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FINAL

OPERABLE UNIT 1
REMEDIAL DESIGN/REMEDIAL ACTION WORK PLAN

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

EPA ID# CA9800013030

PREPARED FOR:

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CONTENTS

APPENDICES

FIGURES

TABLES

amsl	above mean sea level
ARAR	applicable or relevant and appropriate requirements
BDAT	best demonstrated available technology
bgs	below ground surface
Caltech	California Institute of Technology
CCl_4	carbon tetrachloride
CCR	California Code of Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWC	California Water Code
DHS	California Department of Health Services
DO	dissolved oxygen
DTSC	Department of Toxic Substances Control
EAO	Environmental Affairs Office
EM	electromagnetic imaging
EPA	United States Environmental Protection Agency
EW	extraction well
FBR	fluidized bed reactor
FWEC	Foster Wheeler Environmental Corporation
GAC	granular activated carbon
GC/MS	gas chromatograph/mass spectrometer
gpm	gallons per minute
GPR	ground-penetrating radar
HASP	Health and Safety Plan
H&SC	Health and Safety Code
IC	ion chromatography
ICP	inductively coupled plasma
I.D.	inner diameter
IRZ	in situ reactive zone
ISE	ion sensitive electrode
IW	injection well
JPL	Jet Propulsion Laboratory
LACSD	Los Angeles County Sanitation District
LDR	land disposal restriction
LGAC	liquid-phase granular activated carbon
MCL	maximum contaminant level

MW	monitoring well
NA	not applicable
NASA	National Aeronautics and Space Administration
NEMA	National Electrical and Mechanical Association
NL	notification level
NPL	National Priorities List
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORP	oxidation reduction potential
OU	Operable Unit
PCB	polychlorinated biphenyl
PLC	programmable logic control
psi	pounds per square inch
PVC	polyvinyl chloride
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design/Remedial Action
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SACM	Superfund Accelerated Cleanup Model
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
TBD	to be determined
TCE	trichloroethene
TOC	total organic carbon
USA	Underground Services Alert
VOC	volatile organic compound
WDR	waste discharge requirement

1.0 INTRODUCTION

This Remedial Design/Remedial Action (RD/RA) Work Plan presents details regarding expansion and continued operation of the Operable Unit 1 (OU-1) source area treatment system at the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). This response action for source area groundwater is being conducted as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program at JPL. The *Interim Record of Decision (ROD) for the Operable Unit 1 Source Area Groundwater* (NASA, 2006a) documents NASA's decision to undertake this response action.

NASA is the lead federal agency for selecting, implementing, and funding remedial activities at JPL, while the United States Environmental Protection Agency (EPA), Department of Toxic Substances Control (DTSC), and Regional Water Quality Control Board (RWQCB) provide oversight and technical assistance.

The highest concentrations of carbon tetrachloride and perchlorate at the JPL site are located in the north-central portion of the JPL facility, which is referred to as the "source area." The source area is the location where the majority of chemicals is dissolved in groundwater, and is defined as an 8-acre by 100-ft-thick portion of the aquifer (see Figure 1-1). The response action for the OU-1 source area consists of expanding the existing source area demonstration study system and continued system operation. This response action is intended to improve the effectiveness and efficiency of the OU-3 groundwater remedy by reducing chemical mass in groundwater that migrates off-facility.

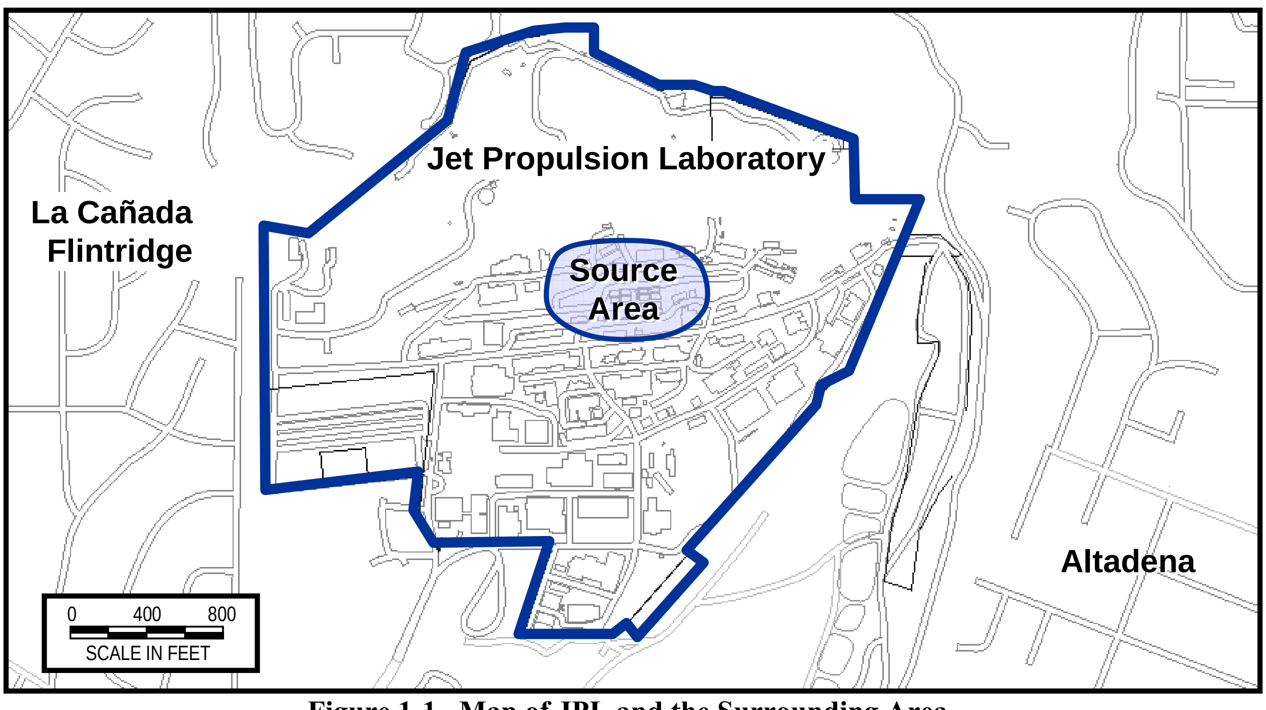


Figure 1-1. Map of JPL and the Surrounding Area

The demonstration study system began operation in March 2005 to evaluate treatment effectiveness. It has proven to be highly effective, removing over 500 lbs of perchlorate and 13 lbs of carbon tetrachloride through July 2006. This response action will expand the existing demonstration study treatment system associated with the source area beneath the JPL facility. The expanded system will continue operations until performance objectives have been achieved.

Remedial action objectives (RAOs) associated with this response action are intended to reduce further migration of chemicals and provide additional data to assess the likelihood of restoring groundwater. EPA recommends evaluating restoration potential prior to establishing objectives for the long-term remedy (U.S. EPA, 1996). The RAOs for the OU-1 source area groundwater response action are as follows:

- Remove chemicals in groundwater and prevent the further spread of volatile organic compounds (VOCs) and perchlorate from the groundwater source area.

- Reduce the amount of chemicals distributed in the source area groundwater to improve the effectiveness and efficiency (and reduce costs) of the final cleanup remedy selected for off-facility groundwater.

This response action is part of a phased approach for characterization and cleanup of groundwater affected by chemicals originating from the JPL facility. A phased approach to cleanup is encouraged by Superfund Accelerated Cleanup Model (SACM) (U.S. EPA, 1992a), whereby characterization and performance data collected during initial phases are used to assess restoration potential. Groundwater restoration potential refers to the likelihood of achieving applicable or relevant and appropriate requirements (ARARs) throughout the facility. In addition, implementation of source treatment is consistent with the U.S. EPA's presumptive response strategy for sites requiring groundwater cleanup (U.S. EPA, 1996).

The remainder of this RD/RA Work Plan is divided into six sections. This section provides an introduction and discusses the remedial action objectives. Section 2.0 provides a project description, including background information, results of the groundwater modeling efforts that were completed to evaluate optimal pumping rates, and locations of new wells associated with the expansion of the source area treatment system. Section 3.0 reviews the ARARs and legal considerations related to water rights. Section 4.0 describes the design of the expansion to the source area treatment system. Section 5.0 summarizes the tasks required to implement the response action, and Section 6.0 provides a proposed schedule for the project.

2.0 PROJECT DESCRIPTION

This section provides a brief background of the events that led to the issuance of the Interim ROD (NASA, 2006a) and the need for the source area groundwater response action. As part of the demonstration study design (NASA, 2003), groundwater modeling was used to estimate the appropriate number and spacing of extraction and injection wells, as well as optimal flow rates. Section 2.2 of this work plan documents additional analysis of extraction and injection well number and spacing associated with the source area groundwater response action.

2.1 Background

The JPL is a federally-funded Research and Development Center in Pasadena, California, currently operated under contract by the California Institute of Technology (Caltech) for NASA. JPL's primary activities include the exploration of the earth and solar system by automated spacecraft and the design and operation of the Global Deep Space Tracking Network.

Located in Los Angeles County, JPL adjoins the incorporated cities of La Cañada Flintridge and Pasadena, and is bordered on the east by the unincorporated community of Altadena. A NASA-owned facility, JPL encompasses approximately 176 acres of land and more than 150 buildings and other structures. Of the JPL Facility's 176 acres, approximately 156 acres are federally owned. The remaining land is leased for parking from the City of Pasadena and the Flintridge Riding Club. Development at JPL is primarily located on the southern half, in two regions: an early-developed northeastern area and a later-developed southwestern area. Figure 1-1 shows the JPL facility and surrounding areas.

During historic operations at JPL, various chemicals (including chlorinated solvents, solid rocket fuel propellants, cooling tower chemicals, sulfuric acid, Freon™, and mercury) and other materials were used at the JPL facility. During the 1940s and 1950s, many buildings at JPL maintained subsurface seepage pits for disposal of sanitary wastes and laboratory chemical wastes collected from drains and sinks within the buildings. Some of the seepage pits received VOCs and other waste materials that currently are found in groundwater beneath and adjacent to JPL. In the late 1950s and early 1960s, a sanitary sewer system was installed at JPL to handle sewage and wastewater, and the use of seepage pits for sanitary and chemical waste disposal was discontinued. Today, laboratory chemical wastes are either recycled or sent off-facility for treatment and disposal at regulated, Resource Conservation and Recovery Act (RCRA)-permitted hazardous waste facilities.

In October 1992, JPL was placed on the National Priorities List (NPL) and, therefore, is subject to the provisions of CERCLA (U.S. EPA, 1992b). The JPL site has been divided into three operable units. OU-1 is on-facility groundwater at JPL; OU-2 is on-facility vadose zone soil at JPL; and OU-3 is off-facility groundwater adjacent to the JPL property.

After being placed on the NPL, additional investigations indicated that two VOCs (carbon tetrachloride and trichloroethene [TCE]) and perchlorate were detected consistently in the source area groundwater at concentrations significantly exceeding their respective state or federal maximum contaminant levels (MCLs) or California Department of Health Services (DHS) notification levels (NLs). The highest concentrations of carbon tetrachloride and perchlorate at the JPL site are located in the north-central portion of the JPL facility, which is referred to as the "source area." The source area is the location where the majority of chemicals is dissolved in the groundwater, and is defined as an 8-acre by 100-ft-thick portion of the aquifer.

Beginning in 1998, NASA began conducting pilot testing of several technologies to address dissolved perchlorate in source area groundwater. The technologies tested include reverse osmosis, fluidized bed reactor (FBR), packed bed reactors, in situ bioremediation, and ion exchange (Foster Wheeler Environmental Corporation [FWEC], 2000; NASA, 2003). Due to the depth and extent of the chemicals in groundwater, in situ (below ground) treatment is not cost-effective at the JPL facility; therefore, groundwater must be pumped from the ground, treated above ground, and reinjected.

Based on these studies, NASA installed a demonstration treatment plant located at the JPL source area in early 2005 (NASA, 2003; NASA, 2005a). The demonstration study area location is illustrated in Figure 2-1. The demonstration study consists primarily of two extraction wells, two injection wells, piping, the treatment system and ancillary equipment. As shown in Figure 2-2, the extraction wells are located west of Building 18 and the treatment system is located near monitoring well (MW) -7. The two injection wells are located north of the treatment system and approximately 330 ft upgradient of the extraction wells. The eastern injection well is located adjacent to the east side of Building 140, and the western injection well is located adjacent to the south side of Building 299. The extracted groundwater is treated using an ex situ groundwater treatment train, consisting of liquid-phase granular activated carbon (LGAC) treatment to remove VOCs, and a FBR to remove perchlorate. This system has been successful in the demonstration phase (NASA, 2005b; NASA, 2005c; NASA, 2006b) and this RD/RA Work Plan documents expansion and continued operation of the source area treatment system.

