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FINAL

FOCUSED FEASIBILITY STUDY FOR OU1 AND OU3

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

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ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
ATSDR	Agency for Toxic Substances and Disease Registry
BDAT	best demonstrated available technology
bgs	below ground surface
Caltech	California Institute of Technology
CCR	California Code of Regulations
CDPH	California Department of Public Health
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CSM	conceptual site model
CWC	California Water Code
DCA	dichloroethane
DHS	Department of Health Services
DTSC	Department of Toxic Substances Control
EW	extraction well
FBR	fluidized bed reactor
FFA	Federal Facilities Agreement
FFRDC	federally-funded research and development center
FS	Feasibility Study
FWEC	Foster Wheeler Environmental Corporation
GAC	granular activated carbon
gpm	gallons per minute
HRS	hazard ranking system
IC	institutional control
JPL	Jet Propulsion Laboratory
LAWC	Lincoln Avenue Water Company
LDR	land disposal restriction
LGAC	liquid-phase granular activated carbon
MCL	maximum contaminant level
MHTS	Monk Hill Treatment System
MNA	monitored natural attenuation
MOA	Memorandum of Agreement

NASA	National Aeronautics and Space Administration
NCP	National Contingency Plan
NL	notification level
NPL	National Priorities List
O&M	operation and maintenance
OU	Operable Unit
PA	preliminary assessment
PCE	tetrachloroethene
PWP	Pasadena Water and Power
RAO	remedial action objective
RCL&W	Rubio Cañon Land and Water
RCRA	Resource Conservation and Recovery Act
RD/RA	remedial design/remedial action
RG	remedial goal
RI	remedial investigation
ROD	Record of Decision
RPM	Remedial Project Manager
RWQCB	Regional Water Quality Control Board
SDWA	Safe Drinking Water Act
SI	site inspection
TCE	trichloroethene
U.S. EPA	U.S. Environmental Protection Agency
VOC	volatile organic compound
WDR	waste discharge requirement

1.0 INTRODUCTION

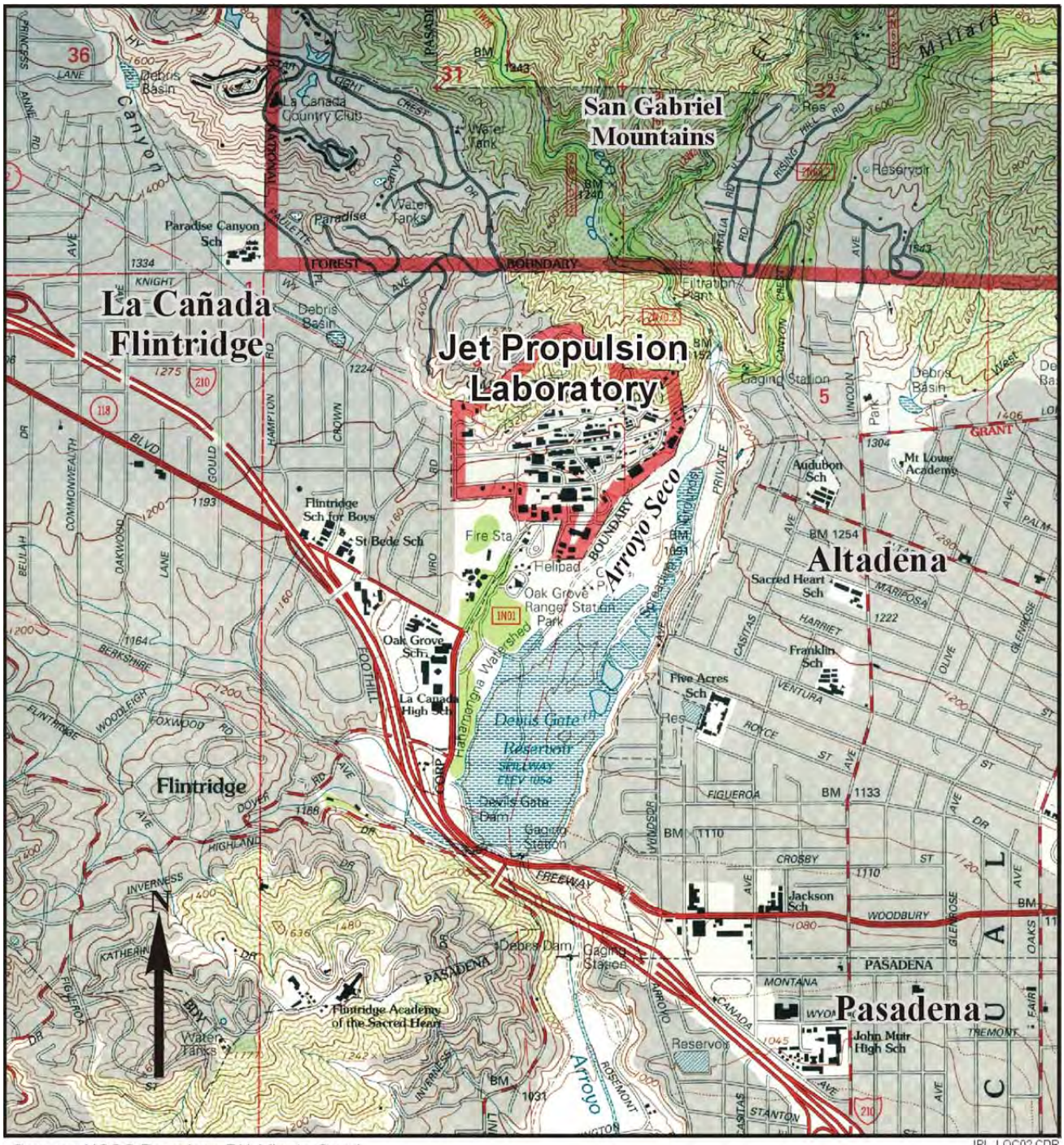
The Jet Propulsion Laboratory (JPL) is a federally-funded research and development center (FFRDC) in Pasadena, California, currently operated under contract with the California Institute of Technology (Caltech) for National Aeronautics and Space Administration (NASA). JPL's primary activities include 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 is situated between the incorporated cities of La Cañada-Flintridge and Pasadena, and is bordered on the east by the unincorporated community of Altadena. 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 in two regions – an early-developed northeastern area and a later-developed southwestern area. Figure 1-1 is a map showing the JPL facility and surrounding areas.

In October 1992, the JPL site was placed on the National Priorities List (NPL) and, therefore, is subject to the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) to regulate investigation and cleanup. For CERCLA purposes, the JPL site has been divided into three operable units (OUs). The three OUs are spatially distinct areas, but are connected in terms of transport of chemicals originating from JPL. OU1 addresses on-facility groundwater at JPL; OU2 addresses on-facility vadose zone soil at JPL; and OU3 addresses off-facility groundwater adjacent to the JPL property. Cleanup of OU2 is complete, as documented in the Remedial Action Report for Operable Unit 2 (NASA, 2007a).

Interim Records of Decision (RODs) are currently in place for both OU1 (NASA, 2007b) and OU3 (NASA, 2007c). Results of the JPL site's first CERCLA five-year review for these OUs concluded that both remedies are operating effectively and are protective of human health and the environment (NASA, 2012a). As such, NASA has prepared this Focused Feasibility Study (FS) Report to evaluate whether enhancements to the interim remedies, or other technologies, are necessary to establish a final remedy for groundwater at the JPL site.

Upon finalization of this Focused FS, the final remedy for OU1 and OU3 will be selected by NASA, in consultation with U.S. Environmental Protection Agency (U.S. EPA), the California Department of Toxic Substances Control (DTSC), and the Regional Water Quality Control Board (RWQCB), and presented in a Proposed Plan that will be available for public review and input. After public review of the Proposed Plan, NASA will respond to public comments and select and describe the final remedy in a final groundwater ROD, addressing groundwater at both OU1 and OU3.



Source: USGS Pasadena 7½-Minute Quad, 1995.
Note: (1) Devil's Gate Reservoir is dry most of the year.

JPL_LOC02.CDR

Scale in Miles
0 0.5 1

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

1.1 Feasibility Study Objectives and Technology Evaluation Process

NASA has prepared this focused FS to advance the JPL CERCLA site toward a final remedy to address chemicals of concern in on-facility (OU1) and off-facility (OU3) groundwater. To achieve this end, remedial action objectives (RAOs) were developed to define the basis for remediation, including numerical remedial goals (RGs). Existing interim remedies were evaluated to determine whether enhancements, or other technologies, were necessary to establish a final groundwater remedy.

Remedial alternatives were assessed against the National Contingency Plan (NCP) evaluation criteria to determine their ability to attain the RAOs. The process used to evaluate remedial alternatives is consistent with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (U.S. EPA, 1988), including the following principal steps:

- Formulate RAOs that provide protection of human health and the environment and comply with applicable or relevant and appropriate requirements (ARARs);
- Identify RGs (i.e., cleanup levels) to achieve the RAOs;
- Identify areas of the site and volumes of media (e.g., soil, groundwater) containing chemicals requiring remediation to achieve the RAOs; and,
- Identify, develop, screen, and evaluate a range of remedial alternatives capable of achieving the RAOs.

Interim remedies are currently operational at both OU1 and OU3, and results of the JPL site's first CERCLA five-year review concluded that both remedies are operating effectively and are protective of human health and the environment (NASA, 2012a). Based on this information, a limited number of remedial alternatives are evaluated in this focused FS. Preparation of a focused FS is in accordance with U.S. EPA *Guidance on Accelerating CERCLA Environmental Restoration at Federal Facilities* (U.S. EPA, 1994). The purpose of that guidance is to encourage and support efforts at federal facilities to accelerate and develop streamlined approaches to the cleanup of hazardous waste. Under this guidance, potential mechanisms for streamlining and accelerating the cleanup process include, among others, use of focused FS reports and presumptive remedies.

1.2 Document Organization

This focused FS is organized as follows:

Section 1: Introduction. This section provides an overview of the CERCLA FS process and summarizes the report organization.

Section 2: Site Description. This section includes a description of the site and its physical setting, site history and potential chemical sources, previous investigations, and the conceptual site model (CSM) including the nature and extent of chemicals in groundwater, chemical fate and transport, and potential exposure pathways.

Section 3: Remedial Action Objectives. This section presents the RAOs and includes a summary of ARARs. This section also identifies the RGs and presents the conceptual remedial footprints.

Section 4: Identification and Screening of Remedial Technologies. This section provides a summary of possible remedial technologies and process options applicable to the site (e.g., to contain, remove, dispose of, and/or treat chemicals in environmental media). Technologies are screened to retain those that are most suitable and appropriate to be incorporated into the remedial alternatives.

Section 5: Development and Detailed Analysis of Remedial Alternatives. This section presents a screening evaluation of remedial alternatives relative to the three pertinent NCP evaluation criteria (effectiveness, implementability, and cost).

Section 6: Comparative Analysis of Remedial Alternatives. This section provides a comparative evaluation of the relative performance of the remedial alternatives retained from Section 5 against the NCP criteria.

Section 7: References. This section contains a list of the documents cited throughout the focused FS.

