minimizing further migration of COCs to downgradient areas is already being achieved by the existing GET A containment system and would be enhanced through the operation of additional containment extraction wells in Zone 4. Alternative Z4-2 could eventually result in the restoration of the currently contaminated portion of the on-property regional aquifer. However, given the complexity of the hydrogeology and the fate and effect of the COCs in the aquifer, it is uncertain how much restoration will occur and over what period.

Estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria for TCE, NDMA, and perchlorate were calculated using the assumptions and pore volumes/one pore volume flush through each hydrostratigraphic layer methodology discussed in Section 5.1.5. The results of these estimates are included in Table 5-1. For alternative Z4-2, the longest time until response objectives are achieved is estimated to be 347 years, with the chemical driver being NDMA.

5.2.11.6 Implementability

The primary technical feasibility issue associated with constructing Alternative Z4-2 will be to establish the hydraulic barrier, given the difficulties of siting extraction wells and pipelines and the complexity of the hydrogeology. This difficulty is partially managed by phasing of well construction and pump testing to allow more detailed understanding of aquifer characteristics and chemical distribution. In addition, monitoring of COC plume capture may indicate that adequate capture is not being maintained by a particular extraction well.

Since all of the Zone 4 facilities would be located on Aerojet property, only technical difficulties would be associated with expanding the hydraulic barrier and GET A treatment facility (and alternatively, as discussed in Section 4, potentially a new treatment facility). These difficulties would include siting and construction of wells and conveyance pipeline in areas of densely overgrown terrain along Alder Creek and in areas where access can be maintained for future servicing/rehabilitation so as not to interfere with any current use of and anticipated future development of the property.

5.2.11.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z4-2 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$2,800,000
Estimated annual monitoring costs:	$60,000
Estimated annual O&M costs:	$320,000
Estimated 30-year present worth costs:	$7,500,000

Based on the estimated time of 347 years until RAOs are achieved (see Section 5.2.11.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z4-2 is $163,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

5.2.12 Alternative Z4-3: Contain, Remediate, and Remove Additional Mass from Zone 4 Groundwater

Alternative Z4-3 would include operation of the hydraulic barrier and the same components as Alternative Z4-2, with the additional operation of three existing groundwater extraction wells to provide additional mass removal. A map showing the capture zone for this alternative is included in Appendix H. The discussion below does not repeat the substance of the discussion as to Alternative Z4-2, but simply notes any differences between the two alternatives resulting from the addition of the mass removal wells.

5.2.12.1 Overall Protection of Human Health and Environment

Alternative Z4-3 would be equally as protective as Alternative Z4-2.

5.2.12.2 Compliance with ARARs

Alternative Z4-3 would provide the same level of compliance with ARARs as Alternative Z4-2.

5.2.12.3 Long-Term Effectiveness and Permanence

With the exception that there would be more mass of chemicals extracted, Alternative Z4-3 would provide the same level of long-term effectiveness and permanence as Alternative Z4-2.

5.2.12.4 Reduction of Toxicity, Mobility and Volume through Treatment

Because of the additional rate of mass removal, the reduction of toxicity, mobility, or volume through treatment for Alternative Z4-3 would be increased over that of Alternative Z4-2.

The same residuals would remain after treatment under Alternative Z4-3 as under Alternative Z4-2. More volume/mass of residuals would be generated under Alternative Z4-3.

5.2.12.5 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be the same as Alternative Z4-2.

Environmental Impacts. Same as Alternative Z4-2.

Time until Response Objectives are Achieved. Same as Alternative Z4-2, with the exception that the estimates of the times to reduce chemical concentrations to below chemical-specific ARARs or risk-based criteria would be different. The results of these estimates are included in Table 5-1. For alternative Z4-3, the longest time until response objectives are achieved is estimated to be 208 years, with the chemical driver being NDMA.

5.2.12.6 Implementability

Same as Alternative Z4-2.

5.2.12.7 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z4-3 are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$2,900,000
Estimated annual monitoring costs:	$60,000
Estimated annual O&M costs:	$330,000
Estimated 30-year present worth costs:	$7,800,000

Based on the estimated time of 208years until RAOs are achieved (see Section 5.2.12.5), the supplemental non-discounted constant dollar cost estimate for Alternative Z4-3 is $102,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

6 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section presents the comparative analysis for the alternatives that were evaluated in Section 5. The relative performance of each alternative is evaluated against the performance of the other alternatives for each of the threshold and primary balancing criteria. This comparative analysis identifies the advantages and disadvantages of each alternative to assist in the decision making process leading to the Proposed Plan.

6.1 Threshold Criteria

Two of the nine criteria specified in the NCP relate directly to statutory findings that must ultimately be made in the ROD. These two criteria are (1) overall protection of human health and the environment, and (2) compliance with ARARs. They are classified as threshold criteria, as each alternative must meet these two criteria.

6.1.1 Overall Protection of Human Health and the Environment

Alternatives Z1-1, Z2-1, Z3-1 and Z4-1, which assume the absence of any groundwater containment facilities and institutional controls, do not provide adequate protection to human health, because it is assumed that contaminated groundwater continues to migrate and it is assumed that there are no institutional controls to prevent public exposure to the groundwater. As previously discussed, existing (non-CERCLA) regulations related to public and private water supplies prevent the use of contaminated water. Therefore, it is unlikely that contaminated groundwater would be extracted for use. However, for purposes of the FS, it is assumed that under the No Action alternatives, contaminated water would be used for potable supply and therefore, this alternative would not be protective of human health.