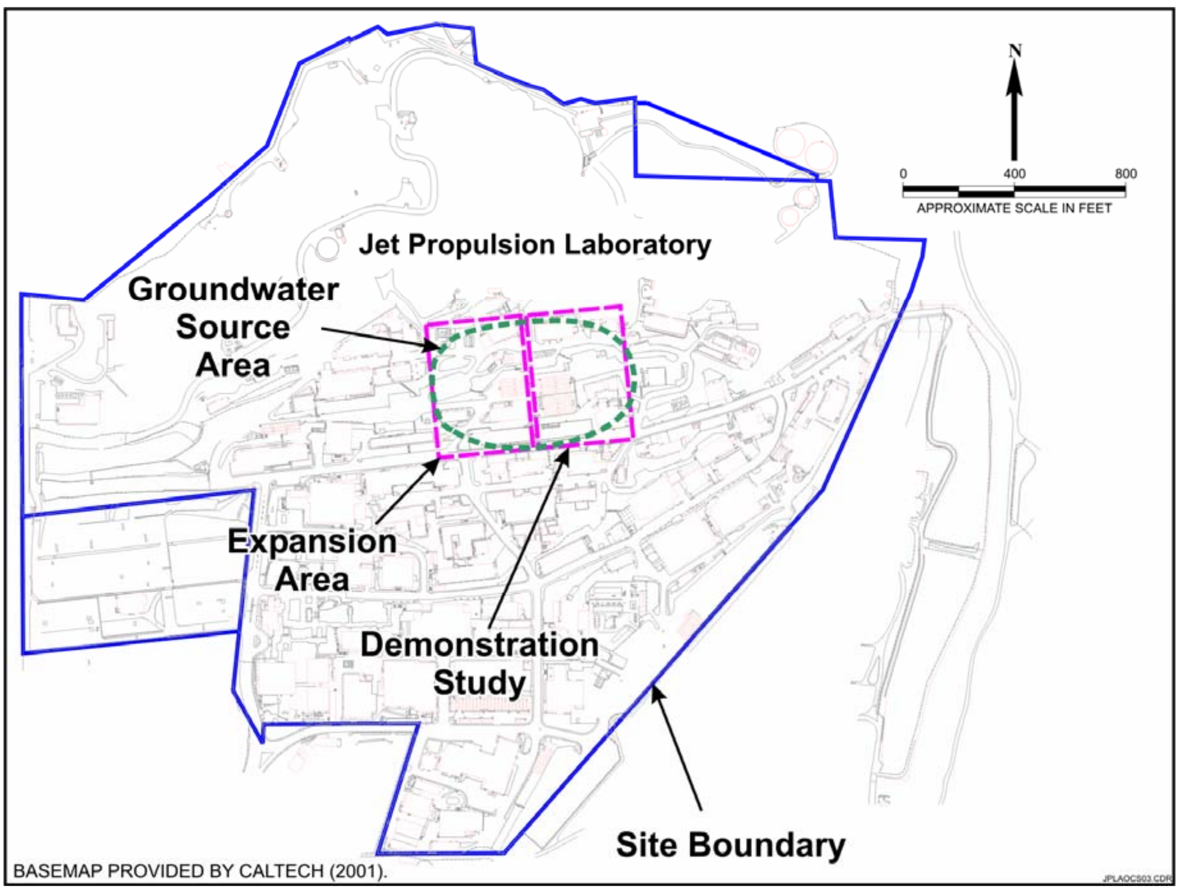


Figure 2-1. Location of the Existing Source Area Groundwater Demonstration Study and Expansion Area

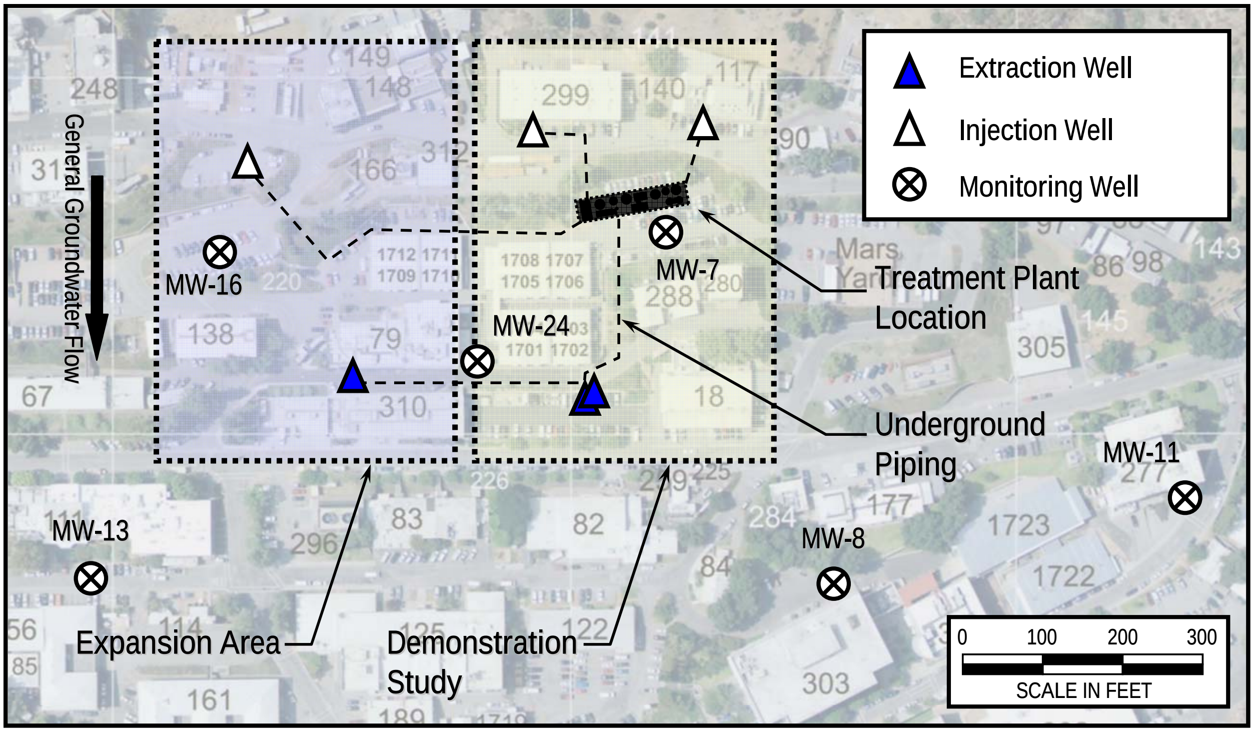


Figure 2-2. Layout of the Existing Demonstration System and the Expansion Area

The source area treatment system expansion will include the installation of one additional extraction well, one additional injection well, and underground/aboveground piping. The expansion will increase the system flow rate from approximately 150 gallons per minute (gpm) to the design flow rate of 350 gpm. The proposed location of the new extraction well is approximately 300 ft west of the existing wells on Aero Road between Building 79 and Building 310. The new injection well location is upgradient of the extraction well, approximately 125 ft north of MW-16 in a parking lot west of the source area treatment plant as shown in Figure 2-2. All extracted groundwater will be treated at the existing treatment system prior to reinjection.

Performance objectives have been established to achieve the RAOs (NASA, 2006a). The system will be operated and optimized until performance objectives have been achieved. The performance of the system will be evaluated on a continued basis and the information regarding the amount of VOCs and perchlorate removed will be reported to the regulatory agencies as part of the semiannual technical memoranda and quarterly technical meetings to effectively evaluate system performance objectives. Additional details regarding the performance objectives and system shutdown are provided in Section 5.0.

2.2 Groundwater Modeling

A groundwater flow model was used to perform groundwater flow and transport simulations and evaluate the performance of the source area treatment system. More specifically, the model was used to estimate the optimal well spacing and pumping rates. Simulations were performed to investigate extraction well capture zones and estimate the amount of drawdown/mounding in the extraction/injection wells.

2.2.1 Model Development

The model used for the source area treatment system simulations was constructed using FEFLOW™ (Diersch, 2002) based on operational data from the demonstration study and the water supply model developed by CH2MHill (2002). The new model was needed to simulate the source area treatment system and provide:

- Increased model resolution in the source area
- The capability to model multiple extraction/injection intervals within hydrostratigraphic unit 1
- A more accurate groundwater flow gradient in the source area
- An extended boundary of the original model domain to include additional monitoring wells and the new extraction/injection wells.

The domain of the new model was selected based on the area of interest. The model was constructed using hydrologic parameters provided in Table 2-1 and installation and operational data from the demonstration study. The northern, no flow boundary was chosen to represent the current understanding of the JPL Thrust Fault, and the other boundaries were placed at suitable distances from the injection and extraction wells (see Figure 2-3).

The model consists of four slices, which are necessary to model flow conditions created by multiple hydrostratigraphic units. The upper three slices represent intervals in the uppermost hydrostratigraphic unit, and the bottom slice corresponds to hydrostratigraphic unit 2. Constant head boundary conditions were specified at the northern and southern extent of the model, and no-flow boundaries represented the eastern and western extents. A southerly gradient of 0.002 ft/ft was simulated according to observed water levels, plume maps, and previous modeling. Because the source area treatment system involves reinjection of all extracted groundwater, pumping is not likely to have a significant influence on the system's water budget.

Groundwater flow simulations performed with the new model involve the following assumptions:

- Groundwater flow through porous materials is expressed by Darcy's flow law.
- Flow conditions are steady-state.
- Boundary conditions represent actual groundwater conditions.
- Geologic materials are fairly homogeneous.
- Output represents the average result within a model element or block.

Given these assumptions, there are limitations to the model. The model does not account for transient changes in groundwater conditions such as precipitation, pumping, or seasonal water level trends. The model also does not account for heterogeneity in the aquifer such as sand channels, perched aquifers, or fining trends in sediments. Drawdown and mounding predictions may not accurately simulate conditions in a well since results represent average conditions in a modeling block. However, simulations performed using the new model are considered appropriate for the intended use. In addition, because the source area treatment system represents a closed system, transient changes in groundwater conditions are unlikely to have a noticeable effect on the model predictions.

Table 2-1. Groundwater Flow and Transport Simulation Parameters

Parameter	Slice			
	1[(a)]	2	3	4
Hydrostratigraphic Unit	1	1	1	2
Layer Top (ft amsl)	1,200	990	960	930
Layer Bottom (ft amsl)	990	960	930	900
Thickness (ft)	210	30	30	30
Horizontal Hydraulic Conductivity (ft/day)	22	22	22	28
Vertical Hydraulic Conductivity (ft/day)	0.92	0.92	0.92	0.062
Porosity	0.30	0.30	0.30	0.30
Storage Coefficient	0.2	0.2	0.2	0.2

(a)Recharge rate: 0.74 ft/year
amsl = above mean sea level

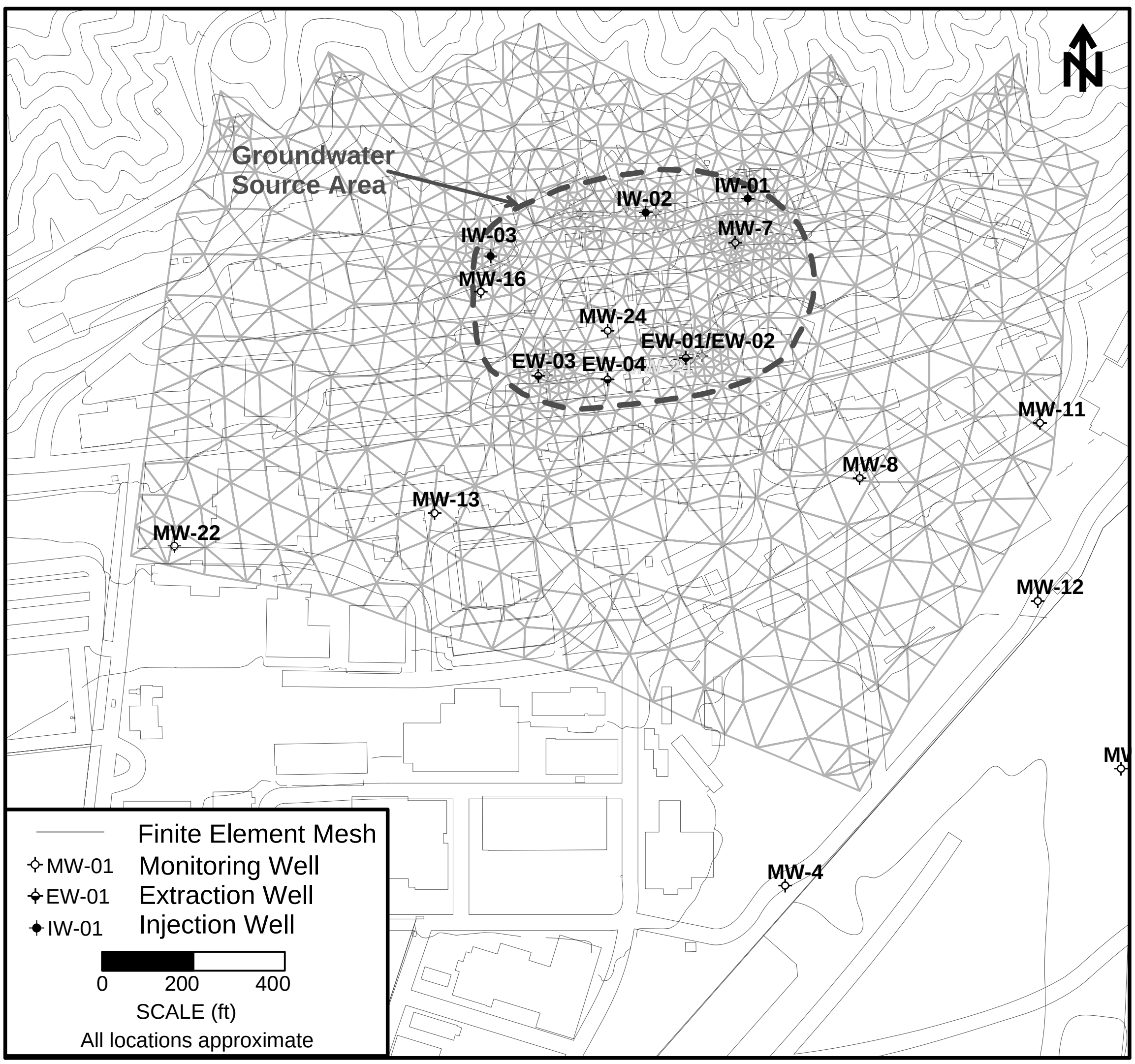


Figure 2-3. Domain and Node Spacing of Groundwater Flow Model

2.2.2 Groundwater Flow and Transport Simulation Results

Two scenarios were evaluated as part of system expansion, identified as Case 1 and Case 2. Case 1 consists of one new upgradient injection well and one new downgradient extraction well installed to operate in conjunction with the existing treatment system, which consists of two upgradient injection wells and two downgradient extraction wells (see Figure 2-2). Case 2 consists of two new extraction wells and one new injection well and was evaluated to determine if an additional extraction well would provide better capture of groundwater in the source area. **Results of the simulations indicate that Case 1 is optimal to contain the source area.**

The modeling for the source area treatment system considered the current operating parameters of the demonstration study injection and extraction wells. Groundwater flow and transport simulations were performed to assess capture zones, mounding, and drawdown in the wells, and groundwater travel times for the different scenarios. Backward particle tracking from the extraction wells indicates the capture zone, whereas forward particle tracking shows the fate of the injected groundwater. Forward particle tracking from the injection well was also used to estimate travel times of the injected groundwater. It should be noted that predictions of mounding and drawdown are estimates for the entire cell or block in which the well is included. Actual drawdown and mounding estimates are likely to be larger than those predicted with the model.