2.0 SITE DESCRIPTION

2.1 Site Location and History

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. JPL is situated on a south-facing slope along the base of the southern edge of the east-west trending San Gabriel Mountains at the northern edge of the metropolitan Los Angeles area. The Arroyo Seco, a streambed with an intermittent stream, lies immediately to the east and southeast of JPL. Within the Arroyo Seco is a series of surface impoundments used as surface water collection and spreading basins for groundwater recharge. Residential development, equestrian clubs (Flintridge Riding Club and Rose Bowl Riders), and a Los Angeles County Fire Department Station (Fire Camp #2) border the JPL facility along its southwestern and western boundaries. Residential development also is present to the east of JPL, along the eastern edge of the Arroyo Seco, and to the northwest of JPL in La Cañada-Flintridge.

In 1992, JPL was placed on the NPL and subject to regulation under CERCLA (Office of the Federal Register, 1992). Around the same time, NASA funded volatile organic chemical (VOC) treatment facilities to treat chemicals originating from JPL for two sets of production wells: (1) four Pasadena Water and Power (PWP) production wells (Arroyo Well, Well 52, Ventura Well, and Well 52) located within and near the Arroyo Seco, and (2) two Lincoln Avenue Water Company (LAWC) production wells (LAWC#3 and LAWC#5) located approximately one mile to the east of the JPL facility. NASA then conducted numerous investigations, completing the CERCLA Remedial Investigation (RI) for OU1 and OU3 in 1999 (Foster Wheeler Environmental Corporation [FWEC], 1999).

Development of an improved analytical method led to the discovery of perchlorate in groundwater beneath and adjacent to JPL in 1997. To determine the optimal approach for treating perchlorate, NASA performed several studies to determine the best technologies for treating JPL groundwater. Based on these studies, NASA installed a demonstration treatment plant in early 2005, located on JPL property in the OU1 source area. An Interim ROD was signed on February 2007, and expansion of the demonstration plant was completed in 2007.

Perchlorate treatment was added to the LAWC VOC treatment system in 2004, and was implemented as a time critical removal action under CERCLA (NASA, 2004). Subsequently, an Interim ROD for OU3 was signed on August 2007 and funding for construction and operation of a centralized treatment system for the City of Pasadena, along with continued funding of the LAWC treatment system, was selected for treatment of off-facility groundwater. Construction of the Monk Hill Treatment System (MHTS) for the City of Pasadena was completed in 2011 (NASA, 2011). Both the MHTS and LAWC treatment system are currently operating.

A chronological list of important site events, investigations, and activities, along with relevant dates is provided in Table 2-1.

Table 2-1. Chronology of Site Events

Date	Event
1936	JPL begins through the Guggenheim Aeronautical Laboratory at the California Institute of Technology.
1940	Army Air Corp funds first permanent structure near present day facility.
1942	Parsons first proposes the use of potassium perchlorate as oxidizer for solid rocket fuel.
1945	JPL continues to grow, under jurisdiction of the U.S. Army Ordnance Corps.
1945-1960	Throughout this time, wastes are disposed of through seepage pits located on JPL property. The seepage pits were constructed and installed according to Army Corps of Engineers guidance specifications.
1958	NASA takes over control of JPL from the Army (Executive Order 10793) in December.
1958-1963	Seepage pits backfilled and sanitary sewer system installed.
1980	• Trichloroethene (TCE) and carbon tetrachloride detected above drinking water standards in City of Pasadena Arroyo Well. • TCE detected in LAWC supply wells (generally below drinking water standards). • CERCLA enacted by Congress on December 11.
1982	City of Pasadena conducts a preliminary hydrogeologic assessment of Arroyo Seco to identify source of chemicals in wells.
1984	• JPL conducts preliminary assessment of seepage pits and groundwater from the City of Pasadena wells. • Two Lincoln Avenue water supply wells (LAWC#3 and LAWC#5) are temporarily closed by the California Department of Health Services (DHS) due to VOC concentrations above drinking water standards.
1985	Two City of Pasadena water supply wells (Arroyo Well and Well 52) are temporarily closed by the California DHS due to VOC concentrations above drinking water standards.
1988	In April, a preliminary assessment/site inspection (PA/SI) was completed at JPL, indicating further site characterization was needed. Based on the PA/SI, a preliminary Hazard Ranking System (HRS) score of 38.3 was determined for JPL (exceeding a score of 28.5 leads a site to be considered for designation on the NPL).
1989	Two additional City of Pasadena water supply wells (Ventura Well and Windsor Well) are temporarily closed due to elevated VOC concentrations.
1990	• NASA funds construction of a water treatment plant (air stripping with vapor-phase granular activated carbon) to handle VOC concentrations and to reopen the temporarily closed City of Pasadena water supply wells. A settlement agreement for the installation and operation of the VOC water treatment plant was signed between Caltech and the City of Pasadena. • JPL removes a suspected VOC source area under Building 306 consisting of a storm drain catch basin (6 feet × 6 feet × 10 feet) and 160 yd^3 of soil and sludge. • Commencement of field activities for the Expanded SI, which discovers carbon tetrachloride, TCE, 1,1-dichloroethane (DCA), and tetrachloroethene (PCE) are present in the groundwater beneath JPL at concentrations greater than drinking water standards. • Based on the Expanded SI, a new HRS score of 50 was determined for JPL.
1992	• JPL placed on the NPL (Office of the Federal Register, 1992). • City of Pasadena provides letter to U.S. EPA staff supporting the CERCLA listing of JPL. • Following placement on the NPL, a Federal Facilities Agreement (FFA) specifying investigation and cleanup work that will be conducted at JPL was negotiated between U.S. EPA, the State of California, and NASA. All parties signed the FFA on December
1992 (Continued)	30. The designated Remedial Project Managers (RPMs) are representatives from U.S. EPA Region IX; DTSC, RWQCB Los Angeles Region, and NASA JPL. • The LAWC installs a VOC water treatment (liquid-phase granular activated carbon [LGAC]) system to reopen the two wells temporarily closed in 1984. • In anticipation of being placed on the NPL, JPL begins a preliminary RI late in the year. • Provisional toxicity value (i.e., oral reference dose) for perchlorate is issued by U.S. EPA Superfund Technical Support Center.

Table 2-1. Chronology of Site Events (Continued)

Date	Event
1993	• The preliminary RI is completed and reported in the *Final Work Plan for Performing a Remedial Investigation/Feasibility Study* (Ebasco, 1993). • During preparation of the RI work plan for JPL, the groundwater beneath and downgradient of JPL was divided into two OUs (i.e., OU1 and OU3) at the request of the U.S. EPA. Soil is considered a separate OU (OU2).
1994	• RI field activities commence. • Finalized the FFA and first Community Relations Plan.
1995	The provisional reference dose for perchlorate is revised.
1997	• Perchlorate detected in groundwater on JPL property. • PWP shuts down Arroyo Well due to perchlorate levels. • Personnel from the Agency for Toxic Substances and Disease Registry (ATSDR) conducts site visits on August 12 and 20 and September 2 and 3.
1998	ATSDR releases its Public Health Assessment report for review and comment on August 4. ATSDR determines that there is no public health risk from the JPL site. Perchlorate was not addressed in the assessment because a maximum contaminant level (MCL) did not exist.
1999	• Final RI for OU1/OU3 submitted in August. • Final RI for OU2 submitted in November. • Ion exchange pilot study completed by Calgon Carbon Corporation. • Final Public Health Assessment released by ATSDR in September.
2000	• An action level of 18 μg/L perchlorate is established by California DHS. • NASA assumes lead role in CERCLA Program on May 18. • Final FS for OU2 submitted in July.
2001	• Proposed Plan for OU2 finalized in April. • OU2 public meetings conducted in May and June. • Completed Granular Activated Carbon (GAC)-Fluidized Bed Reactor (FBR) Pilot Study by US Filter and Envirogen.
2002	• U.S. EPA releases draft risk assessment for perchlorate. • Action level for perchlorate reduced to 4 μg/L by DHS. • NASA finalizes ROD for OU2 in September. • Initiated full-scale operation of soil vapor extraction in OU2. • PWP shuts down the following wells due to perchlorate levels: Well 52, Ventura, Windsor, Sunset, Bangham, Villa, Garfield, and Copelin. • California Office of Environmental Health Hazard Assessment proposes draft public health goal range of 2 to 6 μg/L for perchlorate. • Packed bed bioreactor pilot study completed by FWEC. • In situ bioremediation pilot study completed by ARCADIS.
2003	• Finalized Community Relations Plan – Amendment 1 in January. • Finalized Work Plan to implement an Expanded Treatability Study for OU1 in October.
2004	• Deployed the NASA JPL CERCLA Program Web site. • California Office of Environmental Health Hazard Assessment issues a final public health goal of 6 μg/L for perchlorate. • Initiated construction of the OU1 Expanded Treatability Study system. • Implemented a 2,000 gallons per minute (gpm) ion exchange perchlorate treatment system for LAWC as a time-critical removal action under CERCLA. The system was fully operational in July. • Finalized the RI Addendum Work Plan in December. Objectives of the work plan included: (1) evaluating the downgradient (southern) extent of chemicals that originate from the JPL facility, and (2) determining if the occurrence of perchlorate in the Sunset Reservoir area is associated with migration from the JPL facility. • Installed an additional multi-port monitoring well (MW-25) in the Sunset Reservoir area.

Table 2-1. Chronology of Site Events (Continued)

Date	Event
2005	• Completed construction of the OU1 Expanded Treatability Study system and initiated operations in January. • Finalized the Proposed Plan and conducted a public meeting to discuss expansion of the OU1 system. Public Comment Period: November 1 to December 15. • Operation of the SVE unit at OU2 was concluded in September. • Installed an additional multi-port monitoring well (MW-26). • Conducted an additional investigation and isotope study to evaluate perchlorate occurrence near the Sunset Reservoir wells. • Initial field investigation (geophysical, topographic, geotechnical) was conducted at Windsor Reservoir to evaluate the site for location of the future drinking water treatment plant in June. • Issued a Predevelopment Plan to the City of Pasadena for the Monk Hill treatment plant on November 30. • National Academy of Sciences published *Health Implications of Perchlorate Ingestion.*
2006	• Agreement signed on January 23 between the City of Pasadena and Caltech associated with implementation of a drinking water treatment facility. • Finalized the Proposed Plan and conducted public meetings to discuss the OU3 interim remedial action. Public Comment Period: April 19 to July 7. • Published the Update of the Community Involvement Plan in October.
2007	• Submitted a Technical Memorandum summarizing the results of the additional investigation on January 31. NASA concluded that the perchlorate in the Sunset Reservoir area did not originate from JPL. • Completed and signed the Interim ROD for OU1 in February. • Finalized the Remedial Design/Remedial Action (RD/RA) Work Plan for the OU1 Source Area Treatment System Expansion in February. • Completed Remedial Action Report in March 2007, documenting completion of cleanup activities at OU2. • Completed and signed the Interim ROD for OU3 in August. • Completed construction activities associated with OU1 Source Area Treatment System Expansion in October.
2008	• Submitted responses to all comments received on the additional investigation Technical Memorandum, including comments from the U.S. EPA, DTSC, and PWP. NASA again concluded that the perchlorate in the Sunset Reservoir are did not originate from JPL.
2009	• Finalized the OU1 Source Area Treatment System Installation Report in January. • Completed RD/RA Work Plan for OU3 MHTS in June. • Initiated construction of the MHTS.
2010	• Continued construction of the MHTS.
2011	• Post-construction completion phase begins for OU3 in July (i.e., system operation and maintenance [O&M]). • Completed MHTS Installation Report in September.
2012	• Finalized the First Five-Year Review Report in February (NASA, 2012a). • Continued O&M of the OU1 and OU3 treatment systems.
2013	• Continued O&M of the OU1 and OU3 treatment systems.