Each of the remaining alternatives include actions that break the pathway through which contaminated groundwater would be supplied for potable use. Each of Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 involve operation of groundwater containment systems, thereby providing a hydraulic boundary to minimize the risk of the migration of COCs. Therefore, Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 are sufficiently protective of public health and the environment with respect to these threshold criteria.

6.1.2 Compliance with ARARs

Compliance with ARARs also serves as a threshold criterion that must be met by any alternative for it to be selected as a remedy, unless an ARARs waiver is obtained. Each alternative, except the No Action Alternatives Z1-1, Z2-1, Z3-1 and Z4-1, has the potential to eventually comply with ARARs.

Chemical-specific ARARs will be met by Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3, since under each such alternative, impacted groundwater will be hydraulically contained at and treated to concentrations that meet chemical-specific ARARs prior to management/reuse.

Location- and action-specific ARARs do not apply to the No Action Alternatives Z1-1, Z2-1, Z3-1 and Z4-1. The groundwater extraction, conveyance, and treatment systems variously described under Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 will be designed and operated to comply with all location- and action-specific ARARs.

Identified potential ARARs are detailed in Appendix F.

6.2 Primary Balancing Criteria

Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 are comparatively analyzed in this section for the next five of the nine criteria, the primary balancing criteria. (Alternatives Z1-1, Z2-1, Z3-1 and Z4-1, the No Action alternatives, are not evaluated with respect to the primary balancing criteria, as they did not meet the initial threshold criteria.) These five criteria include long-term effectiveness and permanence; reduction of toxicity, mobility and volume through treatment; short-term effectiveness; implementability; and cost. These five criteria are collectively described as the primary balancing criteria as they provide the primary basis for differentiation among the various alternatives.

Tables 6-1, 6-2, and 6-3 provide summaries of various criteria that are used as means for comparison of alternatives. Table 6-1 includes components such as number of wells, flowrate, and length of new piping. Capital, monitoring, O&M, and present worth costs are summarized on Table 6-2. Table 6-3 provides summaries of the estimated amounts of mass removed, the estimated time until RAOs are achieved, and estimated non-discounted constant dollar costs.

6.2.1 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence is a measure of the following two principal factors:

- The magnitude of residual risk; and
- The adequacy and reliability of controls.

Each of Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 would appear to provide an equal potential to effectively control the migration of COCs as they all would continue to operate an existing or establish a new hydraulic containment barrier. These barriers would permanently remove and treat COCs from affected groundwater, thereby reducing the long-term potential for exposure to COCs in groundwater.

The alternatives that include a mass removal component (Z1-3, Z2-3, Z3-3, and Z4-3) would appear to provide greater long-term effectiveness and permanence than Alternatives Z1-2, Z2-2, Z3-2, and Z4-2.

Although Alternatives Z1-2, Z2-2, Z3-2, and Z4-2 would remove mass, Alternatives Z1-3, Z2-3, Z3-3, and Z4-3 involve a greater amount of mass removal than their counterparts, and therefore probably have the greatest potential to eventually restore the aquifer to beneficial uses and reduce the magnitude of residual risk. However, given the complexity and heterogeneity of the aquifer system and the unknown fate and transport characteristics of some of the COCs (i.e., perchlorate and NDMA), there is no realistic basis for evaluating the extent to which aquifer restoration will occur and over what period of time.

6.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion is a measure of the following five principal factors:

- Statutory preference for treatment as a principal element;
- Irreversibility of treatment;
- Type and quantity of treatment residual;
- Amount of hazardous material destroyed or treated; and
- Reduction in toxicity, mobility, or volume.

With respect to COCs, each of Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 involves management of contaminated groundwater that will achieve reduction in toxicity, mobility or volume through treatment. (A summary of the estimated extraction flowrates under each alternative is presented in Table 6-1.) The remaining alternatives are equal in their preference for treatment and the irreversibility of treatment processes.

Alternatives Z1-3, Z2-3, Z3-3, and Z4-3 include a larger mass removal component (Table 6-3) and therefore would be expected to provide greater reduction in toxicity, mobility and volume of the COCs than Alternatives Z1-2, Z2-2, Z3-2, and Z4-2.

For Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3, groundwater will be treated using various processes that are irreversible. No residuals are associated with the UV/oxidation treatment because contaminants are destroyed. Air strippers produce VOCs in offgas that may require treatment prior to being emitted to the atmosphere, but for Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 it is assumed that the air stripping process would be proceeded by the UV/oxidation process which would reduce VOCs to levels such that treatment of air stripper offgas would not be required. For those alternatives where a perchlorate removal process would be employed, residuals remaining after treatment would include either (1) the minor volume of non-hazardous organic sludge that would be generated by the biological reduction process, or (2) exhausted ion exchange resin. The sludge would be discharged to a sanitary sewer or dewatered and disposed in a non-hazardous landfill. Exhausted ion exchange resin would be regenerated by the vendor.

The groundwater treatment component of Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, Z3-3, Z4-2, and Z4-3 meets the statutory preference for treatment to reduce the principal threat because contaminants are destroyed or collected and the total volume of contaminated media is reduced.

6.2.3 Short-Term Effectiveness

Short-term effectiveness is a measure of the protection afforded by each alternative during the construction and implementation process. As such, the time until RAOs are achieved is an important component of this criterion. The availability of equipment and specialists to implement the alternative is also a consideration.

This criterion is a measure of the following three principal factors:

- Protection of workers and the community during the remedial action;
- Environmental impacts; and
- Time until remedial response objectives are achieved.