Results from the original demonstration study modeling simulations are presented in Table 2-2 and Figure 2-4. Particle tracking indicates the current demonstration study configuration results in an extraction well capture zone width of approximately 700 ft, and that the vast majority of injected water is captured by the extraction wells. Minimal drawdown and mounding (<10 ft) are predicted with the model.

Well configurations and results for the Case 1 simulation (one additional extraction well and one additional injection well) are presented in Table 2-2 and Figure 2-5. The additional extraction well was placed approximately 330 ft from the demonstration study extraction wells. Based on the modeling for Case 1, this placement would result in a 100% capture zone overlap between the two wells. Particle tracking indicates this well configuration results in an approximate capture zone width of roughly 1,200 ft, with the vast majority of injected water being captured by the extraction wells. The particle tracking shows that the capture zones for the two extraction wells do overlap, and that no injected water will migrate between the wells. The particle tracking shows that a minimal amount of injected groundwater may migrate around the extraction wells, but the length of time it would take groundwater to reach the model boundary along this flow path is significant. Minimal drawdown and mounding (<10 ft) are predicted with the model.

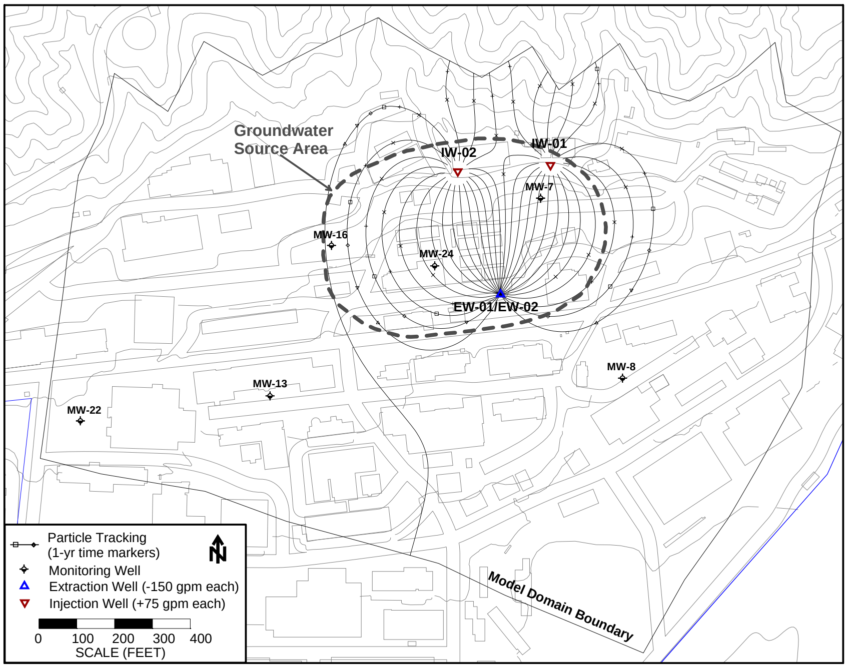
Well configurations and results for the Case 2 simulation (two additional extraction wells and one additional injection well) are presented in Table 2-2 and Figure 2-6. Particle tracking indicates that this well configuration results in an approximate capture zone width of roughly 1,100 ft, which is somewhat reduced compared to the Case 1 simulation. Similar to the Case 1 scenario, the vast majority of injected water is captured by the extraction wells. The particle tracking shows that the capture zones for the three extraction wells overlap, and that no injected water will migrate between the wells. Results of the Case 1 and Case 2 simulations indicate that installation of one additional extraction well is sufficient to contain the area of elevated dissolved chemical mass in groundwater.

Table 2-2. Extraction/Injection Scenarios and Results

Well	Flow Rate (gpm)		
	Demonstration Study	**Case 1**	**Case 2**
EW-01/EW-02	-150	-150	-150
EW-03	0	-150	-75
EW-04	0	0	-75
IW-01	+75	+100	+100
IW-02	+75	+100	+100
IW-03	0	+100	+100
Maximum Extraction Well Drawdown (ft)	7.5	7.8	8.5
Maximum Injection Well Mounding (ft)	2.9	3.0	4.2
Capture Zone Width (ft)	700	1,200	1,100

EW = extraction well; IW = injection well

Case 28 Forward Tracking



Case 28 Backward Tracking

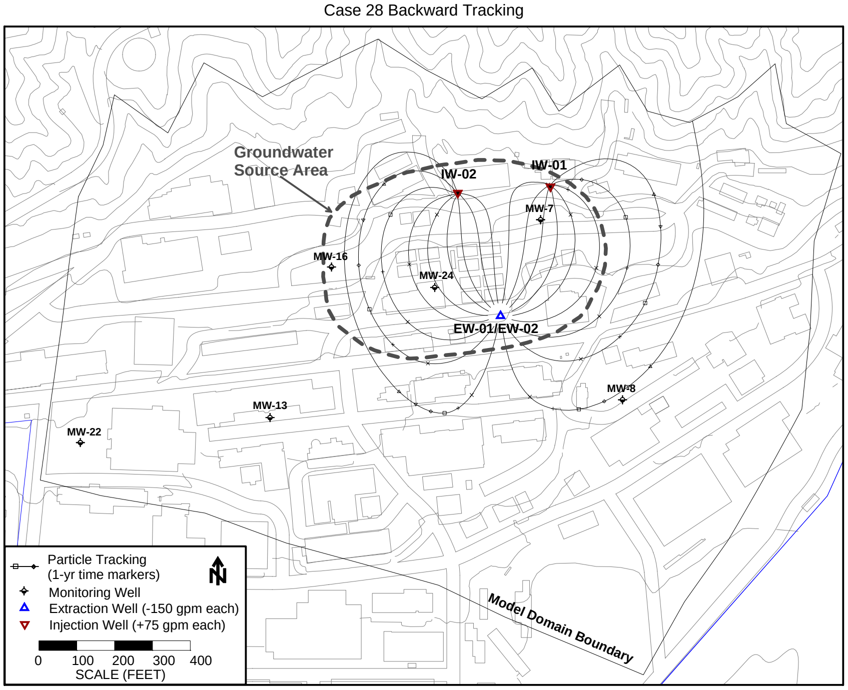
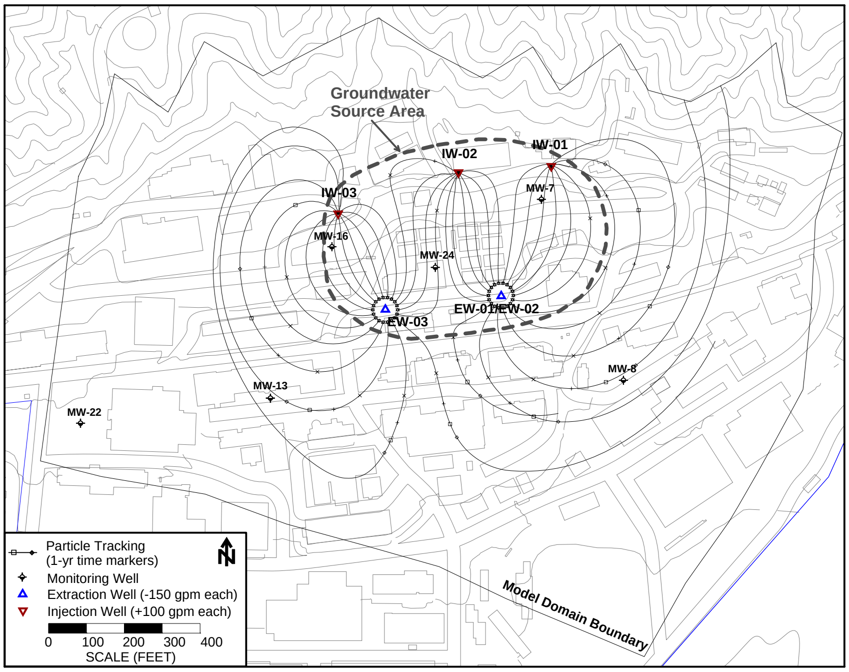


Figure 2-4. Demonstration Study Particle Tracking Results

Case 27 Forward Tracking



Case 27 Backward Tracking

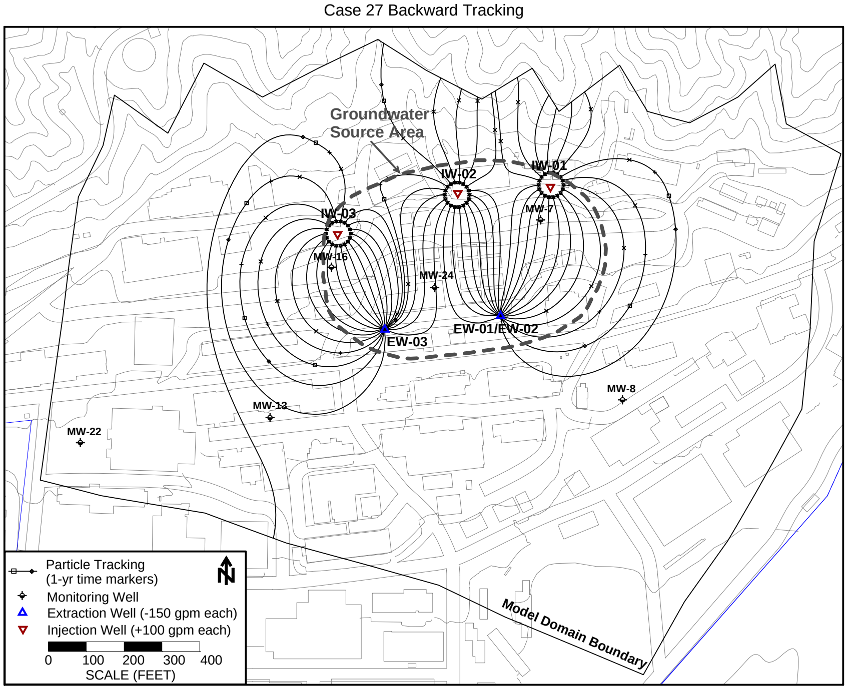
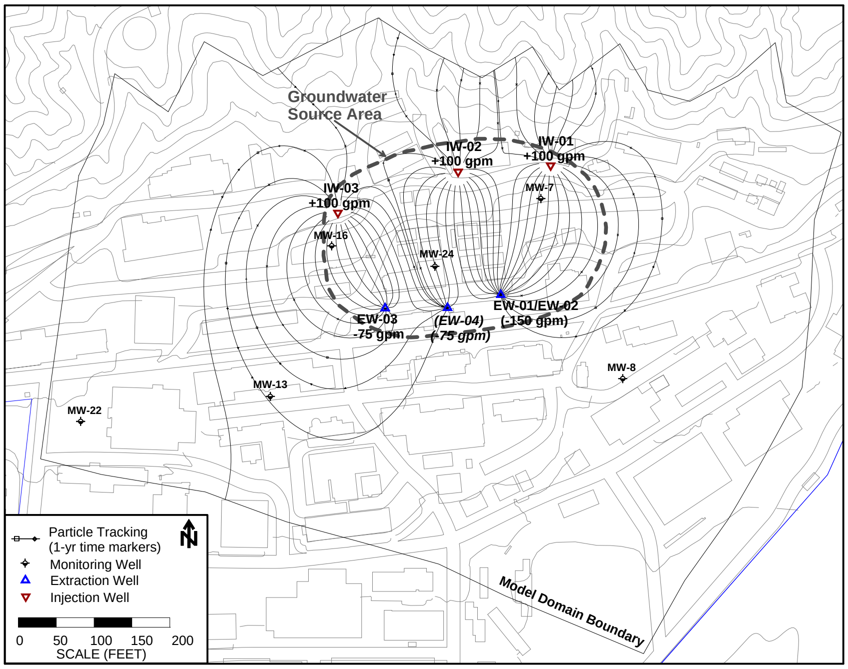


Figure 2-5. Case 1 Particle Tracking Results

Case 29 Forward Tracking



Case 29 Backward Tracking

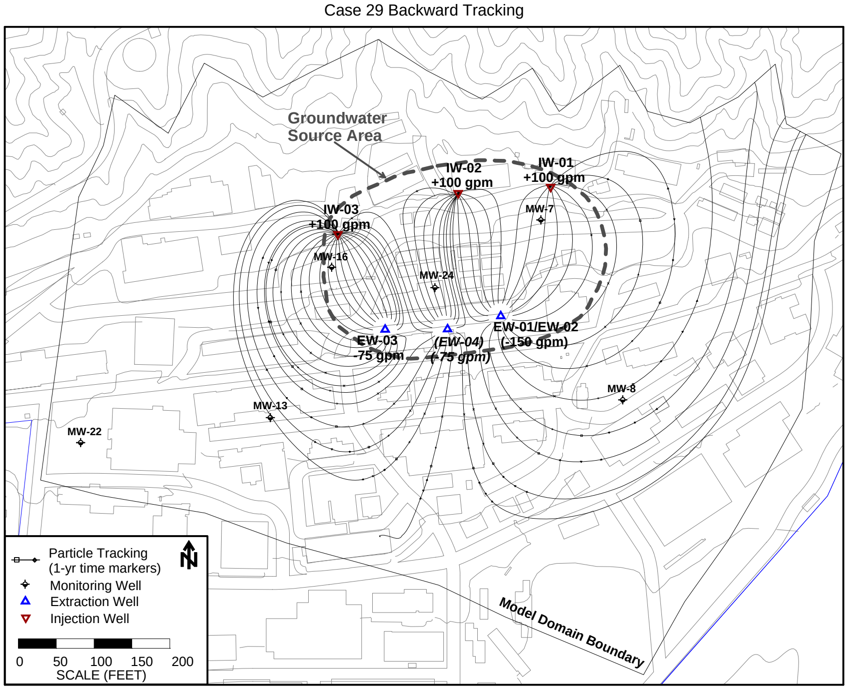


Figure 2-6. Case 2 Particle Tracking Results

3.0 Applicable or Relevant and Appropriate Requirements (ARARs)

Compliance with ARARs addresses whether a response action meets all pertinent federal and state environmental statutes and requirements. An alternative must comply with ARARs or be covered by a waiver to be acceptable. To implement the source area treatment system, various regulatory issues and legal considerations must be examined in regard to the injection of treated groundwater. Because the JPL is on the NPL, the site is subject to the provisions of CERCLA as amended by the Superfund Amendments and Reauthorization Act (SARA). As such, federal regulations and policy governing reinjection of water into the subsurface will be adhered to, in conjunction with complying with the substantive requirements of state regulations and policy (U.S. EPA, 1992c). Legal considerations of reinjection must also be examined because the JPL facility is located in the adjudicated Raymond Basin Watershed.