2.2 Geology and Hydrology

JPL is located immediately south of the southwestern edge of the San Gabriel Mountains (Figure 2-1). The San Gabriel Mountains, together with the San Bernardino Mountains to the east and the Santa Monica Mountains to the west, make up a major part of the east-west trending

Transverse Ranges province of California. This province is dominated by north-south compressional deformation.

The San Gabriel Mountains are primarily composed of crystalline basement rocks. These rocks range in age from Precambrian to Tertiary and include various types of diorites, granites, monzonites, and granodiorites with a complex history of intrusion and metamorphism (Dibblee, 1982). The northwest portion of the San Gabriel Valley, near JPL, is composed of about 1,500 to 2,000 feet of Cenozoic alluvial-fan deposits that unconformably overlie the crystalline basement complex exposed in the San Gabriel Mountains (Smith, 1986). These alluvial deposits typically consist of poorly sorted, coarse-grained sands and gravels, with some finer sand and silty material. Clasts within the alluvial deposits range from silt size to boulders more than three feet in diameter.

Periodic tectonic uplift of the San Gabriel Mountains has occurred during the past one to two million years. This uplift is responsible for the present topography of the area (Smith, 1986). Most of this uplift has occurred along north- to northeast-dipping reverse and thrust faults located along the south to southwest edges of the San Gabriel Mountains. This system of faults along the southern edge of the San Gabriel Mountains is the Sierra Madre Fault system. The Sierra Madre Fault system separates the San Gabriel Mountains to the north from the San Gabriel Valley to the south.

The northernmost portion of JPL consists of Gould Mesa, a flat-topped southern promontory of the San Gabriel Mountains that rises above the main part of the JPL complex. Elevation of the JPL site varies from 1,075 feet in the southern portion to 1,550 feet along the northern portion of the site at Gould Mesa. The remainder of JPL is moderately sloped and has been graded extensively throughout its development. The Arroyo Seco Creek intermittently flows through the Arroyo Seco on the eastern side of JPL. Within the Arroyo Seco, a series of surface impoundments are used as surface water collection and spreading basins for groundwater recharge.

Surface runoff on JPL is generally from north to south. There are no permanent surface water bodies within the boundaries of JPL. Surface water runoff from the mountains to the north is collected and transmitted by an underground storm-drain system through the developed southern portion of the site and is then discharged into the Arroyo Seco.

The San Gabriel Valley contains distinct groundwater basins, including the Raymond Basin, where JPL is located. The Raymond Basin is bordered on the north by the San Gabriel Mountains, on the west by the San Rafael Hills, and on the south and east by the Raymond Fault (Figure 2-1). The Raymond Basin provides an important source of potable groundwater for many communities in the area around JPL, including Pasadena, La Cañada-Flintridge, San Marino, Sierra Madre, Altadena, Alhambra, and Arcadia. The JPL CERCLA site is located in the Monk Hill Subarea of the Raymond Basin.

North of the JPL Thrust Fault, groundwater primarily occurs in joints and fractures in the bedrock. Because the bedrock is of low porosity, it is considered non-water bearing. South of the JPL Thrust Fault, groundwater occurs in alluvial deposits.

The aquifer below JPL consists of four layers that are separated by noncontiguous, low permeability silt layers (Figure 2-2). Layer 1 consists of the upper 75 to 100 feet of saturated alluvium. Layer 2 underlies Layer 1 and is about 150 to 200 feet thick. Layer 3 is about 200 to 300 feet thick and generally overlies crystalline basement rock beneath JPL. Layer 4 occurs only at the far eastern end of JPL, is about 150 feet thick, and rests on crystalline basement rocks.

Depth to groundwater at JPL ranges from 22 feet below ground surface (bgs) to 270 feet bgs. This wide range of depth to water is attributed to steep topography in the northern part of the site and to seasonal groundwater recharge. The depth to groundwater under most of the JPL complex averages approximately 200 feet.

2.3 Conceptual Site Model

This section presents the CSM, a summary of the potential sources of chemicals in groundwater and the distribution of chemicals in groundwater that will be addressed under this focused FS. Physical characteristics (e.g., geology, hydrogeology) that influence the fate and transport of chemicals were presented in Section 2.2. The CSM is used to identify potential exposure pathways, and serves as the basis for development of the remedial alternatives presented in the focused FS.

2.3.1 Historical Source Identification

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 site. 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. The RI identified 40 seepage pits (Figure 2-3), five waste pits, and four discharge points at the site that were used during historic operations (FWEC, 1999a). Some of the seepage pits received VOCs and other waste materials that are currently