Under all alternatives that include remedial action, the community and the environment would be protected during construction and implementation of the remedial action and from potential exposure to COCs through existing institutional controls.

The time required to implement Alternatives Z4-2 and Z4-3 would be shorter than Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z3-2, and Z3-3, because they do not require construction in land not owned by Aerojet. Alternatives Z3-2, and Z3-3 would require the most significant planning, design, and construction activities for the hydraulic containment components constructed on lands not owned by Aerojet.

It is anticipated that the necessary equipment and specialists are available to implement all alternatives.

With respect to comparison of the time until remedial response objectives are achieved among the various alternatives, Alternative Z4-2 would have the longest estimated restoration time of 347 years, followed by Alternatives Z3-2 (327 years), Z3-3 (263 years), Z2-2 (232 years), Z4-3 (208 years), Z1-2 (151 years), Z2-3 (131 years), and Z1-3 (124 years). The estimated times until remedial response objectives are achieved are summarized on Table 6-3.

6.2.4 Implementability

Implementability evaluates the technical and administrative difficulties associated with implementing each alternative. Each of the alternatives is implementable to varying degrees, as discussed in this section. With exception of the No Action Alternatives Z1-1, Z2-1, Z3-1 and Z4-1, there are several technical and administrative difficulties associated with each of the alternatives evaluated in this FS. Technical implementability issues include demonstrating hydraulic capture and control of COC plumes and demonstrating the ability to treat extracted COCs. Administrative difficulties associated with implementing alternatives include obtaining easements for wells and pipelines.

The number of proposed new wells and estimated lengths of piping under each alternative are summarized in Table 6-1. The estimated flow rates for each alternative were discussed previously (Table 6-1). Alternatives Z4-2 and Z4-3 would be the easiest to implement, because construction of proposed facilities would occur on Aerojet property. Following is a listing of alternatives in order of increasing short-term implementability issues based on the magnitude of new facilities that would be constructed: Z1-2/1-3, Z2-2/2-3, and Z3-2/3-3. Alternatives Z3-2 and Z3-3 would be the most difficult to implement as they would involve construction on property that is not owned by Aerojet. Alternatives Z1-3, Z2-3, Z3-3, and Z4-3 potentially present lower implementability concerns over the long term than Alternatives Z1-2, Z2-2, Z3-2, and Z4-2, because they provide greater mass removal which may reduce longer term risks of contingent actions.

6.2.5 Cost

A summary of the estimated costs associated with each alternative is presented in Table 6-2. The cost estimates for each alternative were prepared in accordance with current EPA guidance with respect to level of accuracy and discount rate (i.e., seven percent). For comparison purposes, the estimated total capital cost, estimated annual monitoring costs, estimated annual O&M costs, and estimated 30-year present worth cost estimates are presented in Table 6-2 for each of the alternatives. Wherever possible, actual capital, monitoring, and O&M costs from construction projects at and on-going along with O&M at the Aerojet GET facilities were used for these cost estimates. The basis for the costs and the methodology and information used to develop the costs are provided in Appendix I.

Non-discounted constant dollar costs were also estimated for each alternative, assuming the groundwater containment and restoration systems would be operated for the estimated time until RAOs are achieved. These costs as well as the estimated time until RAOs are achieved are summarized on Table 6-3. Non-discounted constant dollar costs range from $69,000,000 to $430,000,000. Alternative Z3-2 has the highest non-discounted constant dollar cost of $430,000,000, followed by Alternatives Z3-3 ($282,000,000), Z2-2 ($167,000,000), Z4-2 ($165,000,000), Z1-2 ($147,000,000), Z1-3 ($142,000,000), Z2-3 ($105,000,000), and Z4-3 ($69,000,000).

6.3 Modifying Criteria

The final two of the nine criteria are state acceptance and community acceptance. These two criteria are evaluated following comment on the FS report and Proposed Plan and as such are termed modifying criteria.

6.3.1 State Acceptance

This criterion addresses the State's apparent preferences among or concerns about the various alternatives. This criterion will be addressed as part of the final decision-making process during the preparation of the ROD.

6.3.2 Community Acceptance

This criterion addresses the community's apparent preferences among or concerns about the various alternatives. This criterion will be addressed as part of the final decision-making process during the preparation of the ROD.

7 REMEDIAL GOALS: A COMPARISON BETWEEN MAXIMUM CONTAMINANT GOALS AND MORE STRINGENT WATER QUALITY GOALS

7.1 Introduction

This RI/FS was prepared based on a groundwater Cleanup Level for TCE of 5 ug/L. A concentration of 5 ug/L for TCE is both the State of California and Federal Primary MCL for drinking water. TCE at 5 ug/L is consistent with the Cleanup Level contained in all interim and final RODs for groundwater issued in EPA Region IX prior to the date of this report (http://yosemite.epa.gov/r9/sfund/rodex.nsf). It is also the Cleanup Level for TCE contained in the Western Groundwater Operable Unit (OU-3) ROD [USEPA Region 9, 2001], the one other ROD for the Aerojet Sacramento Site.

In the Agency comments (dated March 25, 2004) on the draft PGOU FS report (dated February 19, 2004), it was stated that the California DHS Office of Drinking Water Public Health Goal (PHG) of 0.8 ug/L for TCE should be evaluated as a Cleanup Level for the PGOU. The specific Agency comments demanding the use of the PHG for TCE can be found in following comment numbers: 32, 56, 66, 76, and 80. The purpose of this Section is to directly respond to the Agency comments and to evaluate the impacts on the remedial alternatives for cleanup to 0.8 ug/L for TCE.