3.1 Federal Regulations and Policy

Safe Drinking Water Act − Federal MCLs developed by U.S. EPA under the Safe Drinking Water Act (SDWA) are potential relevant and appropriate requirements for aquifers. The point of compliance for MCLs under the SDWA is at the tap. Therefore, the MCLs are not "applicable" ARARs for the source area treatment system. However, MCLs are generally considered relevant and appropriate as remediation goals for current or potential drinking water sources, and therefore are potential chemical-specific federal ARARs for groundwater remedial actions under CERCLA.

Resource Conservation and Recovery Act − Section 3020 of RCRA applies to the underground injection in the context of RCRA and CERCLA cleanups. RCRA section 3020(a) bans underground injection into or above a geologic formation that contains an underground source of drinking water. However, RCRA section 3020(b) provides exemptions to the ban if certain conditions are met (U.S. EPA, 2002). These conditions include the following:

- The reinjection is part of a response action under Section 104 or 106 of CERCLA, or part of RCRA corrective action intended for site cleanup;
- The groundwater is treated to substantially reduce chemicals prior to such reinjection; and
- The cleanup will, upon completion, be protective of human health and the environment.

For the groundwater to be treated to substantially reduce chemicals, treatment must occur before reinjection; however, the substantial reduction of the chemicals in the groundwater can occur either before or after reinjection of the groundwater (U.S. EPA, 2000).

The applicability of RCRA land disposal restrictions (LDRs) to groundwater reinjection performed during an RCRA corrective action or CERCLA response action is also a consideration (see RCRA sections 3004 (f), (g), and (m), and 40 Code of Federal Regulations [CFR] Parts 148 and 268). Groundwater undergoing reinjection may contain regulated chemicals; thus, the issue could be raised as to whether reinjection of groundwater should meet treatment standards identified as best demonstrated available technology (BDAT). An interpretation of the applicability of the RCRA LDRs is provided in an EPA memorandum titled "Applicability of Land Disposal Restrictions to RCRA and CERCLA Ground Water Treatment Reinjection" (U.S. EPA, 1989a). This memorandum explains that, even though the LDR provisions address the same activity as RCRA section 3020, EPA interprets the provisions of RCRA section 3020 to be applicable instead of LDR provisions (EPA, 1989b).

Another potential issue is whether LDR treatment standards are relevant and appropriate for treated groundwater that is reinjected as part of a CERCLA response action. The EPA believes that the ultimate purpose of treatment is to restore the groundwater to drinking water conditions; thus, standards that have been developed to establish drinking water quality levels (e.g., MCLs) are to be used (U.S. EPA, 1989a). Therefore, promulgated drinking water standards should be used where available. If no promulgated drinking water standard exists, then relevant and appropriate requirements such as health-based standards or LDR treatment standards should be used (U.S. EPA, 1989b).

3.2 State Regulations and Policy

California Safe Drinking Water Act and State MCLs – California has established standards for public drinking water sources, under the California Safe Drinking Water Act of 1976 (Health and Safety Code [H&SC] Section 4010.1 and 4026[c]) and state MCLs for organic chemicals are set forth in California Code of Regulations (CCR). Title 22, Section 64444. Some state MCLs are more stringent than the corresponding federal MCLs. In these instances, the more stringent state MCLs are applicable to the remedial action at JPL. NASA has determined that the substantive provisions of the standards in CCR Title 22, Section 64444 are relevant and appropriate because VOCs will be remediated to a level expected to protect groundwater quality.

General Waste Discharge Requirements – General waste discharge requirements (WDRs) associated with groundwater reinjection during remedial activities are provided by the RWQCB Los Angeles Region in Order No. R4-2005-0030, *General Waste Discharge Requirements for Groundwater Remediation at Petroleum Hydrocarbon Fuel and/or Volatile Organic Compound Impacted Sites* (RWQCB, 2005). These general WDRs are applicable to in situ groundwater remediation or the extraction of groundwater with aboveground treatment and reinjection of treated groundwater to the same aquifer zone. The requirements contained in Order No. R4-2005-0030 are consistent with all water quality control policies, plans, and regulations in the California Water Code (CWC), and the revised Water Quality Control Plan (Basin Plan) for the Los Angeles Region (RWQCB, 1994). The general WDRs are intended to protect and maintain the existing beneficial uses of the receiving groundwater (RWQCB, 2005) and are consistent with the anti-degradation provisions of State Water Resources Control Board Resolution No. 68-16.

RWQCB Order No. R4-2005-0030 requires that groundwater reinjection not adversely impact the receiving groundwater in terms of water quality and chemical concentrations at a "compliance point, downgradient outside the application area." The application area at JPL is the same as the source zone (i.e., the 8-acre by 100-ft thick portion of the aquifer containing elevated levels of VOCs and perchlorate). The compliance points are the monitoring wells located outside the treatment zone, which are monitored on a quarterly basis as part of the JPL groundwater monitoring program. Discharge limitations for pH, mineral content, coliform count, salts, heavy metals, organic pollutants, and nitrogen content, as well as taste and odor, are described in the general WDRs. Similarly, discharge limitations for chemical constituents are MCLs specified in 22 CCR, which are incorporated in the Basin Plan on Table 64431-A of section 64431 (inorganic chemicals), Table 64431-B of section 64431 (fluoride), and Table 64444-A of Section 64444 (organic chemicals). Table 3.1 provides a summary of discharge limits for treated groundwater.

3.3 Application of Federal and State Regulations to the Source Area Treatment System

Reinjection activities following extraction and treatment of groundwater from the source area beneath JPL will be in compliance with federal regulations and policy surrounding RCRA Section 3020(b) and the substantive requirements of state regulations and policy contained in RWQCB Order No. R4-2005-0030. Aboveground treatment using LGAC for VOC removal and FBR for perchlorate removal will be done to substantially reduce chemical concentrations prior to reinjection, and the cleanup will be protective of human health and the environment.

RWQCB Order No. R4-2005-0030 requires that discharge limits be developed at a compliance point located downgradient and outside of the treatment zone (see Table 3-1). The "treatment zone" at JPL is the same as the source zone (i.e., the 8-acre by 100-ft-thick portion of the aquifer containing elevated levels of VOCs and perchlorate). The compliance points are the monitoring wells located outside the treatment zone, which are monitored on a quarterly basis as part of the JPL groundwater monitoring program. The electron donor to be used will be the same as, or similar in nature to, carbon sources/electron donors listed in RWQCB Order No. R4-2005-0030, Provision A(c)(4).

3.4 Legal Considerations

JPL is located in the Monk Hill Subarea of the Raymond Basin. In 1944, the Superior Court of California approved the Raymond Basin Judgment, which adjudicated the rights to groundwater production to preserve the safe yield of the groundwater basin. Adjudication refers to the practice of land owners and other parties allowing the courts to settle disputes over how much groundwater can rightfully be extracted. The courts determine an equitable distribution of water that will be available for extraction each year. In these adjudicated groundwater basins, the courts appoint a Watermaster to administer the court judgment. The Raymond Basin Management Board, made up of representatives of the water purveyors, oversees the management and protection of the Raymond Basin. A total of six Raymond Basin water purveyors operate wells within four miles of JPL.

Table 3-1. Summary of Groundwater Discharge Limits for Treated Water

Compound	Units	Applicable Limits for Treated Water [a]
Perchlorate		None[b]
Carbon tetrachloride	µg/L	0.5
1,1-Dichloroethene	µg/L	6
1,2-Dichloroethane	µg/L	0.5
Tetrachloroethene	µg/L	5
Trichloroethene	µg/L	5
1,4-Dioxane		None[c,d]
Arsenic	µg/L	50
Trivalent chromium	µg/L	50
Hexavalent chromium	µg/L	50
Fluoride	mg/L	2
Nitrogen (as nitrate-nitrogen plus nitrite-nitrogen)	mg/L	45
Nitrate-nitrogen (NO_3-N)	mg/L	10
Nitrite-nitrogen (NO_2-N)	mg/L	1
pH	units	6.5 to 8.5
Color	units	15
Odor threshold	units	3
Turbidity	units	5
Sulfate	mg/L	100 or background
Chloride	mg/L	100 or background
Total dissolved solids	mg/L	450 or background

(a) Discharge limitations as provided in Order No. R4-2005-0030 or specified in Title 22 of the California Code of Regulations unless otherwise designated.
(b) No promulgated drinking water, health-based, or LDR treatment standards exists for perchlorate. Based on previous field-scale implementation, FBR systems are capable of removing perchlorate down to non-detectable levels (i.e., <4 µg/L).
(c) No promulgated drinking water, health-based, or LDR treatment standards exists for 1,4-dioxane. Based on monitoring data, 1,4-dioxane levels in the extracted groundwater are expected to be near 5 µg/L.
(d) 1,4-dioxane levels have been detected at the OU-1 treatment plant on seven different occasions. The concentrations have ranged from 3.7-8.5 µg/L, and six of the seven occurrences were seen in the first two months of operation.

This section discusses the design and construction of the expansion to the source area treatment system. The treatment system expansion layout is provided, along with the construction details for expansion, including an extraction well, injection well, and system piping. Additionally, details regarding the source area treatment equipment, groundwater monitoring well network, system controls, and support facilities and utilities are provided in this section. Construction details regarding the demonstration study system are provided in the OU-1 Installation Report (NASA, 2005a).

4.1 System Layout

The treatment system layout for the system expansion is shown in Figure 4-1. The system expansion will consist primarily of one extraction well, one injection well, and underground piping. The expanded treatment system will utilize the treatment train of the existing demonstration study system.

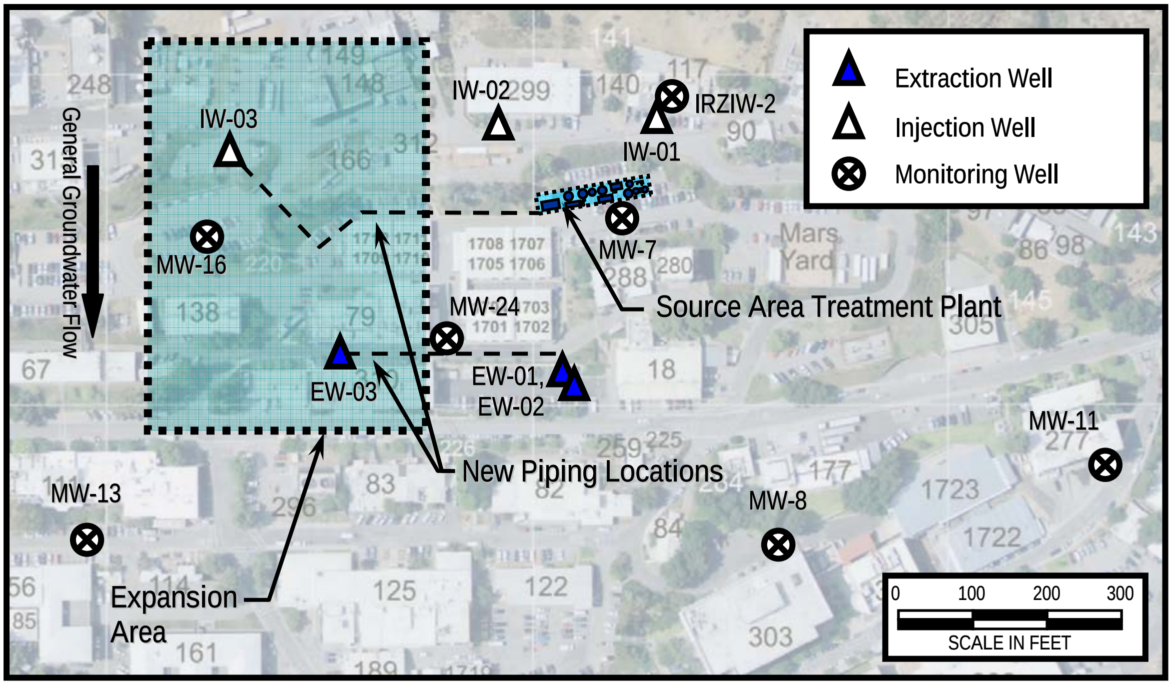


Figure 4-1. Source Area Treatment System Expansion Layout

The new extraction well (EW-03) will be located approximately 300-ft west of EW-01/EW-02 between Building 79 and Building 310. The injection well (IW-03) will be located upgradient of the extraction wells, approximately 125 ft north of MW-16 in a parking lot west of the source area treatment plant.

The extracted groundwater will be pumped to the existing aboveground treatment system, which is located near monitoring well MW-7. The groundwater treatment train consists of two LGAC adsorption units for VOC removal, an FBR unit for perchlorate removal, a post-aeration tank, and a multimedia filter. The process flow diagram is provided in Figure 4-2.