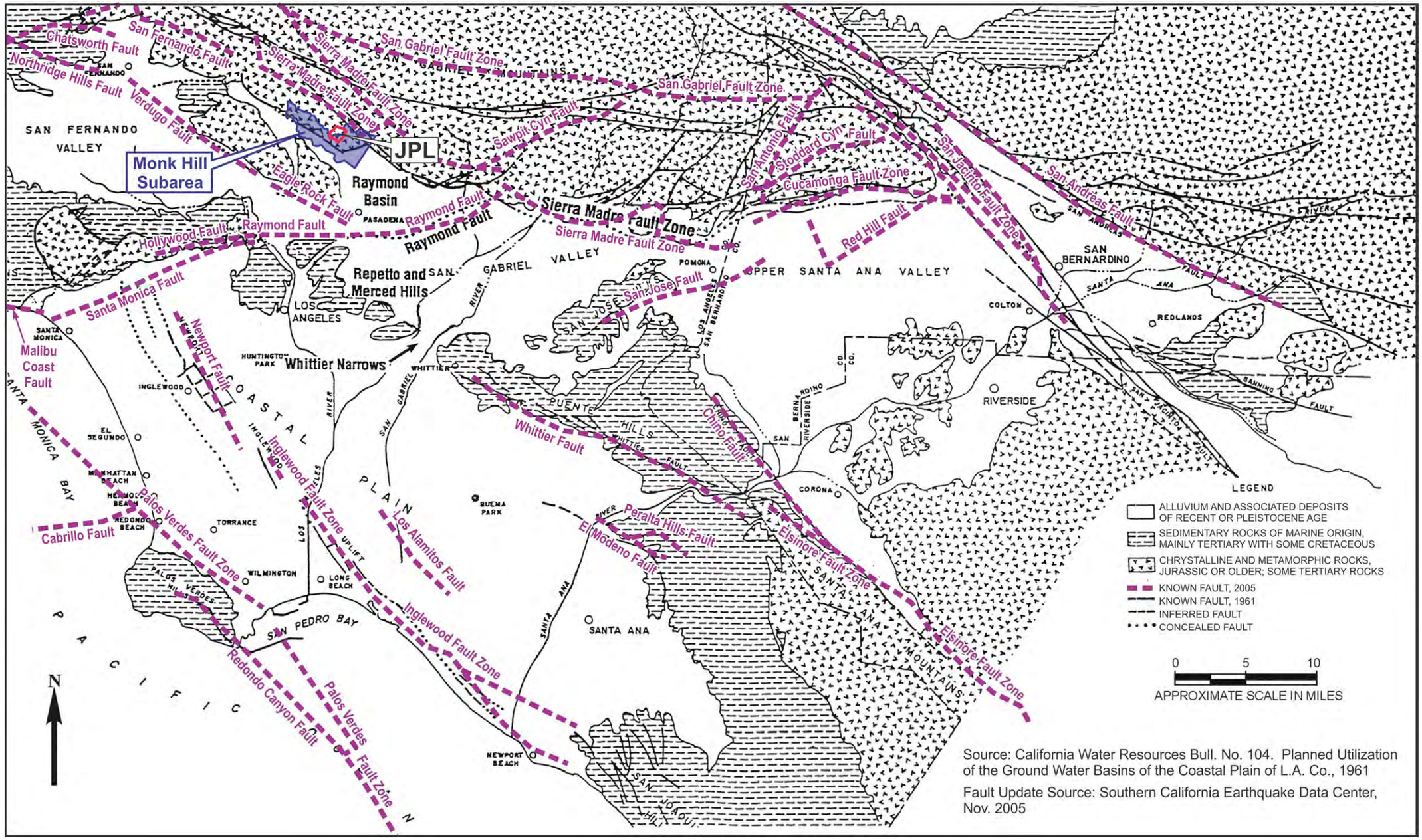


Figure 2-1. Map of Regional Geology and Physiology

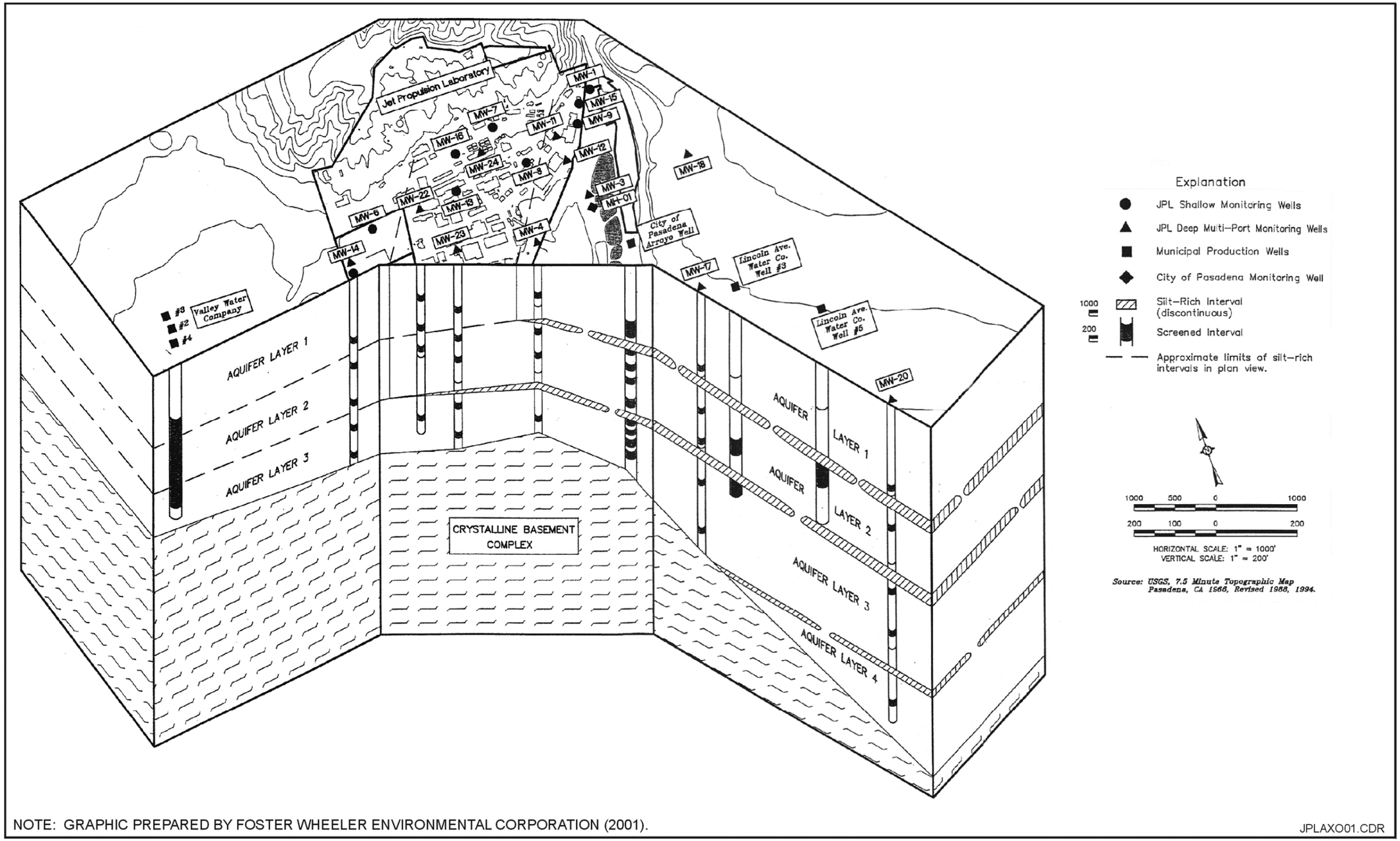


Figure 2-2. Conceptual Model of JPL Aquifer Layers

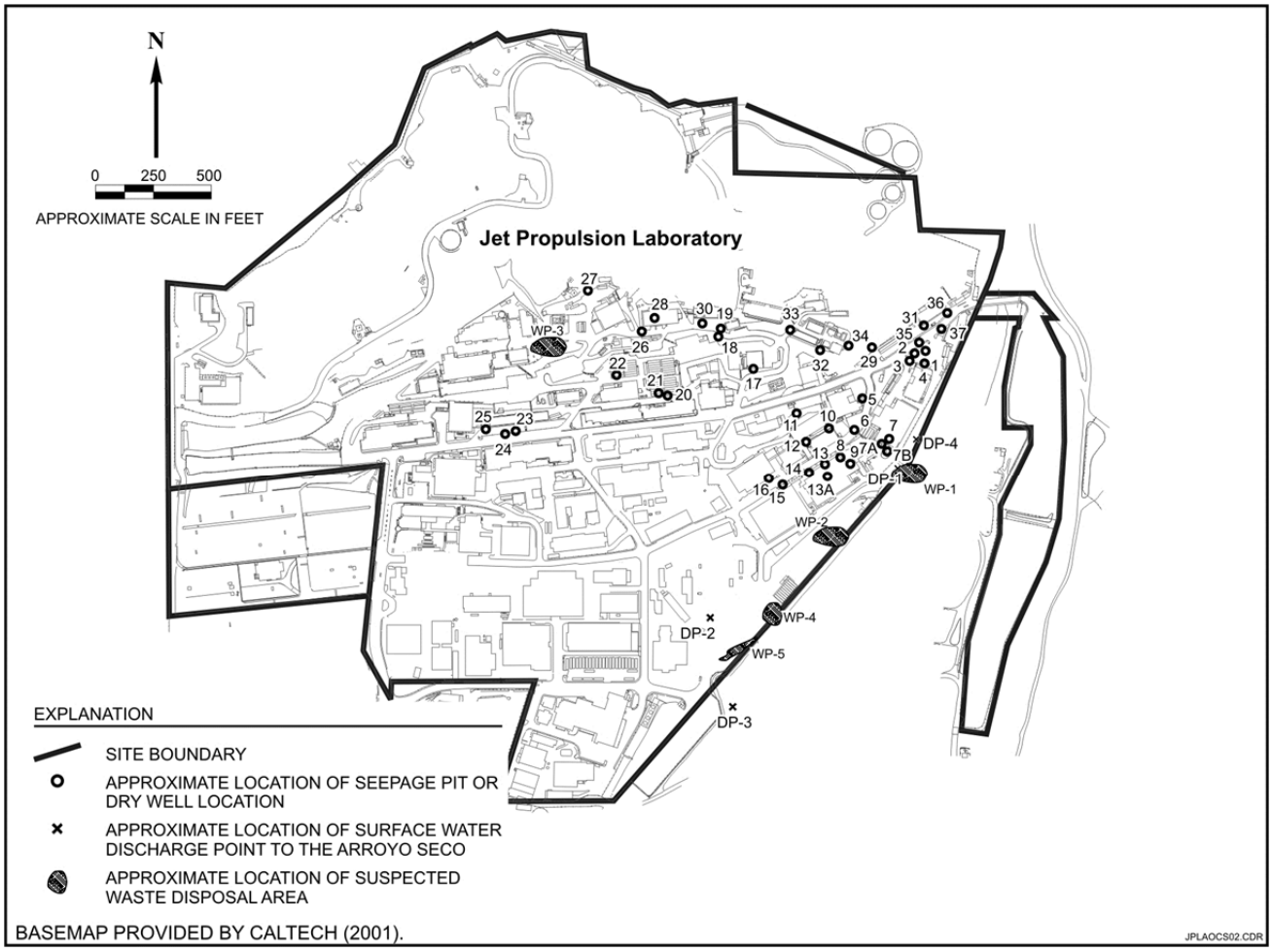


Figure 2-3. Potential Historical Chemical Waste Disposal Locations at the JPL Facility

found in groundwater beneath 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 offsite for treatment and disposal at regulated, Resource Conservation and Recovery Act (RCRA)-permitted hazardous waste facilities.

In 1980, the analyses of groundwater revealed the presence of VOCs in City of Pasadena water-supply wells located southeast of JPL in the Arroyo Seco. At about the same time, VOCs were detected in two water-supply wells used by the LAWC, located east of the Arroyo Seco (FWEC, 1999a). In 1984, increasing concentrations required that these production wells be shut down.

In 1988, a PA/SI was completed at JPL, which indicated that further site characterization was warranted (Ebasco, 1988). Subsequent site investigations were conducted at JPL (Ebasco, 1990a and 1990b) and VOCs were also detected in on-facility groundwater at levels above drinking water standards.

2.3.2 Nature and Extent of Chemicals in Groundwater

A groundwater monitoring program has been in place at JPL since August 1996 and has been expanded as the number of monitoring wells in place was also expanded. JPL monitoring wells are sampled on a quarterly basis to maintain a comprehensive understanding of the subsurface conditions within OU1 and OU3 groundwater. Figure 2-4 shows the locations of monitoring wells within the JPL monitoring well network.

Historical groundwater monitoring activities have indicated that four target chemicals (carbon tetrachloride, TCE, PCE, and perchlorate) have been detected in JPL monitoring wells at concentrations above the state and federal drinking water standards for each chemical. Carbon tetrachloride, TCE, and perchlorate continue to be consistently detected above state and federal drinking water standards. Figures 2-5 through 2-7 show the horizontal and vertical extent of perchlorate, carbon tetrachloride, and TCE, respectively, within OU1 and OU3 during the first quarter 2013 (NASA, 2013a). The perchlorate, carbon tetrachloride, and TCE plumes originating from JPL currently extend approximately one mile southeast of the source area in the north-central portion of the JPL facility.

Perchlorate has been detected in PWP production wells (Sunset, Bangham, Copelin, Garfield, and Villa; collectively referred to as the Sunset Reservoir wells), located approximately 3 to 4 miles downgradient of the JPL facility. In 2005, NASA conducted an additional investigation to determine if the occurrence of perchlorate in the Sunset Reservoir wells was associated with chemical migration from the JPL facility. The additional investigation included installation of two new monitoring wells (MW-25 and MW-26), groundwater modeling (NASA 2003), analysis of groundwater monitoring well data dating back to the early 1990s, analysis of production well water quality data dating back to 1940, and a perchlorate isotope study. Upon completion of the investigation and subsequent technical interactions with PWP and the regulators, NASA concluded that (1) the chemicals from the JPL facility are captured within the Monk Hill Subarea, and (2) the perchlorate detected at the Sunset Reservoir wells is of a different origin than that used at, and originating from, JPL (NASA, 2007d; 2008).

In 2012, PWP prepared additional technical memoranda concerning perchlorate in the Sunset Reservoir wells. NASA thoroughly evaluated these memoranda and again concluded (1) the chemicals from the JPL facility are captured within the Monk Hill Subarea, and (2) the perchlorate detected at the Sunset Reservoir wells is of a different origin than that used at, and originating from, JPL (NASA, 2012b).

The Sunset Reservoir wells were discussed at the April 30, 2013 RPM meeting (NASA, 2013b). Additional meetings and technical discussions were conducted by PWP, U.S. EPA, DTSC, and RWQCB representatives regarding perchlorate in the Sunset Reservoir wells. U.S. EPA issued a letter on November 19, 2013 to Ms. Phyllis Currie, PWP General Manager (U.S. EPA, 2013), which stated that U.S. EPA, DTSC, and RWQCB agreed that based on currently available information, the Sunset Reservoir well area is not part of the NASA JPL CERCLA site. The path forward for the Sunset Reservoir wells consists of continued monitoring of groundwater between the JPL site and the Sunset Reservoir wells. Data from this monitoring will be evaluated, at a minimum, as part of the CERCLA Five-Year Reviews for JPL.