As previously discussed in Section 5 of this Report, TCE dictates the time until response objectives are achieved for the second and third alternatives evaluated in both Zones 1 and 2. Accordingly, remedial alternatives Z1-2, Z1-3, Z2-2 and Z2-3 are evaluated in this section with a Cleanup Level for TCE of 0.8 ug/L. Alternatives Z1-1 and Z2-1 are not evaluated within this section, as they are no-action alternatives. Remedial alternatives for Zones 3 and 4 are not evaluated within this section as NDMA dictates the time until response objectives are achieved for groundwater in those zones and the impacts of a cleanup level of 0.8 ug/L for TCE cannot be determined at this time.

Z1-2, Z1-3, Z2-2 and Z2-3 involve the installation of extraction wells located at the downgradient extent of TCE in groundwater to provide hydraulic capture and restore that groundwater to its beneficial uses. Z1-3 and Z2-3 include the additional operation of existing mass removal extraction wells. The groundwater flow model described in Appendix H to Part 1 of this report was used to provide hydraulic capture to a cleanup level of 0.8 ug/L for TCE. The results of this modeling provide the basis for the description, evaluation, and comparison of alternatives in this section.

The alternatives which evaluate a cleanup level of 0.8 ug/L for TCE were named the same as those in Section 4, but include a “TCE 0.8” descriptor after the number. The listing is as follows:

Alternative Z1-2 (TCE 0.8): Contain and Remediate Zone 1 Groundwater

Alternative Z1-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

Alternative Z2-2 (TCE 0.8): Contain and Remediate Zone 2 Groundwater

Alternative Z2-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

7.2 Overview

The remaining subsections within Section 7 provide descriptions of the four modified alternatives, focused on the additions necessary to obtain a TCE cleanup level of 0.8 ug/L. In the detailed analysis following below, the primary balancing criteria of reduction of toxicity/mobility/volume through treatment, short-term effectiveness, implementability, and cost are evaluated with respect to the alternatives with a TCE cleanup level of 0.8 ug/L. The conclusions are:

- All alternatives are sufficiently and equally protective of public health and the environment, would comply with ARARs, and would provide a relatively equal degree of long-term effectiveness and permanence.

- To hydraulically contain groundwater at a Cleanup Level for TCE of 0.8 ug/L, an increase in the extracted groundwater flowrate of approximately 28% would be required in Zone 1. In Zone 2, the increase would be approximately 7%.

- With the 28% increase in flowrate in Zone 1, the increase in TCE mass removal would be between 3 and 6%. In Zone 2, the increase in TCE mass removal would be between 7 and 10%.

- Restoration of groundwater to a cleanup level of 0.8 ug/L for TCE is estimated to require significantly more time and cost:

    - In Zone 1 the increase is estimated to range from 92 years (an increase of 61%) to 62 years (increase of 50%) for Z1-2 and Z1-3 respectively. These increases in time would result in increased costs ranging from $126,000,000 (86% increase) to $98,000,000 (69% increase).

    - In Zone 2, the increase in years is estimated to be the same as for Zone 1, from 92 years (increase of 40%) to 62 years (increase of 47%). These increases in time would result in increased costs ranging from $83,000,000 (50 % increase) to $59,000,000 (56% increase).

- In addition, to implement the Zone 1 alternatives with a TCE Cleanup Level of 0.8 ug/L, 3 additional extraction wells would need to installed on land not owned by Aerojet. These wells would be installed within rights-of-way on roads in the Fair Oaks bluffs neighborhood on the north side of the American River and within the Gold River development. Alternatives incorporating a TCE Cleanup Level of 0.8 ug/L would be significantly more difficult to implement (both technically and administratively) than alternatives where the TCE Cleanup Level is set at the MCL of 5 ug/L.

7.3 Description of Alternatives

7.3.1 Alternative Z1-2 (TCE 0.8): Contain and Remediate Zone 1 Groundwater

In Zone 1, the TCE Cleanup Level affects both the number of downgradient extraction wells and the pumping rates estimated for providing hydraulic capture. Figures 7-1, 7-2, and 7-3 illustrate the extent of TCE above 5 and 0.8 μg/L in Layers C, D, and E, respectively. Figures H2-11, H2-12, and H2-13 present the modeling results conducted to estimate the numbers, locations, and pumping rates for extraction wells for capturing TCE at 0.8 μg/L in Layers C, D, and E, respectively.

As discussed previously in Section 4 for Alternative Z1-2, the modeling concludes that in addition to the eight existing American River extraction wells (4302, 4325, 4330, 4335, 4380, 4580, 4585, and 4620), existing GET D extraction well 4035, and converted existing GET D recharge wells 5020 and 5105, two new extraction wells, one in Layer C and one in Layer D, would complete hydraulic capture of TCE above 5 μg/L north of the American River (Figures H2-11 and H2-12, respectively). Also, two new on-site extraction wells, one in Layer C and one in Layer D, would provide hydraulic capture of TCE and perchlorate southwest of the GET D recharge field. The cumulative flow rate estimated for Alternative Z1-2 is approximately 3,560 gpm. A conceptual depiction of the facilities that would comprise Alternative Z1-2 is contained on Figure 4-1. Table 4-1 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE, perchlorate, and NDMA under Alternative Z1-2.