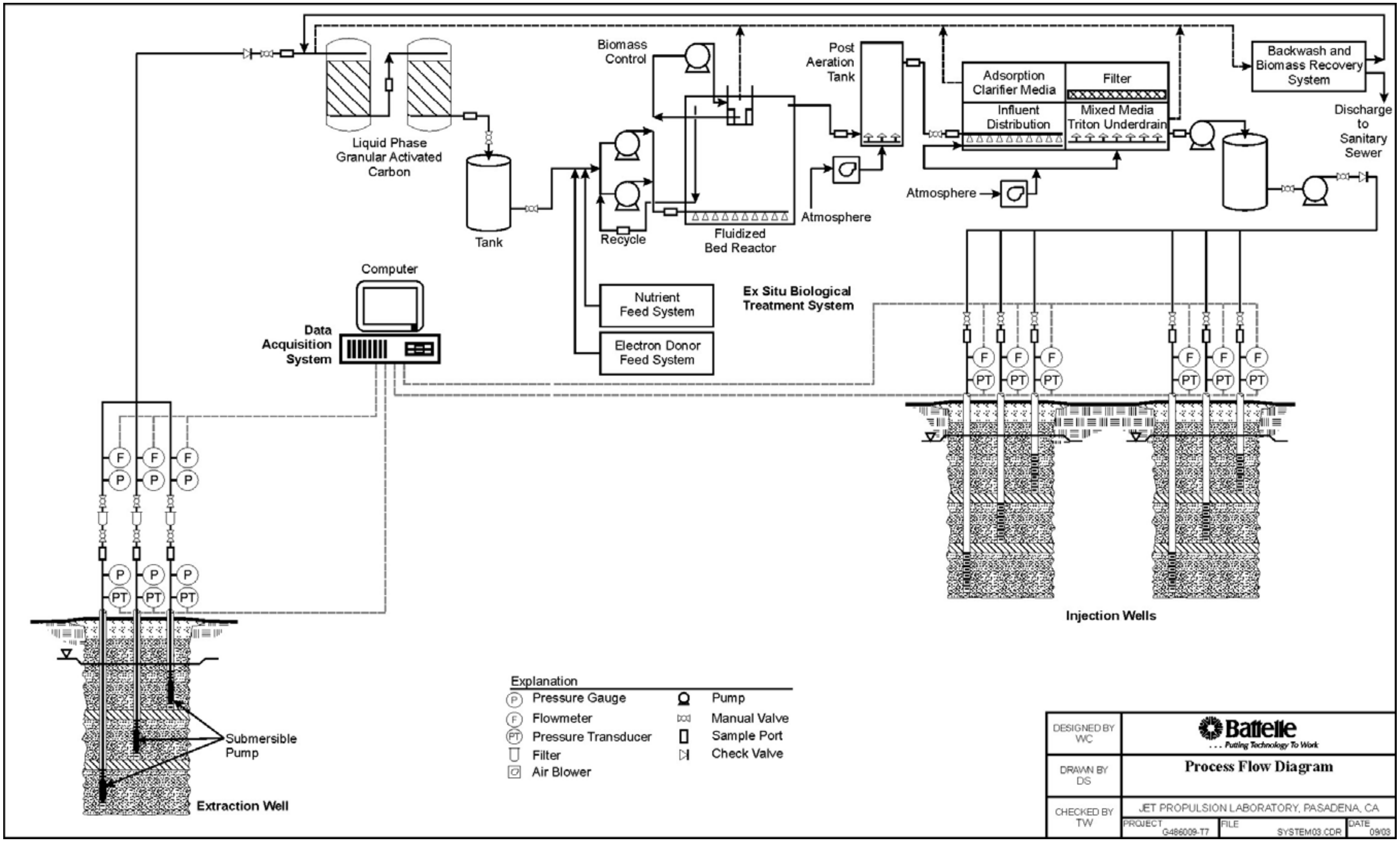


Figure 4-2. Process Flow Diagram

4.2 Extraction Well Design

Figure 4-3 shows a typical well completion diagram. A licensed drilling subcontractor will be hired to perform the necessary drilling activities required for the installation of the groundwater extraction well. The construction and performance of the demonstration study extraction wells was taken into consideration when designing the construction of the new extraction well. The extraction well (EW-03) will be constructed of no smaller than a 6-inch inner diameter (I.D.) low carbon steel casing spanning from 0 to 215 ft bgs with a 100-ft screened interval that spans from 215 to 315 ft bgs constructed of 6-inch I.D. 0.040 slot, wire-wrapped, stainless steel. To allow for sediment accumulation, the bottom of the well will be fitted with a 10 foot section of casing to function as a sediment collection point (i.e. sump). Well construction details are provided in Table 4-1. The depth to the water table is approximately 185 ft below ground surface (bgs) in the test area with an average seasonal fluctuation of approximately 30 ft. The extraction well will be screened entirely in the upper 100 ft of the saturated zone, which extends to approximately 900 ft amsl. RMC™ #8 mesh sand will be installed around the well screen to act as a filter pack. The filter pack will be placed at a minimum of 10 ft above the well screen. The bentonite transition seal, at least 5 ft thick, consisting of ¼ inch time-release coated pellets, will then be placed on top of the filter pack. The cement grout will be pumped into the annulus between the casing and borehole, and the annulus will be grouted from the bentonite seal to the ground surface. The well will be protected with a flush-mount H-20 rated double-door steel well vault. The volumes and quantities of materials required to construct each well will be determined and recorded before the placement of the material. An inventory of each material used will be kept during well installation to ensure that the wells were properly installed. Well development will be the final step in extraction well construction and installation.

Proper well development is an essential part of the well installation process. During well development, fine-grained materials are removed from the filter pack and good communication between the aquifer material and the well is established. Well development for the extraction well will be conducted in several stages, including: removal of drilling mud from the casing (i.e., bailing); brushing; application of a polymer dispersant to facilitate removal of the residual drilling mud from the aquifer and filter pack material; surge pumping (e.g., using a dual-swab airlift tool), and over-pumping the well. Additional details regarding well development techniques are provided in Appendix A.

Well development will be considered complete following the completion of the above reference development methods or when groundwater field parameters, including pH, conductivity, and temperature, stabilize over time and turbidity readings of ≤5 nephelometric turbidity units (NTU) are observed. During the development process, appropriate monitoring and record keeping methods will be used to ensure proper well development.

Following the completion of well development and prior to installation of the extraction pump, an evaluation of the well hydraulics (i.e., vertical flow within the well) will be completed utilizing static (pump off) and dynamic (pump on) spinner logging. This evaluation will require the use of a temporary pump small enough for the logging equipment to enter and exit the well and pass beyond the pump. Additional well evaluations will include conducting a video log of the well interior to evaluate the completeness of well development and collection of depth discrete groundwater samples. Groundwater sample depths will be based on the spinner log results and will be collected from zones within the well exhibiting the highest groundwater flow velocities. These data will be used to develop a baseline flow and vertical concentration profiles of the extraction well and will be correlated with similar data during future maintenance and optimization efforts. Additional details regarding well evaluations are provided in Appendix A.

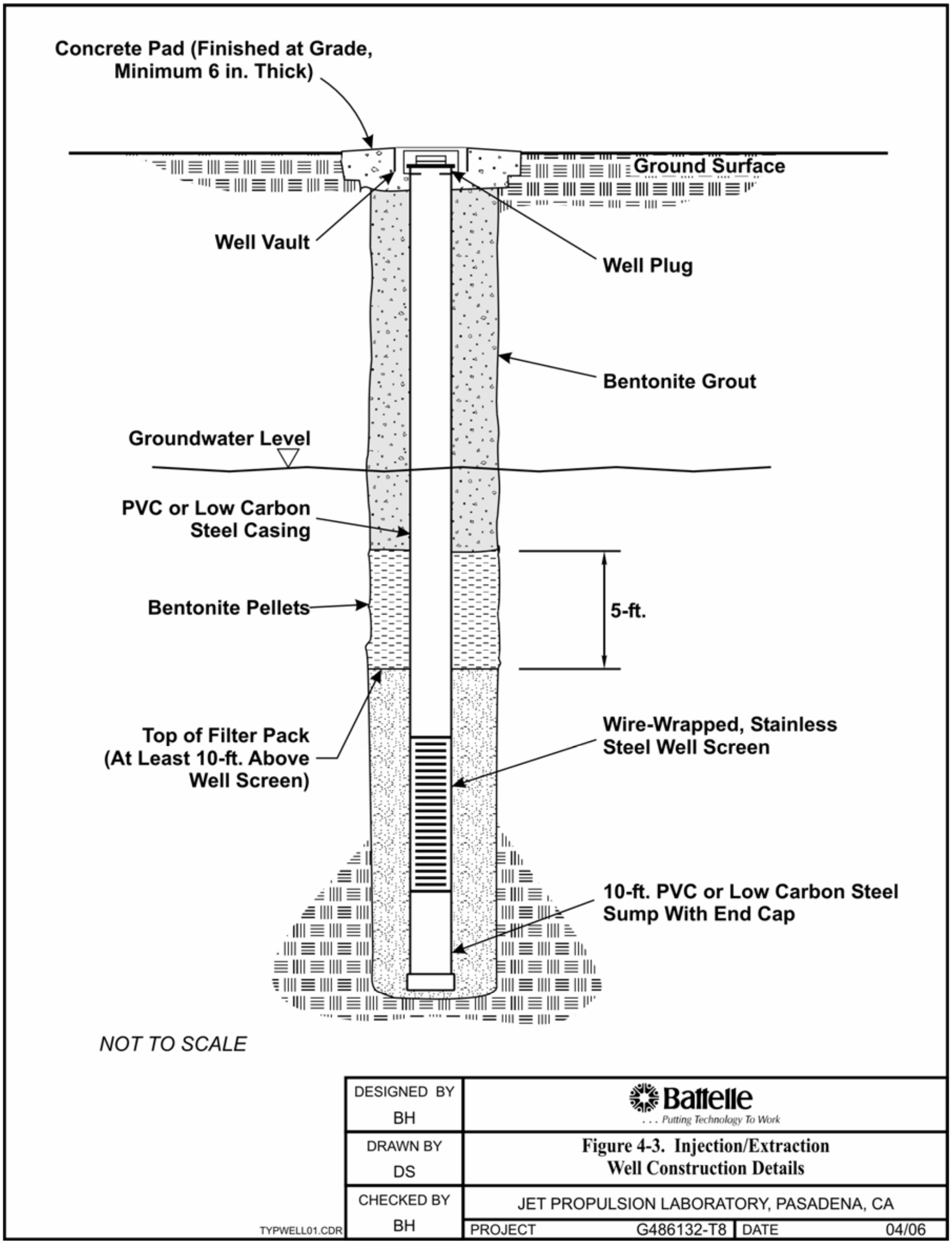


Figure 4-3. Injection/Extraction Well Construction Details

Table 4-1. Well Construction Details

Well Number	Casing Depth (ft bgs)	Screen Depth (ft bgs)	Sump Depth (ft bgs)	Casing/Sump I.D. (inches)	Casing/Sump Material	Screen I.D. (inches)	Screen Material (wire-wrapped)
EW-03	215	215 to 315	315 to 325	≥6	Low Carbon Steel	≥6	Stainless Steel 0.040 slot
IW-03	215	215 to 315	315 to 325	≥8	Steel or PVC	≥8	Stainless Steel 0.050 slot

PVC = polyvinyl chloride

As shown in Figure 4-2, the extraction well will be equipped with a submersible pump. The pump will be controlled using the programmable logic control (PLC) at the groundwater treatment system. A manual valve will be used to reduce the pumping rate, as necessary. In addition, the extraction well will be outfitted with a flow rate meter and flow totalizer to track flow and a pressure transducer and groundwater-level transducer to monitor drawdown. The well head for the new well and the existing extraction wells will be equipped with two 1-inch diameter ports with 1-inch diameter access pipes to accommodate the placement of the water level transducer and for collection of manual water level readings. Additionally, the pump's electrical panel will be outfitted with a voltage/amperage meter. Voltage and amperage readings will be collected on a regular basis to monitor the pump efficiency over time. Pump flow readings, groundwater-level drawdown, and pump efficiency records will be evaluated as part of extraction well performance monitoring. The extraction well will have a cartridge filter to remove particulate matter as necessary. See Sections 4.7 and 4.8 for more information on the system instrumentation and controls.

4.3 Injection Well Design

The new injection well will be installed in the same manner as the extraction well described above. Figure 4-3 shows a typical well completion diagram. The injection well (IW-03) will be constructed of no smaller than a 8-inch I.D. steel or 7.625-inch I.D. schedule 80 PVC casing spanning from 0 ft to 215 ft bgs with a 100-ft screened interval that spans from 215 ft bgs to 315 ft bgs. The injection well screen will be constructed of no smaller than a 8-inch I.D. 0.050 slot, wire-wrapped, stainless steel. The filter pack material used for the injection well will consist of medium aquarium sand. Otherwise, the remainder of the well annulus backfill materials will be consistent with those described in Section 4.2. To allow for sediment accumulation, the bottom of the well will be fitted with a 10 foot section of casing which will function as a sediment collection point (i.e., sump). Additional well construction details are provided in Appendix A and Table 4-1.

Well development for the injection well will include the same steps as described above for the extraction well with the exception of one additional step. This step, referred to as injection development, involves injecting water over a short term then over-pumping. During this process, an injection rate of up to 180 gpm will be attempted.

Injection well development will be considered complete following the completion of the above referenced development methods and when groundwater field parameters, including pH, conductivity, and temperature, stabilize over time and turbidity readings of ≤5 NTU are observed. During the development process, appropriate monitoring and record keeping methods will be used to ensure proper well development.

Following the completion of well development and prior to installation of the injection equipment, an evaluation of the well hydraulics (i.e., vertical flow within the well) will be completed utilizing static (pump off) spinner logging. Additionally, a video log of the well interior will be conducted to evaluate the completeness of well development. Additional details regarding well evaluations are provided in Appendix A.

The existing pumps at the source area treatment system will be used to reinject the treated groundwater into the aquifer. The pumps will be controlled from the PLC at the groundwater treatment system. A manual valve will be used to control the pumping rate to each injection well, as necessary. In addition, each injection well will be outfitted with a flow rate meter and a flow totalizer to track flow and with a pressure indicator and water level transducer to monitor injection pressure and mounding, respectively. The new and existing injection well heads will each be outfitted with two 1-inch ports and two 1-inch PVC drop pipes for installation of the water level transducer and collection of manual water level readings. See Sections 4.7 and 4.8 for information on instrumentation and controls.

4.4 Monitoring Wells

Six monitoring wells will be sampled periodically, in coordination with the site-wide groundwater monitoring program, to track the performance of the system and to monitor for potential lateral and/or vertical migration of the chemical plume. The existing monitoring wells that will be used are shown in Figure 4-1 and include MW-7, MW-8, MW-11 (screens 1 and 2), MW-13, MW-16, and MW-24 (screens 1 and 2). In addition, groundwater levels will be collected on a weekly basis from NASA-JPL monitoring wells MW-7, MW-8, MW-13, and MW-16, as part of the OU-1 system operations.

The injection wells that were installed for the in situ reactive zone (IRZ) demonstration project (ARCADIS, 2002) may be incorporated into the groundwater treatment system to the extent practicable. These wells may be used as reinjection points for treated groundwater and/or the monitoring of water levels within the aquifer.

A summary of the key well construction details for the monitoring wells and the IRZ wells is provided in Table 4-2.

4.5 Aboveground/Belowground Pipeline

Groundwater will be pumped from the new extraction well (EW-03) and routed through a pipeline to the treatment system, where it will be combined with groundwater extracted from the existing wells. The untreated groundwater from EW-03 will be pumped at a design flow rate of approximately 150 to 200 gpm through the pipeline to the treatment system. The treated water will then be recharged to the aquifer through a pipeline and distributed to all of the injection wells, including IW-03. The reinjection pipeline to IW-03 will be designed to convey a flow of at least 150 gpm.