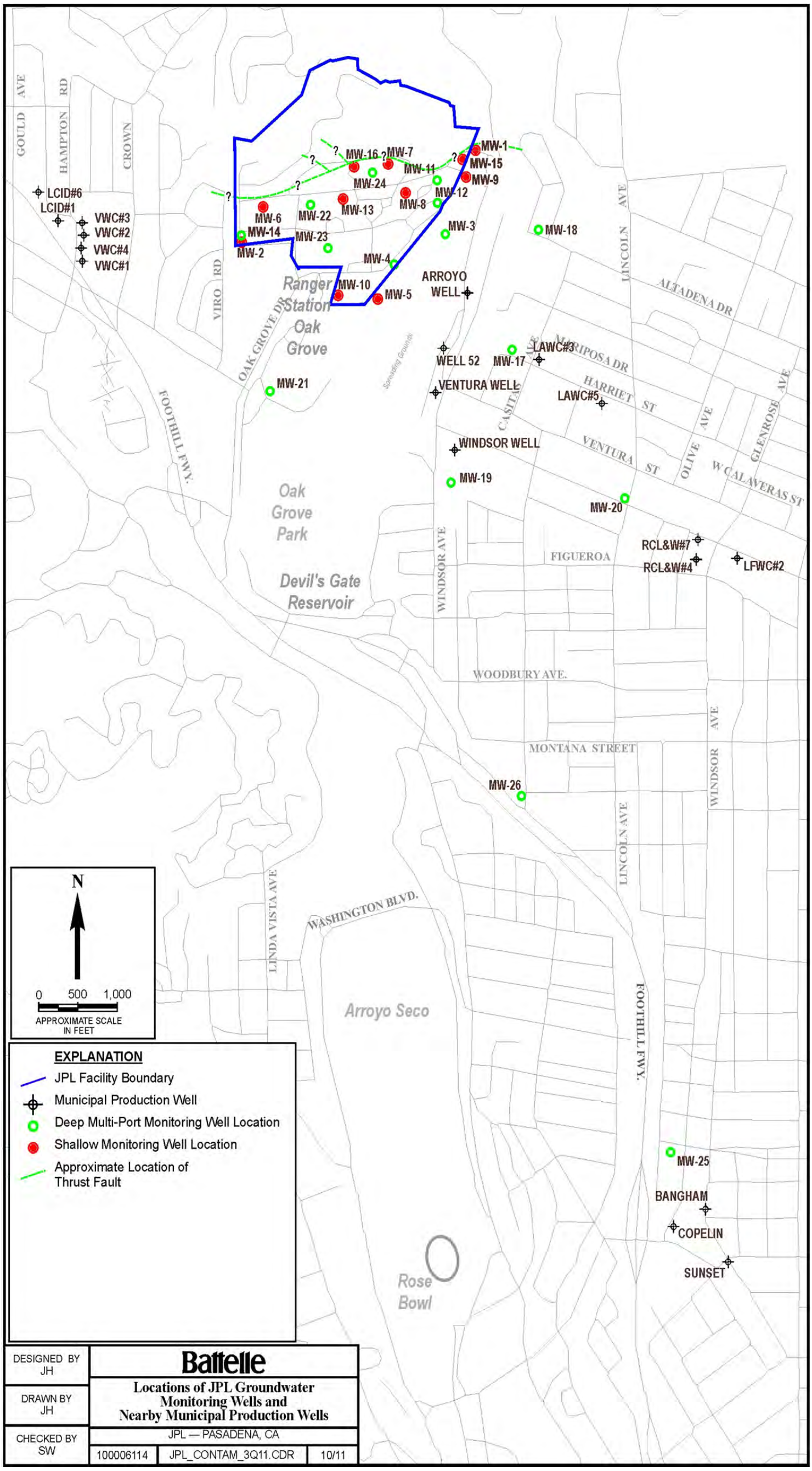


Figure 2-4. Location of JPL Groundwater Monitoring Wells and Nearby Municipal Production Wells

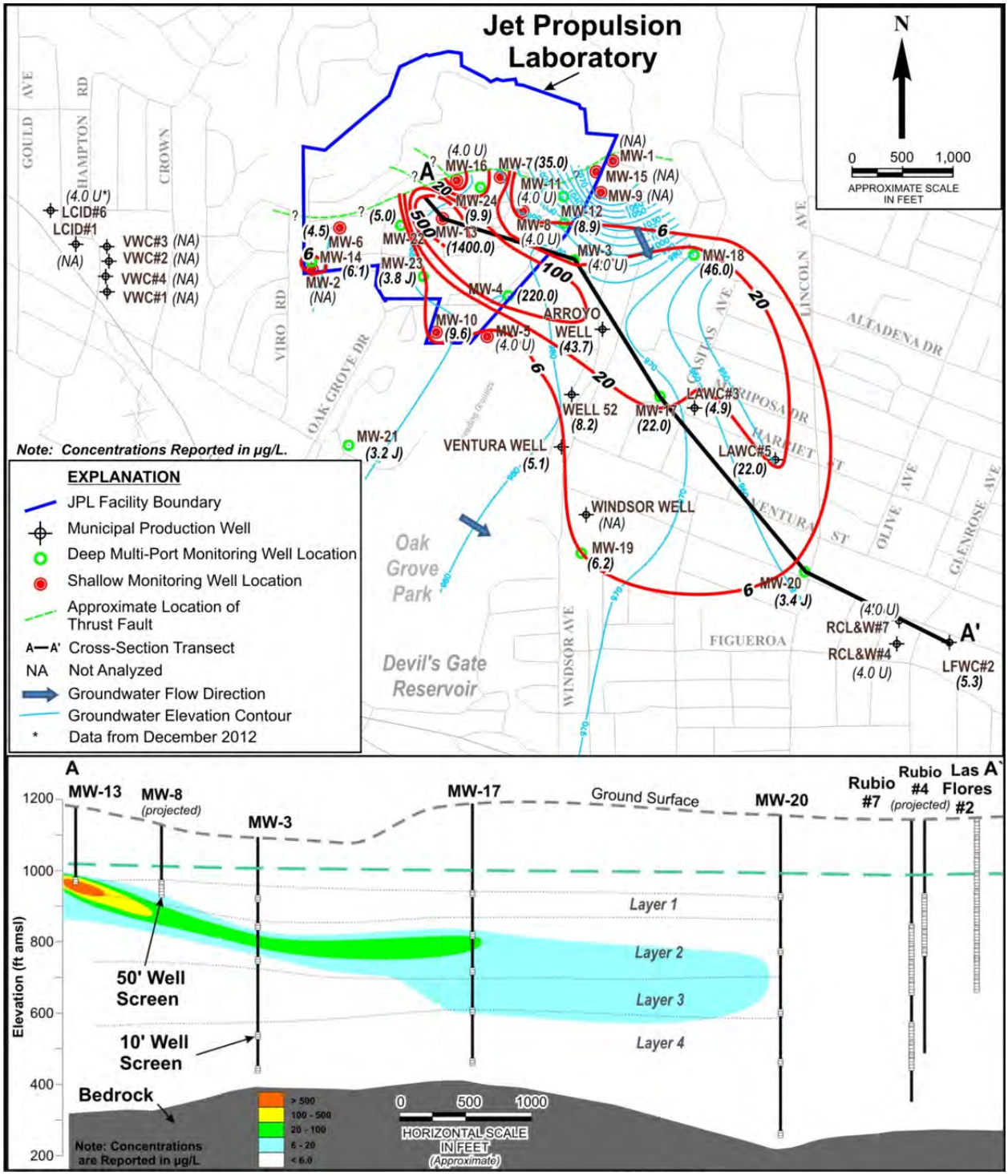


Figure 2-5. Horizontal and Vertical Extent of Perchlorate in Groundwater, January/February 2013

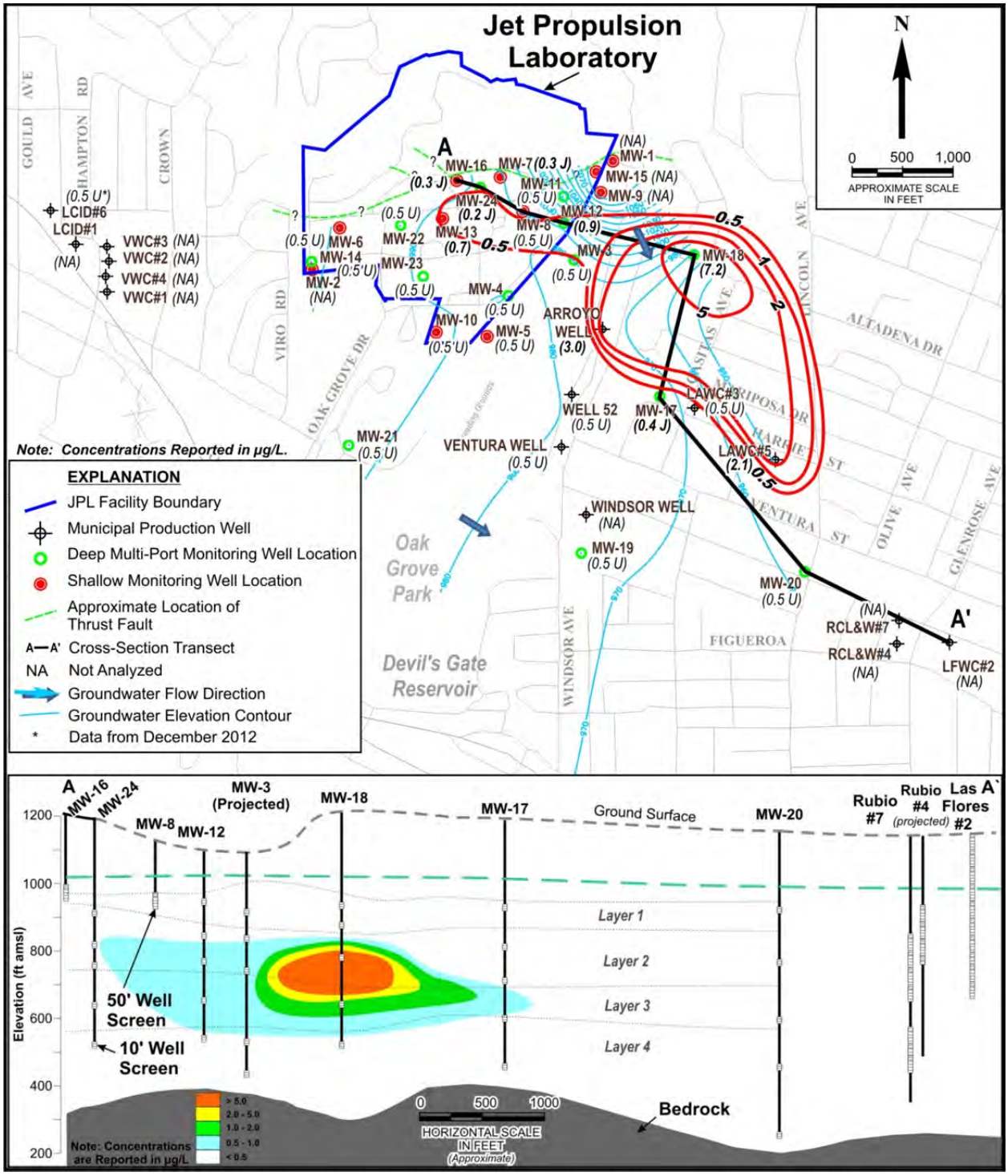


Figure 2-6. Horizontal and Vertical Extent of Carbon Tetrachloride in Groundwater, January/February 2013