Modeling simulations were conducted to evaluate potential differences to Alternative Z1-2 for capturing TCE at 0.8 μg/L. The simulations suggest that for Alternative Z1-2 (TCE 0.8), in addition to the wells proposed, three new extraction wells would be necessary north of the American River; one in Layer C, one in Layer D, and one in Layer E (Figures 7-4, 7-5, and 7-6, respectively). In addition, south of the American River, ARSA extraction well 4375 would need to operate to contain TCE at concentrations between 0.8 and 5 μg/L. A second Layer E well would need to be constructed south of the American River downgradient of extraction well 4375 in the Gold River area. The cumulative flow rate estimated for Alternative Z1-2 (TCE 0.8) is approximately 4,610 gpm versus 3,560 gpm for Z1-2. A conceptual depiction of the facilities that would comprise Alternative Z1-2 (TCE 0.8) is contained on Figure 7-7. Table 7-1 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE, perchlorate, and NDMA under Alternative Z1-2 (TCE 0.8).

As shown on Table 7-1, the treatment, discharge, monitoring, contingent wellhead treatment and institutional control components for Alternative Z1-2 (TCE 0.8) would be the same as those for Z1-2.

7.3.2 Alternative Z1-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

Alternative Z1-3 (TCE 0.8) would include the same components as Alternative Z1-2 (TCE 0.8), with the addition of existing groundwater extraction wells 4220 and 4320 to provide additional mass removal, as with Alternative Z1-3. The cumulative flow rate estimated for Alternative Z1-3 (TCE 0.8) is approximately 4,960 gpm versus 3,900 gpm for Z1-3. A conceptual depiction of the facilities that would comprise Alternative Z1-3 (TCE 0.8) is contained on Figure 7-8. Table 7-2 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE, perchlorate, and NDMA under Alternative Z1-3 (TCE 0.8).

7.3.3 Alternative Z2-2 (TCE 0.8): Contain and Remediate Zone 2 Groundwater

In Zone 2 Alternatives Z2-2 and Z2-3, the downgradient extraction wells are located near the 50 µg/L contour interval for TCE and reducing the TCE Cleanup Level to 0.8 ug/L would not affect the locations of these wells. However, the TCE plume is wider at 0.8 µg/L and higher pumping rates would be required to achieve capture. Figures 7-9, 7-10, and 7-11 illustrate the extents of TCE above 5 and 0.8 µg/L in Layers A, B, and C, respectively. Figures H3-1 through H3-4 present the modeling results conducted to estimate the numbers, locations, and pumping rates for extraction wells for capturing TCE at 5 µg/L in Layers B and C.

As discussed previously in Section 4 for Alternative Z2-2, the modeling results suggest that construction of three groundwater extraction wells screened within Layer C would provide hydraulic capture of TCE and perchlorate and prevent Zone 2 groundwater from migrating further on the IRCTS property. The modeling simulations also indicate that groundwater in Layers A and B would be captured by the extraction wells screened in Layer C. The cumulative flow rate estimated for Alternative Z2-2 (TCE Cleanup Level of 5 ug/L) is approximately 1,400 gpm. A conceptual depiction of the facilities that would comprise Alternative Z2-2 is contained on Figure 4-3. Table 4-3 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE and perchlorate under Alternative Z2-2.

Modeling simulations were conducted to evaluate potential differences in Alternative Z2-2 for capturing TCE at 0.8 µg/L. As stated above, no changes to the location of the three new extraction wells would be necessary. Figures 7-12 and 7-13 present the modeling results conducted to estimate the numbers, locations, and pumping rates for extraction wells for capturing TCE at 0.8 µg/L in Layers B and C. The cumulative flow rate estimated for Alternative Z2-2 (TCE 0.8) would be approximately 1,500 gpm versus 1,400 gpm for Alternative Z2-2. A conceptual depiction of the facilities that would comprise Alternative Z2-2 (TCE 0.8) is contained on Figure 7-14. Table 7-3 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE and perchlorate under Alternative Z2-2 (TCE 0.8).

As shown on Table 7-3, the treatment, discharge, monitoring, and institutional control components for Alternative Z2-2 (TCE 0.8) would be the same as those for Z2-2.

7.3.4 Alternative Z2-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

Alternative Z2-3 (TCE 0.8) would include the same components as Alternative Z2-2 (TCE 0.8), with the addition of existing groundwater extraction well 4420 to provide additional mass removal as with Alternative Z2-3. The cumulative flow rate estimated for Alternative Z2-3 (TCE 0.8) is approximately 1,650 gpm versus 1,550 gpm for Z2-3. A conceptual depiction of the facilities that would comprise Alternative Z2-3 (TCE 0.8) is included on Figure 7-15. Table 7-4 lists the extraction wells and their characteristics, anticipated pumping rates, and the estimated influent concentrations of TCE and perchlorate under Alternative Z2-3 (TCE 0.8).

7.4 Detailed Analysis of Alternatives

In this section, the four alternatives are subjected to a detailed analysis using the seven NCP threshold and primary balancing criteria described previously in Section 5. The two threshold criteria include Overall Protection of Human Health and the Environment and Compliance with ARARs. The five primary balancing criteria include Long-Term Effectiveness and Permanence; Reduction of Toxicity, Mobility, or Volume through Treatment; Short-Term Effectiveness; Implementability; and Cost.