Figure 4-1 shows the anticipated pipeline route for the source area treatment system expansion. The pipeline route requires both aboveground and belowground installation, although the majority of the pipeline will be aboveground. The pipeline route is in the north-central portion of the JPL campus. As discussed in Section 5.1, significant project coordination and site preparation efforts will be required to place and install the underground piping. A licensed construction subcontractor will be hired to perform the necessary trenching activities associated with underground piping. Utility clearances, as discussed in Section 5.1.3, will be performed and necessary arrangements will be made prior to performing any trenching activities.

Table 4-2. Existing Monitoring Well Construction Details

Well	Well Type	Well Depth (ft bgs)	Screened Interval (ft bgs)	Top of Casing Elevation (ft amsl)	Screen Number	Screen Slot Size (inch)	Casing Material
MW-7	Shallow Standpipe	275	225-275	1212.88	NA	0.010	4" low carbon steel
MW-8	Shallow Standpipe	205	155-205	1139.53	NA	0.010	4" low carbon steel
MW-11	Deep Multi-Port	680	140-150 250-260 420-430 515-525 630-640	1139.35	1 2 3 4 5	0.010 0.010 0.010 0.010 0.010	4" low carbon steel
MW-13	Shallow Standpipe	235	180-230	1183.47	NA	0.010	4" PVC
MW-16	Shallow Standpipe	285	230-280	1236.27	NA	0.010	4.5" PVC
MW-24	Deep Multi-Port	725	275-285 370-380 430-440 550-560 675-685	1200.91	1 2 3 4 5	0.010 0.010 0.010 0.010 0.010	4" low carbon steel
IW1 (ARCADIS)	Shallow Standpipe	253	223-253	1215.88	NA	0.020	4" low carbon steel
IW2 (ARCADIS)	Shallow Standpipe	298	248-298	1235.62	NA	0.020	4" low carbon steel
IRZMW1 (ARCADIS)	Shallow Standpipe	280	225-280	1216.50	NA	0.020	4" low carbon steel
IRZMW2 (ARCADIS)	Shallow Standpipe	253	223-253	1215.52	NA	0.020	4" low carbon steel
IRZMW3 (ARCADIS)	Shallow Standpipe	280	225-280	1216.25	NA	0.020	4" low carbon steel

NA = not applicable

At this time it is anticipated that 4-inch diameter, Schedule 80 PVC piping will be used to convey groundwater extracted from EW-03. All extraction and injection lines will be outfitted with check valves to prevent backflow (Figure 4-2). During the source area treatment system expansion, it is estimated that excavation and backfill will be required for approximately 320 linear ft of trench, 3 ft deep, and 2 ft wide. The trench will contain a sand bed that is approximately 6 inches above and 6 inches below the buried pipeline. If visual staining of native material is noted, the stained soil will be placed in a drum, analyzed, and disposed off-facility as appropriate. Otherwise, the native material will be used as backfill. The PVC conveyance pipe will be pressure tested during installation to ensure that there are no leaks in the line prior to backfill. To the extent possible, piping runs will be strategically sited to avoid existing utilities. All trenching of road crossings and/or parking lots will include the removal and replacement of the existing asphalt and/or concrete. Where appropriate, system piping will be installed aboveground.

4.6 Treatment Equipment

The key components of the existing groundwater treatment train include a LGAC adsorption system, groundwater storage tank, FBR, post-aeration tank, and multimedia filter. Figure 4-2 provides an overall process flow diagram of the treatment system, and the major system components are discussed in the following subsections.

4.6.1 LGAC Adsorption Units

Two LGAC adsorption units, placed in series, are currently used to remove VOCs from the extracted groundwater prior to treatment with the FBR. The LGAC is used to reduce carbon tetrachloride, 1,1-dichloroethene, trichloroethene, tetrachloroethene, and other VOCs in groundwater to the appropriate levels. The LGAC adsorption units are capable of a maximum series flow rate of 500-gpm and total VOC concentrations of 100 µg/L and consist of two, 8-ft-diameter tanks with approximately 10,000 lbs of granular activated carbon (GAC) each.

4.6.2 Groundwater Storage Tank

The aboveground polyethylene storage tank (T-201), with secondary containment, is inline after the LGAC adsorption units to provide flow equalization and to act as a reservoir for VOC-treated groundwater. The tank will hold approximately 15 minutes of system flow at 350 gpm or 5,000 gallons.

4.6.3 Fluidized Bed Reactor

The FBR is an attached growth bioreactor in which microbes are supported and grow on a GAC matrix within the reactor. Microbial growth is promoted within the FBR by adding an electron donor source and a specially blended nutrient solution of nitrogen and phosphorus into the influent groundwater flow. Using the electron donor source, facultative anaerobic microbes within the reactor first consume the dissolved oxygen available in the influent groundwater. After the dissolved oxygen has been depleted, perchlorate -degrading microorganisms begin to reduce the nitrate to nitrogen gas and water and the perchlorate to chloride and water.

The treatment system consists of one stainless steel FBR unit sized at 11.5 ft in diameter and 24 ft tall. This unit has a maximum hydraulic capacity of 350 gpm. FBR system sizing is based on treatment of the average nitrate and perchlorate levels in groundwater at the maximum anticipated flow rate. If the influent concentrations are greater than the design criteria, either equalization will be used to dilute the influent concentration or the flow to the bioreactor will be reduced to equalize the loading rate to the reactor. Approximately 32,000 lbs of GAC is used as the filter media within the reactor. The FBR was seeded with a proprietary biological inoculum provided by Shaw.

The primary components of the FBR system include the chemical feed system, the reactor and fluidization pumps, and the biomass separation system. A brief discussion of these components is provided below.

The chemical feed system consists of a nutrient feed unit and an electron donor feed unit. The added nutrients include nitrogen and phosphorus. Ethanol and acetic acid are the most common electron donor sources used in FBRs. Acetic acid is currently being used as the electron donor source. In addition, a pH control unit is utilized to stabilize the influent groundwater pH to within the 6 to 8 optimal operating range.

The total flow through the FBR consists of both the forward flow of untreated groundwater and the recycle flow of treated groundwater. One of two fluidization pumps is used to pass the total influent flow up through the bioreactor to cause fluidization of the reactor media. Fluidization means that the media particles are suspended and not in direct contact with other particles. Fluidization increases the surface area available for microbial growth and therefore increases the efficiency of perchlorate reduction per unit volume of the reactor. A fluid distribution system, with a header and lateral system, ensures a uniform upflow velocity across the bottom of the bed. As the water travels up through the media, the bed is hydraulically expanded and fluidized. A flow rate is maintained to achieve at least a 25% to 30% expansion of the bed.

The FBR also includes a biomass separation system. In general, as biomass continues to grow on the FBR media, the particle surface area increases and the media particles become less dense. The lowest density particles with the highest attached biomass move up to the top of the FBR causing further bed expansion. For this reason, a biomass control system is utilized at the top of the reactor to remove the excess biomass and to maintain the target bed height. The biomass control system is designed to operate on an intermittent basis, as necessary, based on operating conditions. The system relies upon an airlift tube to pump the media from the top of the fluidized bed into a mixing chamber. Within the lift tube and mixing chamber, the coated media are agitated, thereby causing the biomass to separate from the media. The cleaned media then returns to the reactor through a return pipe and settles down in the fluidized bed. The separated biomass from the mixing chamber is drawn off and discharged in the sanitary sewer (with approval) or transported to an appropriate off-site facility for disposal.

Treated effluent from the FBR is collected through submerged headers and directed toward the effluent discharge or recycle. The headers are submerged to minimize turbulence within the effluent collection system that could re-introduce dissolved oxygen into the recycle stream. The recycle nozzle is set lower than the effluent nozzle to allow 100% recycle flow without the loss of volume.

4.6.4 Post-Aeration Tank

After treatment in the FBR, a post-aeration system raises the dissolved oxygen level in the treated groundwater to 4 to 5 mg/L to promote the degradation of any excess electron donor and to maintain aerobic conditions in the multimedia filter. The post-aeration tank is a 9-ft-diameter by 20-ft-tall vessel constructed of fiberglass-reinforced plastic. The tank contains a fine bubble diffuser grid to sparge the water and raise the dissolved oxygen levels in the FBR effluent.

4.6.5 Multimedia Filter

A multimedia (anthracite coal, silica sand, and garnet) filter system is used both to filter the bioreactor effluent (to remove any residual biomass and other suspended solids), and to facilitate the aerobic consumption of any remaining electron donor prior to groundwater reinjection. The media filter utilizes granular materials of varying sizes and specific gravities to allow for deep bed filtration. Deep bed filtration is a process that allows particles to be removed throughout the entire depth of the bed because media pore spaces at the bottom of the filter are smaller than those at the top. The size of the filter vessel is 28 ft long, 9 ft wide and 8.5 ft tall. The filter is outfitted with an air scour for periodic backwashing of the system. A polymer addition system is also available to promote coagulation of suspended solids, if necessary.

4.7 Instrumentation and Controls

The expanded treatment system will utilize the same PLC with operator interface used to monitor and control the operation of the existing groundwater extraction and injection pumps, and the groundwater treatment system. The new equipment will be merged with the existing National Electrical and Mechanical Association (NEMA) 4 Panel that includes the appropriate system motor controls, indicator lights, and alarms. Figure 4-2 indicates where the existing and proposed flow meters, pressure transducers, pressure gauges, and sample ports are or will be located. Table 4-3 provides an overview of the proposed instrumentation components that will be external to the existing groundwater treatment train. The groundwater treatment system (i.e., LGAC, FBR, post-aeration tank, and multimedia filter units) has separate instrumentation and controls as specified by the manufacturer, which will be integrated with the new equipment.

Table 4-3. Pumping Instrumentation and Controls

Item	Quantity	Medium	Fitting Size	Fitting Material	Type of Operation	Range of Operation
Submersible Pump Switch	1	NA	NA	NA	On/off	NA
Submersible Pump Hour Meter	1	NA	NA	NA	Operational Time	NA
Ext. Well Flow Meter	1	Water	4"	PVC	Flow Rate	0-200 gpm
Ext. Well Flow Totalizer	1	Water	4"	PVC	Total Flow	NA
Ext. Well Level Transducer	1	Water	NA	PVC	Water Level	0-250 ft H_2O
Injection Well Flow Meter	1	Water	4"	PVC	Flow Rate	0-200 gpm
Injection Well Flow Totalizer	1	Water	4"	PVC	Total Flow	NA
Injection Well Level Transducer	1	Water	NA	NA	Water Level	0-250 ft H_2O
Injection Well Pressure Indicator	1	Water/Air	1/4"	PVC	Pressure Monitoring	0-200 psi
Injection Well Pump Switch	1	NA	NA	NA	On/Off	NA
Injection Well Pump Hour Meter	1	NA	NA	NA	Operational Time	NA

psi = pounds per square inch

The PLC in EW-01 and EW-02, which controls the submersible groundwater extraction pumps by monitoring the water table level using a pressure transducer setup to ensure that drawdown is not excessive or outside of anticipated normal limits, will also be linked to EW-03. The submersible pumps and the entire system will be shut down when the low-level system shutoff alarm is triggered. In addition, flow rate signals from each well will be transmitted to the PLC where flow rate will be indicated and totalized. Three elapsed-time meters will be used to record the number of hours each groundwater extraction pump has operated. Fiber optic lines will be used to communicate between the individual wells and the control panel located near the groundwater treatment system. All extracted groundwater will flow through a common pipeline and through a bank of bag filters to remove particulates. Pressure gauges will be monitored to determine the pressure drop across the bag filters to determine when the bag filters need to be replaced. These pressure gauges will be manually monitored and are not part of the PLC system.

The PLC in IW-01 and IW-02, which controls the groundwater reinjection pumps by monitoring the water table level using pressure transducers set up to ensure that groundwater mounding is within anticipated normal limits, will also be configured to monitor IW-03. The reinjection pumps and the entire system will shut down if the high-level system shutoff alarm is triggered. In addition, flow rate signals for each well will be transmitted to the PLC where flow rate will be indicated and totalized. Elapsed-time meters will be used to record the number of hours each groundwater injection pump has operated.

Telemetry will be used to communicate between the individual well sites and the control panel located near the groundwater treatment system.

The groundwater storage tank (located after the LGAC units), which is equipped with a liquid level cutoff switch, will shut down the groundwater extraction pumps if the level of water in the tank reaches a pre-determined height. The tank contains a high-high level switch, a high level switch, and a low level switch. The high-high level switch deactivates the extraction pumps to avoid overflow of the tank. The outlets from the tank, which are plumbed to the FBR system, are located below the high level switch that activates the groundwater extraction pumps for more pumping. If the water level reaches the low level indicator, the system automatically shuts down and triggers an alarm on the control panel to indicate that a system error has occurred.

4.8 Support Facilities and Utilities

A trailer set up on-site stores monitoring, safety, and maintenance related equipment. The trailer area includes a refrigerator for samples, workbench, storage shelves, eye wash station, fire extinguishers, and a first aid kit. The trailer set up is also used for staging field monitoring events and sample collection.

The power supply currently supplied to the source area treatment system is sufficiently sized to accommodate the additional power requirements of system expansion. Table 4-4 describes the preliminary electrical power requirements for system expansion. A licensed electrician will be subcontracted to install power to the new equipment, as necessary.

Table 4-4. Power Requirements (Source Areat Treatment System Expansion)

Item	Power Requirements
Groundwater Extraction Pump	460 volt, 3 Phase, 4 Wire, 40 Amps
Flowmeters/Totalizers, Pressure Transducers	Low voltage 4 to 20 Milli-Amps
Pressure Switch	120 volt, 1 Phase, 15 Amps

5.0 SYSTEM IMPLEMENTATION

The specific tasks that will be required for implementation of the source area treatment system expansion at NASA JPL are summarized below.

5.1 Coordination and Site Logistics

This response action will require careful coordination with the Navy, NASA, and Caltech personnel to ensure the successful installation, construction, and operation of the expanded system. Battelle will coordinate the activities necessary to prepare the site for the installation of wells, trenches, structures, and utilities to support system expansion, including surveying, underground utility clearance, and coordinating provisions for waste management and disposal.