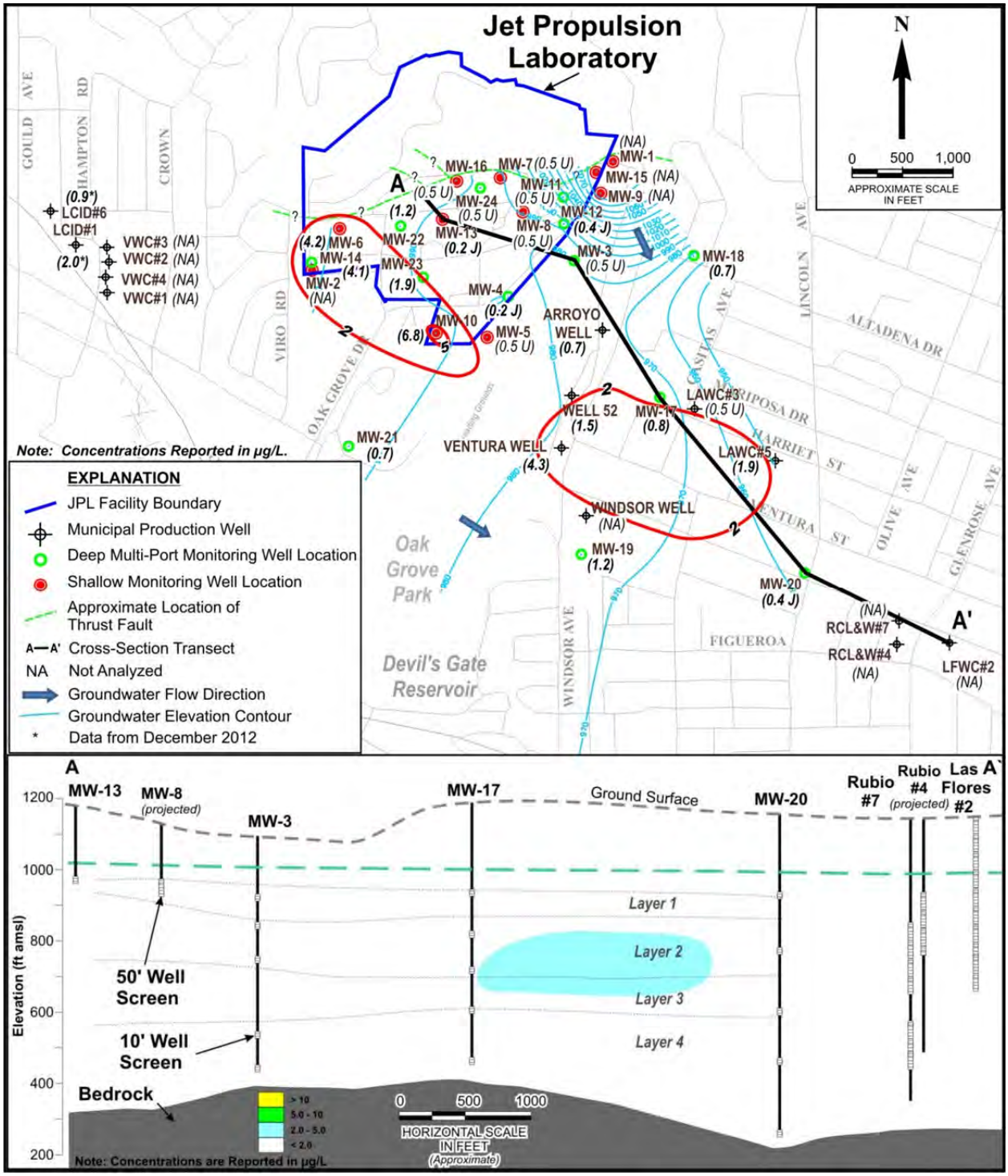


Figure 2-7. Horizontal and Vertical Extent of TCE in Groundwater, January/February 2013

2.3.3 Fate and Transport

The fate and transport characteristics and the potential for downgradient migration of chemicals in groundwater were described in detail in the JPL OU1/OU3 RI (FWEC, 1999a). Perchlorate and VOCs originating from JPL are contained within the Monk Hill Subarea of the Raymond Basin by the drinking water production wells that are associated with the OU3 treatment systems (i.e., MHTS and LAWC treatment system). The next set of downgradient production wells is owned by Rubio Cañon Land and Water (RCL&W) Association. Perchlorate levels in weekly samples collected from RCL&W#4 and RCL&W#7 (see Figure 2-4) have been well below the state MCL for perchlorate.

2.3.4 Receptors and Exposure Pathways

The groundwater at the JPL facility is not extracted for distribution within the facility and on-site workers at the facility do not have access to untreated water from the site. In addition, vapor intrusion from groundwater at OU1 is not considered a complete exposure pathway given the depth of groundwater at the site, which averages approximately 200 feet bgs. Removal of VOCs in the vadose zone (OU2) was completed in 2007 (NASA, 2007a). No direct exposure pathways to OU1 groundwater exist for the human or ecological receptors, and exposure would require the OU1 source area treatment system to malfunction in some way to release untreated groundwater. However, redundancies that are built into the treatment system and continuous monitoring make this exposure pathway highly unlikely.

In addition, it is highly unlikely that residents living in the areas overlying OU3 will come in contact with untreated groundwater because the chemicals are located in groundwater that is more than 200 feet bgs and does not recharge surface water bodies. Groundwater pumped from nearby water production wells must meet strict state and federal water quality standards prior to distribution to consumers. Treatment facilities to remove perchlorate and VOCs are in place via the MHTS and LAWC treatment systems for Pasadena and LAWC production wells. Therefore, no direct exposure pathways to OU3 groundwater exist for the human or ecological receptors. The only possible exposure pathway would be if a water treatment system malfunctioned. However, redundancies that are built into the treatment systems and continuous monitoring make this exposure pathway highly unlikely.

The ecological scoping assessment conducted as part of the OU1/OU3 RI (FWEC, 1999a) concluded that no groundwater exposure pathways to plants and animals are possible at OU1 or OU3. Therefore, no further characterization of ecological risks to plants and animals due to groundwater impact was warranted.

2.4 Current Status of Interim Remedies

This section presents a brief summary of the current OU1 and OU3 Interim Remedies, and provides a summary of the current operations.

2.4.1 OU1 Source Area Treatment System

The OU1 source area treatment system addresses groundwater beneath the JPL facility which has historically contained the highest concentrations of perchlorate and VOCs (i.e., the source area). The system consists of three groundwater extraction wells (EWs), ex situ treatment using LGAC and FBR, and reinjection of treated groundwater, with a maximum treatment capacity of 300 gallons per minute (gpm).

Since system startup in early 2005, the OU1 treatment system has successfully treated more than 2,600 acre feet of groundwater, removing approximately 1,700 pounds of perchlorate and 40 pounds of VOCs. Influent perchlorate concentrations at the OU1 system have decreased significantly, from approximately 2,300 µg/L in February 2005 to approximately 45 µg/L in February 2013 (see Figure 2-8). Concentrations of perchlorate and VOCs at the effluent of the OU1 system (i.e., treated water) are consistently non-detect. In addition, operation of the source area treatment system appears to have resulted in a significant reduction of chemicals of concern in wells MW-7, MW-16 and MW-24, which are located within the treatment zone (NASA, 2013c). Semi-annual progress reports are prepared as part of the JPL CERCLA program to document system operations and performance.

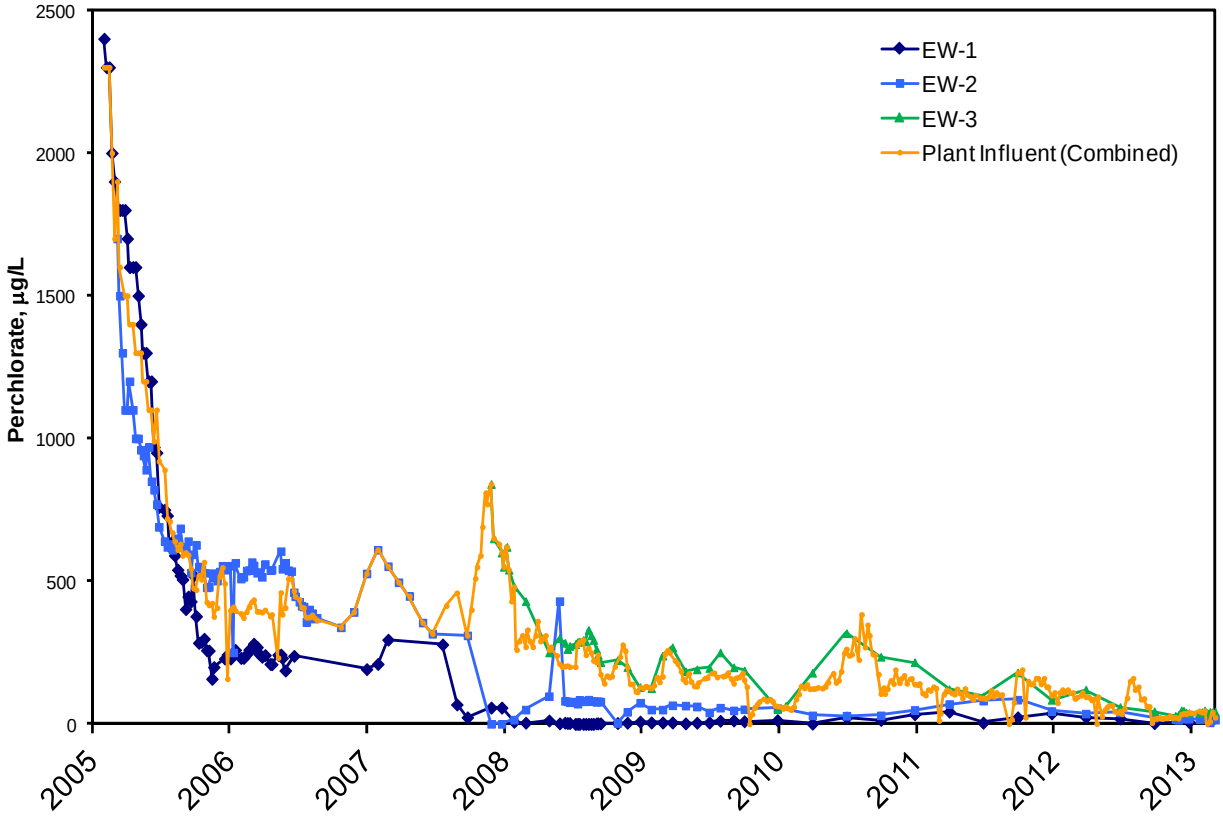


Figure 2-8. Influent Perchlorate Concentrations at the OU1 Source Area Treatment System

2.4.2 OU3 MHTS and LAWC Treatment System

The OU3 off-facility treatment interim remedy consists of groundwater extraction, ex situ treatment using LGAC and ion exchange at two separate treatment systems: 1) MHTS and 2) LAWC treatment system. The treated groundwater is used as a drinking water source for the PWP and LAWC customers.

Since system startup in July 2004, the 2,000 gpm LAWC treatment facility has successfully treated over 17,000 acre feet of groundwater, removing approximately 896 lb of perchlorate and 200 lb of VOCs. Annual progress reports are prepared as part of the JPL CERCLA program to document system operations and performance (NASA, 2013d).

The MHTS began operations in July 2011 and has successfully treated approximately 6,700 acre feet of groundwater, removing approximately 600 lb of perchlorate and 52 lb of VOCs. MHTS has a 7,000 gpm treatment capacity, although the actual treatment rate is dependent on demand. Annual progress reports are prepared as part of the JPL CERCLA program to document system operations and performance (NASA, 2013e).

During the design and permitting of the MHTS and LAWC system, there was some concern that low levels of 1,2,3-trichloropropane and 1,4-dioxane may be present in the raw water due to detections in MW-18 (Screen 4). As part of the drinking water permits for the two systems, periodic monitoring of the raw water for these compounds is required by CDPH. To date, all samples collected at Arroyo Well, Well 52, Ventura Well, LAWC#3, and LAWC#5 have been non-detect for 1,2,3-trichloropropane (i.e., <0.005 µg/L) and 1,4-dioxane (i.e., <1 µg/L). Windsor Well has not yet been used during system operation due to elevated nitrate levels, so samples have not been collected. Periodic monitoring will continue as part of system operations.