With respect to the threshold criteria, like the alternatives developed in Section 4 for Zones 1 and 2, all four alternatives would be protective of human health and the environment and would meet all ARARs that pertain to the protection of groundwater resources and the cleanup of releases. The groundwater extraction and conveyance facilities would continue to be operated in a manner designed to comply with all location- and action-specific ARARs. In addition, with respect to the primary balancing criteria of Long-Term Effectiveness and Permanence, the analysis of Alternatives Z1-2 (TCE 0.8), Z1-3 (TCE 0.8), Z2-2 (TCE 0.8), and Z2-3 (TCE 0.8) yields the same conclusions as those for Alternatives Z1-2, Z1-3, Z2-2 and Z2-3. Therefore, the detailed analysis presented in this section focuses on the remaining four primary balancing criteria of Reduction of Toxicity, Mobility, or Volume through Treatment; Short-Term Effectiveness; Implementability; and Cost and the effects of the TCE cleanup level of 0.8 ug/L.

7.4.1 Alternative Z1-2 (TCE 0.8): Contain and Remediate Zone 1 Groundwater

7.4.1.1 Reduction of Toxicity, Mobility and Volume through Treatment

Similar to the discussion in Section 5 for Alternative Z1-2, the hydraulic containment system for Alternative Z1-2 (TCE 0.8) would be operated, capturing the COCs and preventing them from migrating, reducing the toxicity, mobility, and volume of the COCs.

Residuals remaining after treatment would include VOCs in the offgas of the air stripping process at the ARGET treatment facility. These residuals are expected to be below chemical-specific ARARs and risk-based criteria. Exhausted ion exchange resin would also be produced, which would be regenerated by the vendor.

Based on the influent chemistry concentrations estimated in Table 7-1, the mass removal rate for TCE is projected to be 3.8 lbs/day, less than 6 percent more than for Alternative Z1-2.

7.4.1.2 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be similar to, although longer than, Alternative Z1-2 (see Section 5). The longer impact would result from a longer construction period for the pipeline to serve the additional proposed extraction wells, Z1-C1 in the Fair Oaks bluff area and Z1-E2 in the Gold River area.

Environmental Impacts. Same as Alternative Z1-2 (see Section 5).

Time until Response Objectives are Achieved. As shown on Table 7-5, the estimated time to reduce TCE to below 0.8 ug/L is 243 years, 92 years (61 percent) longer than the 151 years to reduce TCE to below 5 ug/L under Alternative Z1-2.

7.4.1.3 Implementability

The primary technical feasibility issue associated with constructing Alternative Z1-2 (TCE 0.8) would be the difficulty in establishing the hydraulic barrier at the downgradient extent of TCE in groundwater at the PHG concentration of 0.8 ug/L, given the difficulties of siting extraction wells and pipelines and the complexity of the hydrogeology.

There are technical and administrative difficulties associated with the construction of the portion of the hydraulic barrier not within land owned by Aerojet, including siting and construction of wells and conveyance pipeline. The majority of construction would occur on County Park property, within rights-of-way on roads in the Fair Oaks bluffs neighborhood on the north side of the American River above the County Park, and within the Gold River development. Construction of extraction wells and conveyance piping in these locations would involve securing the necessary easements, which will be difficult particularly in the bluffs and Gold River neighborhoods. Assuming easements can be obtained to route conveyance piping from proposed well Z1-C1 within the existing roads in the Fair Oaks bluffs area, installation of piping so as not to interfere with existing buried utilities and to not interrupt traffic patterns would be a significant challenge. Potential delays in the start of implementation of this remedial alternative as well as delays in completion of construction could result because of these issues.

7.4.1.4 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z1-2 (TCE 0.8) are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Capital costs:	$4,000,000
Annual monitoring costs:	$180,000
Annual O&M costs:	$830,000
30-year present worth costs:	$16,500,000

Based on the estimated time of 243 years until RAOs are achieved (TCE in Layers C, D, and E - Table 7-5), the supplemental non-discounted constant dollar cost estimate for Alternative Z1-2 (TCE 0.8) is $273,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

If groundwater from proposed extraction wells located north of the American River were treated at a location adjacent to Well 1047, estimated costs for Alternative Z1-2 (TCE 0.8) would be as follows:

Capital costs:	$5,200,000
Annual monitoring costs:	$180,000
Annual O&M costs:	$830,000
30-year present worth costs:	$17,700,000
Non-discounted constant dollar costs:	$283,000,000

7.4.2 Alternative Z1-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 1 Groundwater

7.4.2.1 Reduction of Toxicity, Mobility and Volume through Treatment

The reduction in toxicity, mobility, and volume through treatment for Alternative Z1-3 (TCE 0.8) would be the same as for Alternative Z1-2 (TCE 0.8). Based on the influent chemistry concentrations estimated in Table 7-2, the mass removal rate for TCE is projected to be 3.9 lbs/day, less than 3 percent more than for Alternative Z1-3.

7.4.2.2 Short-Term Effectiveness

The protection of the community and workers and the potential environmental impacts for this Alternative Z1-3 (TCE 0.8) would be the same as Alternative Z1-2 (TCE 0.8).

Time until Response Objectives are Achieved. As shown on Table 7-5, the estimated time to reduce TCE to below 0.8 ug/L is 186 years, 62 years (50 percent) longer than the 124 years to reduce TCE to below 5 ug/L under Alternative Z1-3.

7.4.2.3 Implementability

Same as Alternative Z1-2 (TCE 0.8).