5.1.1 Project Coordination

Battelle will coordinate with the Navy and NASA to complete all pre-fieldwork, installation, operation, and monitoring activities. The project coordination and site logistics will include the following activities:

- Obtaining the necessary work plan review by the appropriate federal, state, and local regulatory authorities. Their concurrence will be important in ensuring that all regulatory issues have been adequately addressed.
- Coordinating with the Navy, NASA, and Caltech personnel to obtain the appropriate construction approvals.
- Coordinating facility access clearance for project personnel, equipment, and vehicles.
- Coordinating system installation (including utility location, well installation, piping installation, site surveying, and waste management).
- Coordinating with Caltech health and safety personnel throughout all site construction activities.
- Coordinating with JPL facilities, Fire Department and Security personnel.
- Installing and developing the extraction and injection well at the site.
- Allocating and scheduling analytical laboratory resources.

Upon receipt of NASA, Navy, and regulatory approval of this work plan, Battelle will conduct a pre-fieldwork site walk to point out proposed locations of wells, piping, and equipment. As necessary, Battelle will coordinate with the Caltech Environmental Affairs Office (EAO) and the JPL security office for facility access, utility map review, equipment storage area designation, well and piping placement, electrical service connection, traffic control, and other facility logistical support.

5.1.2 Safety Issues

A Site Health and Safety Plan (HASP) covering activities performed during this project is provided in Appendix C. Level D personal protective equipment is expected to be sufficient for the activities described in this plan. Air monitoring for organic vapor will be conducted during the drilling and groundwater sampling activities. A sign will be posted at the work site listing 24-hour phone numbers of site representatives. Phone numbers for the Battelle Corporate Health and Safety Manager, the Project Manager, and the NASA representatives also will be presented.

5.1.3 Surveying

Following the completion of system expansion installation, a California-licensed surveyor will be hired to locate the newly installed extraction well and injection well locations, and the underground piping route. Surveyed locations of system equipment will be incorporated into final site drawings for this project.

5.1.4 Utility Clearance

Battelle will review all available utility maps, including well locations and underground piping routes, prior to finalizing the layout of the system expansion. Battelle will schedule a meeting with the Caltech Facilities Engineering and Construction Section to discuss the proposed drilling locations and review the utility maps. To the extent possible, well locations and piping runs will be strategically sited to avoid existing utilities. Prior to performing any subsurface activities, drilling and trenching areas will be scanned for underground utilities by a utility-locating contractor. The utility-locating contractor will employ several methods, including ground-penetrating radar (GPR), magnetometer, magnetic gradiometer, and/or electromagnetic imaging (EM). As required by California State law, Battelle will notify Underground Services Alert (USA), a communication center which will provide notice to utility owners having underground utilities traversing the JPL facility. USA requires at least 48 hours of notification prior to conducting any underground excavation. Following map review, geophysical utility locating, and USA clearance, the surface of the ground will be clearly marked where underground utilities are located. The utilities identified during these studies will be incorporated into the design drawings. To the extent possible, if any proposed work locations are affected by the presence of buried utilities, the affected locations will be offset to avoid impact to them. Prior to the initiation of drilling activities, Battelle will attempt to dig a pilot hole by hand to a depth of approximately 5 ft bgs at each proposed well location to verify that no underground utilities are present.

5.1.5 Waste Management

The primary wastes generated from the source area treatment system are listed below:

- Drill cuttings and well development water
- Excavation/trenching soil
- Decontamination rinse water
- Spent carbon
- Biomass recovered from the FBR and backwash water from the multimedia filter.

The amount of waste generated will vary based on actual field operations. Waste currently generated by the existing treatment system (spent carbon, biomass from FBR, etc.) will likely increase following the implementation of system expansion, due to enhanced treatment capacity; however, waste management will not deviate from the current standard. Waste samples will be analyzed for VOCs, perchlorate, polychlorinated biphenyls (PCBs), pesticides, metals, and hexavalent chromium. Based on laboratory results, the waste will be classified as hazardous or non-hazardous in accordance with the Code of Federal Regulations (40 CFR 261.31 to 261.33 and 261.21 to 261.24) and the California Code of Regulations (22 CCR). Battelle will prepare all required waste profiles and manifests for the waste. An appropriate EPA-certified waste disposal facility will be selected and a licensed transporter will haul the waste off-site for disposal. All waste transported off-site will be accompanied by the appropriate hazardous or non-hazardous waste manifest, signed by the Caltech EAO. The disposal of waste will be in accordance with federal, state, and local laws, regulations, and instructions.

Biomass recovered from the FBR and backwash water from the multimedia filter will continue to be disposed of in the sanitary sewer (with approval). Approval is obtained from the Los Angeles County Sanitation District (LACSD) based on samples taken prior to discharging to the sanitary sewer. Discharges are typically done using a batch method every 4-5 weeks, producing approximately 5,000 to 12,000 gallons of discharge solids. A copy of the LACSD permit is available as Appendix D.

5.2 System Installation and Shakedown

During system expansion and shakedown, all associated equipment will be procured, delivered to the site, installed, and tested. Battelle staff will primarily perform this work; however, staff from various subcontractors will assist in the installation and startup of the new equipment. It is estimated that the procurement phase, the system installation, and shakedown phase will occur over a two to three-month period. The work will proceed on installation of the new equipment as follows:

- Underground utility survey;
- Installation of the new extraction well and injection well;
- Completion of trenching for all piping and utilities, and installation and testing of groundwater conveyance piping;
- Installation and plumbing the necessary instrumentation and controls;
- Surveying installed piping and well locations and elevations;
- Completion of electrical and other utilities hookup; and
- Performing system startup and shakedown.

Active testing of the new groundwater extraction well pump will be conducted to establish a target pumping rate. Hydraulic shakedown testing of the system will be performed to ensure proper pump rates and hydraulic control within the system, and to test that the automatic shutdown switches operate properly.

5.3 System Operation and Maintenance

Proper operation and maintenance (O&M) is a critical factor in optimizing the performance of the overall treatment system. A full-time operator is currently on-site five days a week to ensure proper operation of the treatment system. The operator will continue the same O&M schedule following the installation of the new equipment. Additional O&M assistance will be provided as needed. The primary responsibilities of the operator include:

- Verifying that the system is running and operating normally;
- Troubleshooting problems with the system as they arise;
- Performing routine system inspections and maintenance as specified in the manufacturer’s O&M manual; and
- Performing monitoring and sample collection to determine the effectiveness of the treatment systems and that they are in compliance with appropriate regulations.

Under normal daily operating conditions, the primary functions of the expanded treatment system will be automated, including the following steps:

- Groundwater pumping from the extraction wells (EW-01, EW-02, and EW-03)
- Delivery of the extracted groundwater to the groundwater treatment train including the LGAC units, the FBR, the post-aeration tank, and the multimedia filter
- Delivery of treated groundwater to the injection wells (IW-01, IW-02, and IW-03).

The operator(s) will be on-site, as necessary, to make sure that the system is operating as intended and to perform any manual tasks specified by the manufacturer.

5.4 System Monitoring

In addition to the routine O&M described above, the operator will continue to be responsible for conducting sampling and analysis to evaluate the effectiveness of the source area treatment system. More detailed information on system monitoring is presented in the Sampling and Analysis Plan (SAP) which is included in Appendix B. This section provides an overview of the parameters that will be tracked during performance monitoring and compliance monitoring for the source area treatment system. In addition, hydraulic monitoring will be conducted to track hydraulic control within the subsurface and to monitor biofouling and/or plugging of the injection wells.

5.4.1 Monitoring Well Network Sampling

Periodic sampling of the monitoring well network will be important in tracking the treatment effectiveness of the expanded treatment system. Table 5-1 summarizes the parameters and associated EPA analytical methods that will be used for baseline monitoring and subsequent monthly sampling of the monitoring well network.

Table 5-1. Summary of Analytical Methods for the Monitoring Well Network Sampling

Parameter	Analytical Method	Method Number	Monitoring Well Network
Field Parameters (pH, DO, ORP, temperature, specific conductance)	ISE	Field	1/quarter
Perchlorate	IC	314	1/quarter
Ions (nitrate, nitrite, orthophosphate, sulfate, chlorate, chloride, bromide)	IC	300	1/quarter
VOCs	GC/MS	8260B	1/quarter

DO = dissolved oxygen; ORP = oxidation reduction potential; IC = ion chromatograph; GC = gas chromatograph; MS = mass spectrometer; ISE = ion selective electrode

5.4.2 Performance and Compliance Monitoring for the Treatment System

Table 5-2 summarizes both the performance and compliance monitoring planned for the expanded treatment system. The parameters and associated EPA analytical methods are listed, along with the proposed sample collection frequencies at each sampling point. The performance and compliance monitoring is consistent with the modifications proposed in July 2006 (NASA, 2006c).

The LGAC system performance will be evaluated based on influent and effluent VOC concentrations by sampling the midpoint between the two LGAC units to assess breakthrough and the LGAC replacement frequency. The FBR system performance will be evaluated primarily based on influent and effluent nitrate and perchlorate concentration. Other parameters, such as pH, ORP, DO, sulfide, and total organic carbon (TOC), will be monitored in the field to adjust FBR operating parameters as necessary. The influent and effluent DO levels will be measured at the post-aeration tank to track its operation. The multimedia filter will also be monitored to track electron donor degradation and its removal efficiency for suspended solids.

In addition, each extraction well interval will be monitored using field equipment and sampled on a weekly/monthly basis for perchlorate, inorganic ions, and VOCs. The system inlet (e.g., the combined flow at the LGAC inlet) and the system outlet (e.g., the multimedia filter outlet) will also be analyzed on a monthly basis to meet the regulatory requirements for the reinjection of groundwater. When the expanded demonstration study is put into operation the new well (EW-3) will get additional weekly monitoring for perchlorate concentrations to closely track the change in concentration.

Table 5-2. Summary of Analytical Methods for the Source Areat Treatment System Performance and Compliance Monitoring

Parameter	Analytical Method	Method Number	Extraction Well Intervals	LGAC Inlet	LGAC Mid	FBR Inlet	FBR Outlet	Multimedia Filter Inlet	Multimedia Filter Outlet
Field Parameters (pH, DO, ORP, temperature, specific conductance)	ISE	Field	NA	5/week	NA	5/week	5/week	NA	NA
Perchlorate	ISE	Field	NA	5/week	NA	5/week	5/week	NA	NA
Nitrate	ISE	Field	NA	2/week	NA	5/week	2/week	NA	NA
Sulfide	ISE	Field	NA	NA	NA	2/week	2/week	NA	NA
TOC	Meter	Field	NA	NA	NA	2/week	2/week	NA	NA
Perchlorate	IC	314	1/month	NA	NA	1/week	1/week(a)	NA	NA
Ions (nitrate, nitrite, sulfate, chloride, fluoride)	IC	300	1/month	1/month	NA	1/week (nitrate)	1/week (nitrate/sulfate)	NA	NA
Sulfide	Titrimetric	376.1	NA	NA	NA	1/qtr	1/qtr	NA	NA
VOCs	GC/MS	8260B	1/month	1/week	1/week	NA	1/week	NA	NA
1,4-Dioxane	MS	8270C	1/qtr	1/month	NA	NA	1/month	NA	NA
Inorganics(b)	ICP	6010B	NA	1/qtr	NA	NA	NA	NA	1/qtr
Hexavalent Chromium	IC	7199	NA	1/qtr	NA	NA	NA	NA	1/qtr
Total Dissolved Solids	NA	160.1	NA	1/qtr	NA	NA	NA	1/qtr	1/qtr
Total Suspended Solids	NA	160.2	NA	1/month	NA	NA	NA	1/month	1/month
Turbidity	Nephelometric	180.1	NA	1/month	NA	NA	NA	1/month	1/month

(a) Sample results in 24 hours

(b) antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, lead, magnesium, mercury, molybdenum, nickel, iron, selenium, silver, thallium, vanadium, and zinc

ICP = inductively coupled plasma

5.4.3 Hydraulic Monitoring

Groundwater levels will be monitored within the treatment system well field to assess the hydraulic capture zone of the expanded treatment system and to track potential clogging and/or biofouling of wells. Groundwater level measurements will start at least 24 hours before the startup of extraction (EW-03) and/or injection (IW-03) well operations. Groundwater levels at the extraction wells and injection wells will be recorded electronically through the use of pressure transducers connected to the PLC device located at the groundwater treatment system. These readings will be compared with manual measurements taken at least monthly. In addition, the groundwater levels in the monitoring well network will be measured manually on at least a monthly basis. Both the manual and electronic groundwater-level measurements will be recorded to the nearest 0.01 ft. The manual groundwater-level measurements will be recorded on the appropriate field data forms or in the field notebook.

A pattern of continuously rising groundwater levels in the injection wells, without corresponding regional water table changes, may indicate clogging and/or biofouling of these wells. Operation and maintenance of the system will involve proactive measures to track and minimize well clogging and/or biofouling. The injection wells may require periodic cleaning by chemical, physical, and/or mechanical methods to remove microbial slimes and/or other solids. Some common approaches for biofouling control include using chemicals such as chlorine, ozone, chlorine dioxide, hydrogen peroxide, biocides, or pH control. Redevelopment of the well may also be necessary on a periodic basis. A combination of these chemical, physical, and mechanical methods may be used during system operation to maintain adequate groundwater injection capacity. The capacity of extraction wells can also be reduced over time due to clogging and/or biofouling; therefore, similar maintenance may be required. Additional details regarding hydraulic monitoring and well performance monitoring are provided in Appendix A.

5.5 Data Interpretation and Reporting

The data obtained from the treatment system will continue to be tabulated, reviewed, and interpreted on a continuous basis. In addition, Battelle will continue preparing progress reports regarding system performance and the progress in meeting the treatment objectives and performance criteria. These progress reports will be submitted via e-mail on a semi-annual basis.

The progress reports for the treatment system will include a summary of VOC, perchlorate, and nitrate mass removal. It will also include results from hydraulic monitoring and a summary of other pertinent operational information for the groundwater treatment system including operational hours, electron donor and nutrient dosing levels, biomass growth and recovery, and other key measures of system performance.

5.6 Performance Objectives, System Optimization, and Exit Strategy

The response action for OU-1 is intended to provide source treatment and containment to prevent migration of chemicals off-facility and reduce cleanup times for OU-3. JPL is located within the Raymond Basin Watershed, which is a current source of drinking water.