3.0 REMEDIAL ACTION OBJECTIVES

3.1 Chemicals of Concern

A human health risk assessment was completed for OU1 to evaluate the potential risks to human health associated with hypothetical exposure to chemicals in untreated groundwater beneath the JPL facility. It is important to note that a direct pathway for exposure to groundwater at OU1 does not exist. Groundwater is in a deep aquifer and does not recharge surface water bodies within the area of concern. Further, the impacted groundwater is treated and reinjected. Nevertheless, a hypothetical residential use scenario was evaluated during the RI (FWEC, 1999a). Using hypothetical conditions and assumptions, several VOCs and perchlorate were identified as contributing to non-cancer and cancer risks associated with this hypothetical exposure pathway, with carbon tetrachloride and perchlorate identified as the predominant chemicals contributing to risks (FWEC, 1999a). Carbon tetrachloride, TCE, and perchlorate were consistently detected above the state and federal drinking water levels during site investigations and were all targeted for treatment in the source area at OU1 (NASA, 2006a).

The Monk Hill subarea is located within the Raymond Basin and is a source of potable groundwater for several communities in the area (Pasadena, La Cañada-Flintridge, and Altadena) (FWEC, 2000). These communities are expected to grow at a modest rate for the foreseeable future and the demand for groundwater as drinking water is expected to continue. The off-facility groundwater in OU3 contains elevated levels of VOCs and perchlorate, which requires treatment prior to drinking water use by the local community. Results presented in the OU1/OU3 RI (FWEC, 1999a) and as part of the groundwater monitoring program indicate that carbon tetrachloride, perchlorate, and TCE are present in groundwater beneath the Arroyo Seco and within the capture zones of the MHTS and LAWC treatment system production wells at concentrations exceeding state and federal drinking water standards. The chemicals of concern in OU1 and OU3 are carbon tetrachloride, TCE, and perchlorate.

3.2 Remedial Action Objectives

RAOs guide the development and assessment of remedial alternatives in an FS. Therefore, RAOs were developed as part of this focused FS to evaluate remedial alternatives to address chemicals in groundwater at both OU1 and OU3.

There is not a complete exposure pathway for groundwater at OU1 and OU3. In OU1, groundwater is present in a deep aquifer, does not recharge surface water bodies, and is not used as a source of drinking water within the area of concern. Even so, treatment of the source area has been targeted to prevent migration of dissolved chemicals to OU3 at concentrations that would negatively impact drinking water production. As discussed in Sections 1 and 2, the OU1 system is in place and operating effectively (NASA, 2012a; 2013c).

OU3 groundwater is a current source of drinking water for the City of Pasadena and Altadena communities. There is not a complete exposure pathway for OU3 groundwater because groundwater is being treated prior to use. NASA has funded two treatment systems, the MHTS

and the LAWC treatment system, to restore use of the groundwater as a source of drinking water and to contain the chemical plumes. These two OU3 systems are in place and operating effectively (NASA, 2012a; 2013d; 2013e).

Based on this information, the following RAOs have been identified for OU1 and OU3 groundwater:

1. *Protect human health and the environment by preventing exposure to VOCs (carbon tetrachloride and TCE) and perchlorate in groundwater originating from JPL.*
2. *Restore unrestricted beneficial use of groundwater containing VOCs and perchlorate originating from JPL.*
3. *Prevent further migration of carbon tetrachloride, TCE, and perchlorate beyond the current extent.*

The current extent of carbon tetrachloride, TCE, and perchlorate, and the boundary of OU3 are shown in Figure 3-1.

3.3 Remediation Goals

Because the groundwater is used as a source of drinking water, State and federal MCLs are identified as the RGs (see Section 3.4.1 below). The MCLs for the primary chemicals of concern are as follows:

- Carbon tetrachloride: 0.5 μg/L
- TCE: 5.0 μg/L
- Perchlorate: 6.0 μg/L

This focused FS identifies and evaluates remedial alternatives that will address groundwater at OU1 and OU3 with chemical concentrations greater than these RGs. Figure 3-1 shows the boundary of the chemical plume originating from JPL exceeding the RGs and depicts the capture zone of the MHTS and LAWC treatment systems.

3.4 Applicable or Relevant and Appropriate Requirements (ARARs)

This section summarizes the evaluation and identification of ARARs for OU1 and OU3, and sets forth the regulatory requirements for the remedial alternatives that are analyzed in detail in this focused FS report (see Section 6).

Section 121(d) of CERCLA (42 U.S.C. Section [§] 9621[d]), as amended, states that remedial actions on CERCLA sites must attain (or the decision document must justify the waiver of) any federal or more stringent state environmental standards, requirements, criteria or limitations that are determined to be legally applicable or relevant and appropriate. ARARs are identified on a site-specific basis for remedial actions where CERCLA authority is the basis for cleanup.

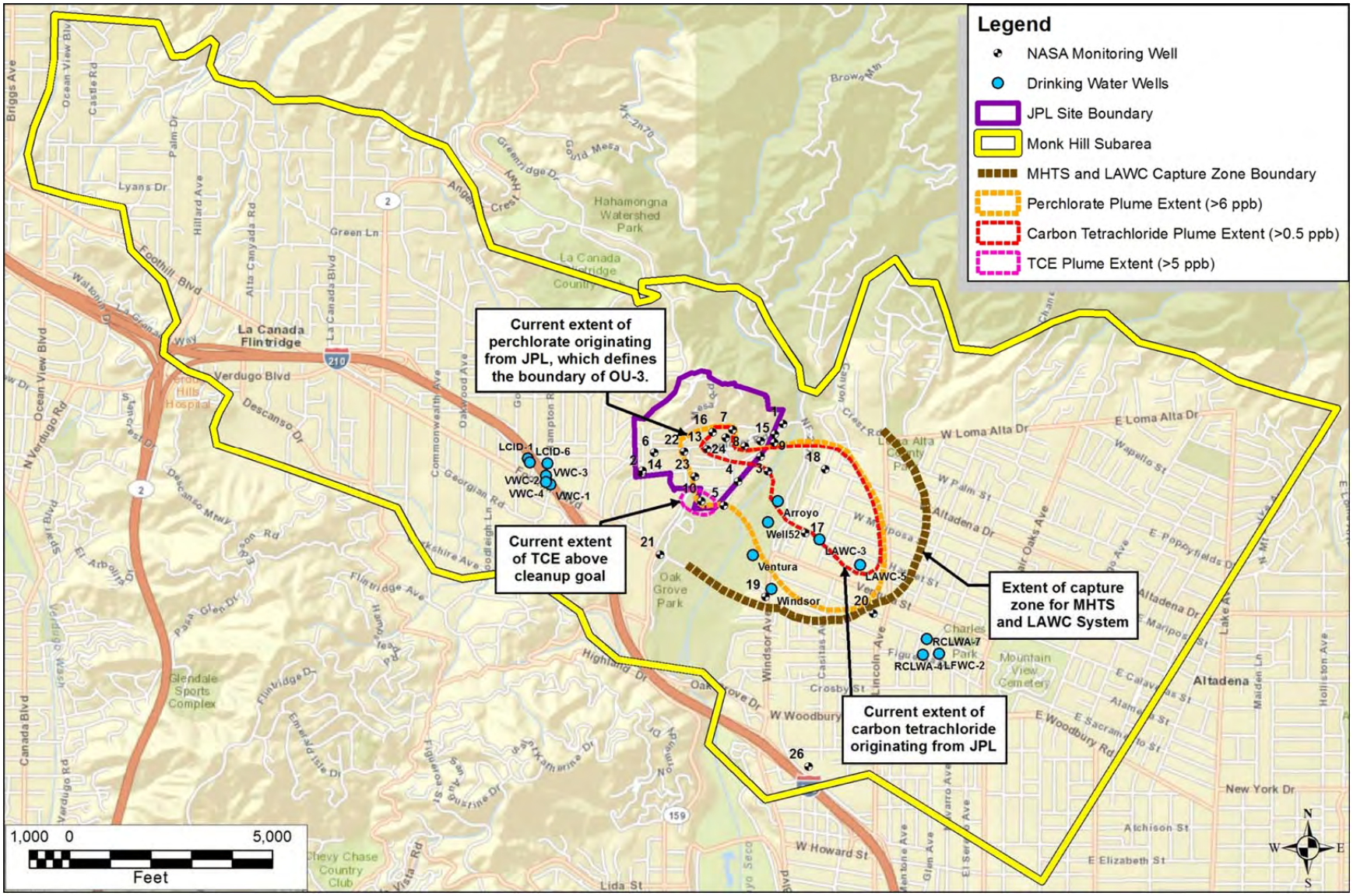


Figure 3-1. Boundary of the Chemical Plume Originating from JPL Exceeding the RGs, which Defines the Boundary of OU3

Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address circumstances at a CERCLA site. An applicable federal requirement is an ARAR. A state requirement is applicable only if it is more stringent than federal ARARs.

If the requirement is not legally applicable, then the requirement is evaluated to determine whether it is relevant and appropriate. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not applicable, address problems or situations similar to the circumstances of the proposed response action and are well suited to the conditions of the site (U.S. EPA, 1988). A requirement that is not legally applicable must be determined to be both relevant *and* appropriate to be considered an ARAR.

Pursuant to U.S. EPA guidance (U.S. EPA, 1988), ARARs are generally divided into three categories, namely chemical-, location-, and action-specific. This classification was developed to aid in the identification of ARARs. However, some ARARs do not fall precisely into one group or another and may instead be identified in multiple categories.

As the lead federal agency, NASA has primary responsibility for identifying federal ARARs at OU1 and OU3. Federal and state action-specific and location-specific ARARs were previously identified during development of the Interim RODs for OU1 and OU3, and have been determined to still apply. In accordance with U.S. EPA guidance, interim actions do not need to comply with chemical-specific ARARs that will be addressed by the final remedy. Therefore, chemical-specific ARARs are identified as part of this focused FS for a final remedy. A discussion of all ARARs that have been identified for OU1 and OU3 is presented in this section.

3.4.1 Chemical-Specific ARARs

Chemical-specific ARARs are generally health- or risk-based numerical values applied to site-specific conditions that result in the establishment of a cleanup level. The following chemical-specific ARARs were identified for OU1 and OU3.

Federal Safe Drinking Water Act (SDWA) and Federal MCLs. Federal MCLs developed by U.S. EPA under the 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 "applicable" for the treated effluent water from the MHTS and LAWC treatment systems currently operating at OU3. However, MCLs are not "applicable" ARARs for groundwater at NASA sites, but rather MCLs are generally considered relevant and appropriate as RGs for current or potential drinking water sources. Therefore, MCLs are potential chemical-specific federal ARARs for the final groundwater remedial action at OU1 and OU3.