7.4.2.4 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z1-3 (TCE 0.8) are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$4,000,000
Estimated annual monitoring costs:	$200,000
Estimated annual O&M costs:	$970,000
Estimated 30-year present worth costs:	$18,600,000

Based on the estimated time of 186 years until RAOs are achieved (TCE in Layer D – Table 7-5), the supplemental non-discounted constant dollar cost estimate for Alternative Z1-3 (TCE 0.8) is $240,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

If groundwater from proposed extraction wells located north of the American River were treated at a location adjacent to Well 1047, estimated costs for Alternative Z1-3 (TCE 0.8) would be as follows:

Capital costs:	$5,200,000
Annual monitoring costs:	$200,000
Annual O&M costs:	$950,000
30-year present worth costs:	$19,600,000
Non-discounted constant dollar costs:	$319,000,000

7.4.3 Alternative Z2-2 (TCE 0.8): Contain and Remediate Zone 2 Groundwater

7.4.3.1 Reduction of Toxicity, Mobility and Volume through Treatment

The reduction in toxicity, mobility, and volume through treatment for Alternative Z2-2 (TCE 0.8) would be the same as for Alternative Z2-2. Based on the influent chemistry concentrations estimated in Table 7-3, the mass removal rate for TCE is projected to be 1.1 lbs/day, approximately 10 percent more than for Alternative Z2-2.

7.4.3.2 Short-Term Effectiveness

Protection of Community and Workers. The short-term impact on the risks to the community and workers would be the same as Alternative Z2-2 (see Section 5) as would be the environmental impacts.

Time until Response Objectives are Achieved. As shown on Table 7-5, the estimated time to reduce TCE to below 0.8 ug/L is 324 years, 92 years (40 percent) longer than the 232 years to reduce TCE to below 5 ug/L under Alternative Z2-2.

7.4.3.3 Implementability

The technical and administrative feasibility issues associated with constructing Alternative Z2-2 (TCE 0.8) would be the same as those discussed for Alternative Z2-2 in Section 5.2.5.6.

7.4.3.4 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z2-2 (TCE 0.8) are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$5,200,000
Estimated annual monitoring costs:	$40,000
Estimated annual O&M costs:	$520,000
Estimated 30-year present worth costs:	$12,200,000

Based on the estimated time of 324 years until RAOs are achieved (TCE in Layers B and C – Table 7-5), the supplemental non-discounted constant dollar cost estimate for Alternative Z2-2 (TCE 0.8) is $250,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

7.4.4 Alternative Z2-3 (TCE 0.8): Contain, Remediate, and Remove Additional Mass from Zone 2 Groundwater

7.4.4.1 Reduction of Toxicity, Mobility and Volume through Treatment

The reduction in toxicity, mobility, and volume through treatment for Alternative Z2-3 (TCE 0.8) would be the same as for Alternative Z2-2 (TCE 0.8) except that based on the influent chemistry concentrations estimated in Table 7-4, the mass removal rate for TCE is projected to be 1.6 lbs/day, less than 6 percent more than for Alternative Z2-3.

7.4.4.2 Short-Term Effectiveness

The protection of the community and workers and the potential environmental impacts for this Alternative Z2-3 (TCE 0.8) would be the same as Alternative Z2-2 (TCE 0.8).

Time until Response Objectives are Achieved. As shown on Table 7-5, the estimated time to reduce TCE to below 0.8 ug/L is 193 years, 62 years (47 percent) longer than the 131 years to reduce TCE to below 5 ug/L under Alternative Z2-3.

7.4.4.3 Implementability

Same as Alternative Z2-2 (TCE 0.8)

7.4.4.4 Costs

Estimated capital, annual O&M, and 30-year present worth costs for Alternative Z2-3 (TCE 0.8) are as follows. Detailed cost estimates and a present worth summary are included in Appendix I.

Estimated capital costs:	$5,400,000
Estimated annual monitoring costs:	$44,000
Estimated annual O&M costs:	$590,000
Estimated 30-year present worth costs:	$13,300,000

Based on the estimated time of 193 years until RAOs are achieved (TCE in layer B – Table 7-5), the supplemental non-discounted constant dollar cost estimate for Alternative Z2-3 (TCE 0.8) is $164,000,000. The detailed non-discounted constant dollar cost estimate is included in Appendix I.

7.5 Comparative Analysis of Alternatives using the MCL and PHG for the TCE Cleanup Level

This section presents the comparative analysis for the Zone 1 and 2 alternatives, with a Cleanup Level for TCE of 5.0 versus 0.8 ug/L. The relative estimated performances of the alternatives are evaluated using each of the threshold and primary balancing criteria evaluated in Sections 5.2 and 7.2. This comparative analysis identifies the advantages and disadvantages of a cleanup level of 5.0 versus 0.8 ug/L.

7.5.1 Threshold Criteria

Alternatives Z1-2, Z1-3, Z2-2, Z2-3, Z1-2 (TCE 0.8), Z1-3 (TCE 0.8), Z2-2 (TCE 0.8), and Z2-3 (TCE 0.8), are. The threshold criteria of Overall Protection of Human Health and the Environment and Compliance with ARARs would be equally met for all of the alternatives.

7.5.2 Primary Balancing Criteria

The five Primary Balancing Criteria include long-term effectiveness and permanence; reduction of toxicity, mobility and volume through treatment; short-term effectiveness; implementability; and cost. These five provide the primary basis for differentiation among the various alternatives.

7.5.2.1 Long-Term Effectiveness and Permanence

Each of the alternatives would appear to provide an equal potential to effectively control the migration of COCs as they all would continue to operate an existing or establish a new hydraulic containment barrier. These barriers would permanently remove and treat COCs from affected groundwater, thereby reducing the long-term potential for exposure to COCs in groundwater.