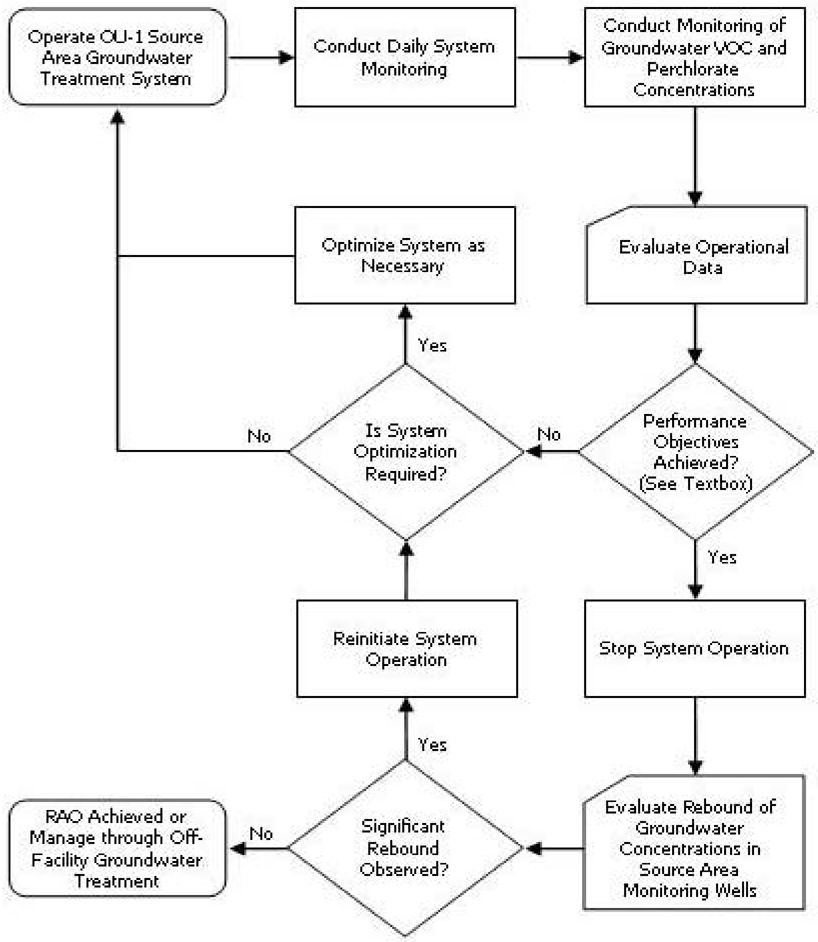
It is anticipated that the response action will help reduce OU-3 groundwater treatment costs and help restore aquifer water quality. The approach for implementing groundwater extraction, treatment, and reinjection at OU-1 is summarized in Figure 5-1. Performance objectives have been established to achieve the RAOs. The system will be operated and optimized until performance objectives have been achieved. The performance of the system will be evaluated on a continued basis and the information regarding the amount of VOCs and perchlorate removed will be reported to the regulatory agencies as needed to effectively evaluate system performance objectives. The performance objectives include the following:

- Reduction of overall VOC and perchlorate concentrations within the groundwater monitoring wells and extraction wells compared to baseline levels.

- Asymptotic mass removal achieved, after appropriate system optimization. Asymptotic conditions will have been reached when the upper limb of the cumulative mass removal curve approaches zero.

- Operation only as long as cost-effective. The OU-1 source area groundwater treatment system will no longer be cost-effective when operating costs per unit of VOC and perchlorate mass removed from the groundwater indicate that the additional cost of continuing to operate the system is not warranted and/or when shutdown of the OU-1 system is not anticipated to significantly increase the cost of the OU-3 groundwater remedy or significantly prolong the time to achieve groundwater cleanup.

The existing groundwater monitoring network will be evaluated during the remedial design phase to determine if sufficient coverage is available to monitor changes in the lateral and vertical distribution of VOCs and perchlorate, as well as the effectiveness of cleanup. Additional groundwater monitoring wells will be installed as necessary to monitor effectiveness of the response action. Optimization of the treatment system will be accomplished primarily by varying process operating conditions. Field readings and laboratory analyses will then be used to evaluate the treatment train system response and performance. The overall strategy will be to focus on maximizing system throughput, while maintaining treated effluent water quality. The amount of groundwater extracted from each extraction well will be increased and/or reduced based on optimizing influent chemical mass loading rates. The system O&M manual (Appendix E) contains specific procedures for optimizing operation of the LGAC adsorption units, the FBR, the post-aeration tank, and the multimedia filter. After the performance objectives have been achieved, the OU-1 system may be idled and groundwater monitoring will continue to evaluate rebound. If significant rebound occurs, the OU-1 system will be reinitiated; otherwise, the system will be permanently shut down and dismantled. When performance objectives have been achieved, NASA will request shutdown of the OU-1 system. NASA will shut down the OU-1 system once approval has been granted by the U.S. EPA, DTSC and RWQCB.



Performance Objectives

1. **VOC and Perchlorate Concentration Reduction** – Reduction of overall VOC and perchlorate concentrations within the groundwater monitoring wells compared to baseline levels.
2. **Asymptotic Mass Removal** – Asymptotic mass removal achieved after appropriate system optimization. Asymptotic conditions will have been reached when the upper limb of the cumulative mass removal curve is substantially linear and the slope of the curve approaches zero.
3. **Cost-Effectiveness** – Operate only as long as cost-effective. The system will no longer be cost-effective when operating costs per unit of VOC and perchlorate mass removed from the groundwater indicate that additional cost of continuing to operate the system is not warranted and/or when shutdown of the OU-1 system is not anticipated to significantly increase the cost of the OU-3 groundwater remedy or significantly prolong the time to achieve groundwater cleanup.

Flow Chart Symbols

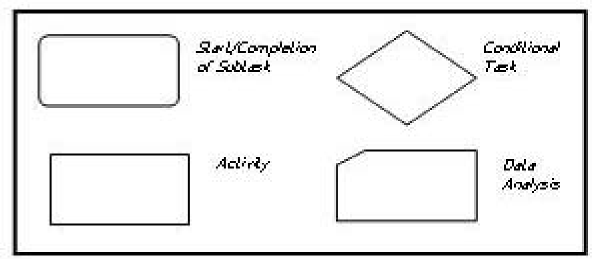


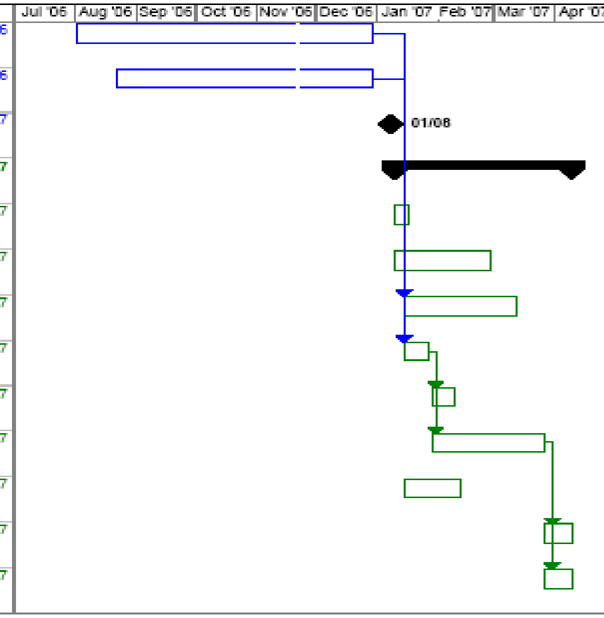
Figure 5-1. Remedial Approach Flowchart

6.0 PROJECT SCHEDULE

The proposed schedule for implementing the tasks outlined in Section 5.0 is provided in Table 6-1. The completion of the tasks outlined in Section 5.0 will begin after approval of the ROD associated with this work has been received. A number of the tasks listed below will occur concurrently and as promptly as possible.

Table 6-1. Proposed Schedule for the Source Area Treatment System Expansion

ID	Task Name	Duration	Start	Finish
1	**ROD Finalization**	107 days	Wed 08/02/06	Fri 12/29/06
2	**RD/RA Work Plan**	94 days	Tue 08/22/06	Fri 12/29/06
3	**Coordination Meeting with NASA/Navy/Caltech**	0 days	Mon 01/08/07	Mon 01/08/07
4	**System Installation and Shakedown**	63 days	Wed 01/10/07	Mon 04/09/07
5	Utility Clearance and Survey	5 days	Wed 01/10/07	Tue 01/16/07
6	Procurement Phase	35 days	Wed 01/10/07	Tue 02/27/07
7	Underground/Aboveground Piping Installation	40 days	Mon 01/15/07	Mon 03/12/07
8	Extraction Well Installation	10 days	Mon 01/15/07	Fri 01/26/07
9	Injection Well Installation	10 days	Mon 01/29/07	Fri 02/09/07
10	Well Development	40 days	Mon 01/29/07	Mon 03/26/07
11	Drilling Waste Disposal	21 days	Mon 01/15/07	Mon 02/12/07
12	Instrumentation and Controls Installation	10 days	Tue 03/27/07	Mon 04/09/07
13	System Startup and Shakedown	10 days	Tue 03/27/07	Mon 04/09/07



Project: RD-RA Schedule
Date: Tue 11/21/06

Page 1

Note: Schedule is subject to subcontractor availability.

7.0 REFERENCES

ARCADIS. 2002. *Work Plan for the Pilot Study to Create an In Situ Reactive Zone and Demonstrate Perchlorate Treatment at the Jet Propulsion Laboratory*. Prepared for Naval Facilities Engineering Service Center and NASA.

CH2MHill. 2002. *JPL Groundwater Modeling Report*. Prepared for Southwest Division Naval Facilities Engineering Command and NASA.

Diersch, H.-J. G. 2002. FEFLOW Finite Element Subsurface Flow and Transport Simulation System. WASY Institute for Water Resources Planning and Systems Research Ltd. Berlin, Germany.

Foster Wheeler Environmental Corporation (FWEC). 2000. *Draft Feasibility Study Report for Operable Units 1 and 3: On-Site and Off-Site Groundwater*. National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, CA. January.

National Aeronautics and Space Administration (NASA). 2003. *Revised Final Operable Unit 1 Expanded Treatability Study Work Plan*. NASA Jet Propulsion Laboratory. NAS7.010106, NASA-JPL, SSIC No. 9661. October.

National Aeronautics and Space Administration (NASA). 2004. *Air Regulations Applicability Analysis for Operable Unit 1 Expanded Treatability Study, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. April.

National Aeronautics and Space Administration (NASA). 2005a. *Operable Unit 1 Expanded Treatability Study Installation Report, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. June.

National Aeronautics and Space Administration (NASA). 2005b. *Technical Memorandum: Operable Unit 1 Quarterly Progress Report, Expanded Treatability Study System Operations, January to March 2005*. April 11.

National Aeronautics and Space Administration (NASA). 2005c. *Technical Memorandum: Operable Unit 1 Demonstration Study Progress Report, April to August 2005, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. October.

National Aeronautics and Space Administration (NASA). 2006a. *Draft Interim Record of Decision and Remedial Action Plan for the Operable Unit 1 Source Area Groundwater, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. July.

National Aeronautics and Space Administration (NASA). 2006b. *Technical Memorandum: Operable Unit 1 Demonstration Study Progress Report, September 2005 to February 2006, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. April.

National Aeronautics and Space Administration (NASA). 2006c. *Technical Memorandum: Operable Unit 1 Source Area Groundwater Treatment System Modifications to Performance and Compliance Monitoring, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. July.

California Regional Water Quality Control Board (RWQCB). 2005. General Waste Discharge Requirements for Groundwater Remediation at Petroleum Hydrocarbon Fuel and/or Volatile Organic Compound Impacted Sites. File No. 01-116. Regional Water Quality Control Board Los Angeles Region. May 16.

California Regional Water Quality Control Board (RWQCB). 1994. Water Quality Control Plan: Los Angeles Region, Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties. Regional Water Quality Control Board Los Angeles Region. June 1994.

United States Environmental Protection Agency (U.S. EPA). 1989a. "Applicability of Land Disposal Restriction to RCRA and CERCLA Ground Water Treatment Reinjection, Superfund Management Review: Recommendation No. 26." Memorandum from Don R. Clay, Assistant Administrator, Office of Solid Waste and Emergency Response. OSWER Directive No. 9234.1-06. December 27.

United States Environmental Protection Agency (U.S. EPA). 1989b. "Applicability of Land Disposal Restriction to RCRA and CERCLA Ground Water Treatment Reinjection, Superfund Management Review: Recommendation No. 26." Memorandum from Don R. Clay, Assistant Administrator, Office of Solid Waste and Emergency Response. OSWER Directive No. 9234.1-06. December.

United States Environmental Protection Agency (U.S. EPA). 1992a. *The Superfund Accelerated Cleanup Model (SACM) under CERCLA and the NCP*. Office of Solid Waste and Emergency Response Directive 9283.1-06. May.

United States Environmental Protection Agency (U.S. EPA). 1992b. "National Priorities List for Uncontrolled Hazardous Waste Sites**.**" 47180-47187 *Federal Register*, Vol. 57, No. 199.

United States Environmental Protection Agency (U.S. EPA). 1992c. "Permits and Permit 'Equivalency' Processes for CERCLA On-Site Response Actions." Memorandum from Henry L. Longest II, Director, Office of Emergency and Remedial Response. OSWER Directive No. 9355.7-03. February.

United States Environmental Protection Agency (U.S. EPA). 1996. Presumptive Response Strategy And Ex Situ Treatment Technologies For Contaminated Groundwater At CERLA Sites. Office of Solid Waste and Emergency Response. EPA 540/R-96/023.

United States Environmental Protection Agency (U.S. EPA). 2000. *Applicability of RCRA Section 3020 to In-Situ Treatment of Ground Water*. Memorandum from Elizabeth A. Cotsworth, Director Office of Solid Waste, Office of Solid Waste and Emergency Response. Washington, DC. December.

United States Environmental Protection Agency (U.S. EPA). 2002. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action for Facilities Subject to Corrective Action Under Subtitle C of the Resource Conservation and Recovery Act. Office of Solid Waste and Emergency Response. EPA/530/R-01/015.