Alternatives Z1-3 (TCE 0.8) and Z2-3 (TCE 0.8) would involve a very slightly greater amount of mass removal, albeit over a greater time period, than their counterparts, and therefore likely have a slightly greater potential to eventually restore the aquifer to beneficial uses and reduce the magnitude of residual risk. However, given the complexity and heterogeneity of the aquifer system and the unknown fate and transport characteristics of TCE, there is no realistic basis for evaluating the extent to which aquifer restoration will occur and over what period of time.

Because the impacted groundwater will be hydraulically contained as well as treated to a lower TCE concentration, those alternatives with a TCE Cleanup Level of 0.8 ug/L would potentially provide greater degree of long-term effectiveness and permanence than those alternatives with a TCE Cleanup Level of 5.0 ug/L.

7.5.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

Based on the total flowrates and influent chemistry concentrations estimated in Tables 4-1 through 4-4 and Tables 7-1 through 7-4, both total flowrates and mass removal rates for TCE are projected to be slightly higher for those alternatives with a TCE cleanup level of 0.8 ug/l.

The comparisons of flowrates and mass removal rates are illustrated in Table 7-6. Specifically:

- Alternative Z1-2 (TCE 0.8) is estimated to have a 29 % higher flowrate and 6% greater TCE mass removal rate than Alternative Z1-2;

- Alternative Z1-3 (TCE 0.8) is estimated to have a 27 % higher flowrate and 3% greater TCE mass removal rate than Alternative Z1-3;

- Alternative Z2-2 (TCE 0.8) is estimated to have a 7 % higher flowrate and 10% greater TCE mass removal rate than Alternative Z2-2; and

- Alternative Z2-3 (TCE 0.8) is estimated to have a 6 % higher flowrate and 7% greater TCE mass removal rate than Alternative Z2-3.

7.5.2.3 Short-Term Effectiveness

Short-term effectiveness is a measure of the protection afforded by each alternative during the construction and implementation process. As such, the time until RAOs are achieved is an important component of this criterion. The availability of equipment and specialists to implement the alternative is also a consideration.

Under all alternatives, the community and the environment would be protected during construction and implementation of the remedial action and from potential exposure to COCs through existing institutional controls. It is anticipated that the necessary equipment and specialists are available to implement all alternatives.

For the Zone 1 alternatives, because Alternatives Z1-2 (TCE 0.8) and Z1-3 (TCE 0.8) require the installation of 3 additional extraction wells within land not owned by Aerojet, they would require significantly more planning, design, and construction activities than their counterparts.

In comparing the time until RAOs are achieved, the alternatives with a TCE cleanup level of 0.8 ug/l would have a significantly longer timeframe. The comparisons of the time until RAOs are achieved are illustrated in Table 7-6. Specifically:

- The time until RAOs are achieved for Alternative Z1-2 (TCE 0.8) is estimated to be 243 years as compared to 151 years for Alternative Z1-2, a 61% increase;
- The time until RAOs are achieved for Alternative Z1-3 (TCE 0.8) is estimated to be 186 years as compared to 124 years for Alternative Z1-3, a 50% increase;
- The time until RAOs are achieved for Alternative Z2-2 (TCE 0.8) is estimated to be 324 years as compared to 232 years for Alternative Z2-2, a 40% increase;
- The time until RAOs are achieved for Alternative Z2-3 (TCE 0.8) is estimated to be 193 years as compared to 131 years for Alternative Z2-3, a 47% increase;

7.5.2.4 Implementability

As stated above for the Zone 1 alternatives, Alternatives Z1-2 (TCE 0.8) and Z1-3 (TCE 0.8) require the installation of 3 additional extraction wells within land not owned by Aerojet, they would be more difficult to implement than their counterparts.

With respect to Zone 2, implementability among the alternatives would be equal.

7.5.2.5 Cost

For comparison purposes, the estimated 30-year present worth costs and non-discounted constant dollar costs given the estimated time until RAOs are achieved are presented in Table 7-6 for each of the alternatives with both a cleanup level of 5.0 ug/L and 0.8 ug/L for TCE . The estimated 30-year present worth cost comparisons indicate:

- Alternative Z1-2 (TCE 0.8) is estimated to have a 23 % higher estimated 30-year present worth cost than Alternative Z1-2, an increase of $3,100,000;
- Alternative Z1-3 (TCE 0.8) is estimated to have an 20 % higher estimated 30-year present worth cost than Alternative Z1-3, an increase of $3,100,000;
- Alternative Z2-2 (TCE 0.8) is estimated to have a 9 % higher estimated 30-year present worth cost than Alternative Z2-2, an increase of $1,000,000; and
- Alternative Z2-3 (TCE 0.8) is estimated to have a 4 % higher estimated 30-year present worth cost than Alternative Z2-3, an increase of $500,000.

The estimated non-discounted constant dollar cost comparisons given the estimated time until RAOs are achieved show significantly higher costs for those alternatives with a cleanup level for TCE of 0.8. Specifically:

- Alternative Z1-2 (TCE 0.8) is estimated to have a 86 % higher estimated non-discounted constant dollar cost than Alternative Z1-2, an increase of $126,000,000;

- Alternative Z1-3 (TCE 0.8) is estimated to have an 69 % higher estimated non-discounted constant dollar cost than Alternative Z1-3, an increase of $98,000,000;

- Alternative Z2-2 (TCE 0.8) is estimated to have a 50 % higher estimated non-discounted constant dollar cost than Alternative Z2-2, an increase of $83,000,000; and

- Alternative Z2-3 (TCE 0.8) is estimated to have a 56 % higher estimated non-discounted constant dollar cost than Alternative Z2-3, an increase of $59,000,000.

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