California SDWA and State MCLs. California has established standards that apply to sources of public drinking water, under the California SDWA of 1976 (H&SC Section 4010.1 and 4026[c]) and state MCLs for organic and inorganic chemicals set forth in California Code of Regulations (CCR), Title 22, Section 64444. Some state MCLs are more stringent than the

corresponding federal MCLs, as is the case with carbon tetrachloride and perchlorate. In these instances, the more stringent state MCLs are applicable. NASA has determined that the substantive provisions of the standards in CCR Title 22, Section 64444 are relevant and appropriate because VOCs and perchlorate must be removed from drinking water to meet the requirements of the California SDWA.

3.4.2 Location-Specific ARARs

Potential location-specific ARARs are based on various attributes of the site location, for example the presence of cultural or biological resources at a site. There are no location-specific federal or state ARARs associated with the potential remedies under CERCLA. However, some local and legal requirements associated with potential remedial alternatives were identified given the location of the OU3 groundwater treatment plants in the City of Pasadena, the County of Los Angeles, and the Raymond Basin.

Local Permit Requirements. The Windsor Reservoir site is located within the city limits of Pasadena, and as part of the MHTS construction, the City of Pasadena was required to obtain local permits prior to constructing the new treatment facility. These included a Conditional Use Permit and a Building Permit. LAWC also complied with the construction permitting requirements of the County of Los Angeles when it built its treatment plant in 2004. Any modifications to these existing systems would have to comply with local permit requirements.

Adjudicated Groundwater Rights. 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 landowners and other parties allowing the courts to settle disputes over how much groundwater can rightfully be extracted. In an adjudicated groundwater basin, the court appoints a Watermaster to administer the court judgment and determine an equitable distribution of water that will be available for extraction each year. 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, including the City of Pasadena and LAWC, operate wells in the Monk Hill Subarea. The City of Pasadena and LAWC will continue to be subject to the extraction, reporting, and monitoring requirements associated with the Raymond Basin Judgment.

NASA has worked closely with RBMB, PWP, and LAWC to ensure that treated groundwater is used in the most beneficial manner. For the MHTS and LAWC system, treated groundwater is used for drinking water supply and quantities are reported to the RBMB in accordance with the adjudication. All wastewater generated by the OU3 systems is treated as required to meet surface water discharge requirements and discharged to the Arroyo Seco where it infiltrates back into the aquifer.

While NASA is not a party to the adjudication, NASA has worked closely with the RBMB, designing/installing treatment equipment to minimize the amount of wastewater. In fact, since 2005 NASA has reinjected 99.9% (2,853 extracted and 2,850 ac-ft reinjected) of the treated groundwater, and the small quantity of wastewater that is generated is reported to the RBMB on a monthly basis.

3.4.3 Action-Specific ARARs

This focused FS evaluated potential remedial alternatives to address chemicals in groundwater at OU1 and OU3. General descriptions of the remedial alternatives are presented in Section 5, and detailed descriptions and comparative analysis of the remedial alternatives are presented in Section 6. Action-specific ARARs have been identified for technologies included in the alternatives that are evaluated in detail in this FS:

- OU1: groundwater extraction, ex situ treatment using LGAC and FBR, and reinjection of treated groundwater.
- OU3: groundwater extraction, ex situ treatment using LGAC and ion exchange, and use of treated groundwater as a drinking water source for the City of Pasadena and LAWC customers.

Potential federal and state action-specific ARARs for OU1 and OU3 are described below.

RCRA Hazardous Waste Identification Criteria. These criteria are promulgated by the federal government to define RCRA hazardous waste. A RCRA hazardous waste is a waste that appears on one of the four hazardous wastes lists (F-list, K-list, P-list, or U-list), or exhibits at least one of four hazardous waste characteristics − ignitability, corrosivity, reactivity, or toxicity. Hazardous waste is regulated under RCRA Subtitle C. This requirement may apply to the disposal of ion exchange, LGAC media, and other process waste from ex situ treatment operations at OU1 and/or OU3. The spent media would be characterized in accordance with RCRA and disposed of accordingly.

Non-RCRA (California) Hazardous Waste Identification Criteria. These criteria are promulgated by the State of California to define non-RCRA (California) hazardous waste. A non-RCRA (California) hazardous waste can be identified as a listed waste, or as a waste that exhibits hazardous characteristics − ignitability, corrosivity, reactivity, and toxicity. This requirement may apply to the disposal of ion exchange, LGAC media, and other process waste from ex situ treatment operations at OU1 and/or OU3. The spent media would be characterized in accordance with California hazardous waste requirements and disposed of accordingly.

RCRA Underground Injection Control. Section 3020 of RCRA applies to the underground injection in the context of RCRA and CERCLA cleanups, such as that included as part of a potential remedial alternative for OU1. 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 an exemption from that 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 a 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.

The second point above means that 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 proposed remedial alternatives would be conducted pursuant to CERCLA, and groundwater treated prior to reinjection under remedial alternatives that include these activities. Based on this, activities at OU1 would be exempt from the RCRA underground injection control ban.

RCRA Land Disposal Restrictions. The applicability of RCRA land disposal restrictions (LDRs) to groundwater reinjection performed during a RCRA corrective action or CERCLA response action is also a consideration (RCRA Sections 3004(f), (g), and (m), and 40 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 a U.S. EPA memorandum titled "Applicability of Land Disposal Restrictions to RCRA and CERCLA Ground Water Treatment Reinjection" (U.S. EPA, 1989). This memorandum explains that even though the LDR provisions address the same activity as RCRA Section 3020, U.S. EPA interprets the provisions of RCRA Section 3020 to be applicable instead of LDR provisions.

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. U.S. 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. Therefore, promulgated drinking water standards should be used where available.

RWQCB General Waste Discharge Requirements. General waste discharge requirements (WDRs) associated with any 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 (RWQB, 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 shall not adversely impact the receiving groundwater in terms of water quality and chemical concentrations at a "compliance point, downgradient and outside the application area." The potential application

area for this ARAR at JPL is the same as the OU1 source zone (i.e., the 8-acre by 100-ft thick portion of the aquifer containing elevated levels of VOCs and perchlorate). Impacts to the water quality and chemical concentrations of the receiving groundwater would be evaluated as part of NASA's groundwater monitoring program at JPL based on analytical results from samples collected from monitoring wells located inside the application area (i.e., source area), wells located outside the source area but still within the plume of target chemicals, and wells located outside the current plume of target chemicals. Groundwater would be treated prior to reinjection to reduce concentrations of target chemicals. The electron donor used as part of the ex situ treatment would 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). Therefore, remedial alternatives in this focused FS with groundwater extraction, treatment, and reinjection will comply with the substantive requirements associated with groundwater reinjection in the general WDRs and State Water Resources Control Board Resolution 68-16.

California Department of Public Health (CDPH) Policy Memo 97-005. *Policy Memo 97-005: Policy Guidance for Direct Domestic Use of Extremely Impaired Sources* provides guidance by which CDPH would evaluate proposals, establish appropriate permit conditions, and approve the use of a source for any direct potable use within a CERCLA OU. According to CDPH policy, drinking water downgradient of the JPL facility is considered an "extremely impaired source" because it meets the following criteria as quoted in the policy: (1) a chemical exceeds three times its associated MCL or notification level (NL) based on acute health effects, and (2) the drinking water is considered threatened due to the proximity to known chemicals in the groundwater from the JPL facility. CDPH guidance is applicable to the City of Pasadena and LAWC as part of purveying drinking water. This policy requires additional documentation from the drinking water purveyor prior to restoring use of the drinking water supply wells. CDPH Policy Memo 97-005 was addressed during design and implementation of the OU3 interim response action (Battelle, 2010).

California Environmental Quality Act. The City of Pasadena was required to perform a California Environmental Quality Act (CEQA) assessment during the design of the MHTS (as part of the OU3 interim action) to evaluate the potential impacts to the following environmental factors: aesthetics, biological resources, hazards and hazardous materials, mineral resources, public services, utilities/service systems, agricultural resources, cultural resources, hydrology/water quality, noise, recreation, air quality, geology/soils, land use/planning, population/housing, and transportation/traffic. This was completed and approved prior to construction of the MHTS to ensure that work was conducted in such a way that environmental impacts associated with the treatment plant were addressed.

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

The primary objective of the technology identification and screening phase of this focused FS is to develop an appropriate range of possible remedies suitable to address chemicals in groundwater associated with OU1 and OU3. In this section, technologies and process options are identified, described, and subjected to an initial screening analysis. NASA has performed a number of studies and pilot tests to determine the best technologies for treatment of groundwater. These studies are referenced below with respect to the evaluation of potential remedial technologies and the identification of the most appropriate technologies for OU1 and OU3.

In addition, U.S. EPA presumptive remedy guidance was used to identify remedial technologies where appropriate (U.S. EPA, 1996). Presumptive remedies are preferred technologies for common categories of sites based on historical patterns of remedy selection and U.S. EPA's scientific and engineering evaluation of performance data on technology implementation. Those technologies that are retained following the evaluation in this section are carried forward to form the remedial alternatives presented in Section 5 of this focused FS.

The screening analysis of technologies and process options is based on a subset of the NCP evaluation criteria. Specifically, the NCP criteria used for this initial screening analysis include effectiveness, implementability, and cost (U.S. EPA, 1988). These criteria are summarized below.

Effectiveness
The effectiveness of each technology or process option is evaluated based on the ability of the technology/option to meet the RAOs, potential effects to human health and the environment during the construction and implementation phase, and reliability with respect to the chemical constituents and conditions at the site.

Implementability
Implementability encompasses both the technical and administrative feasibility of implementing a technology or process option (U.S. EPA, 1988). This includes the availability of necessary equipment and labor to implement the process option as well as the ability to obtain necessary permits and approvals. It should be noted that CERCLA actions conducted on site are exempt from permits, although CERCLA actions are still undertaken in a manner consistent with the conditions of permits that would otherwise apply.

Cost
Cost plays a limited role in the screening of technologies and process options. The relative cost for each option is estimated as to whether it is low, moderate, or high. Costs are based on engineering judgment and available information associated with the respective option.

4.1 Institutional Controls

Institutional controls (ICs) are restrictive measures placed on the use of land or an area to prevent or limit exposure to hazardous substances left in place at a site, or to ensure effectiveness of a given remedy (U.S. EPA, 2010). Both OU1 and OU3 at the JPL site are located within the Raymond Basin, which is subject to adjudicated water rights. The adjudicated water rights act to restrict groundwater extraction in accordance with the safe yield determined by the Raymond Basin Adjudication. All extractions from the Basin are tracked, monitored, and reported as part of the adjudication, and installation of new wells must be coordinated with the Raymond Basin Management Board. So while adjudicated water rights are not directly associated with the JPL CERCLA site, it is noted that this control is currently in place, and as such, restricts groundwater extraction and use within the Raymond Basin.

In addition, groundwater treatment systems in California are required to obtain a drinking water permit from CDPH that ensure system owners are providing clean water to customers. LAWC and PWP, as well as RCL&W Association, have permits from CDPH for operation of their systems. New groundwater wells would trigger a permit amendment or a new permit. Therefore, CDPH drinking water permits, and the associated sampling and oversight, provide an additional control that is currently in place and restricting groundwater use with the Raymond Basin.

ICs that could be implemented specifically as part of groundwater remedies discussed in this focused FS include Memoranda of Agreement (MOAs), or other agreements, with the Raymond Basin Management Board and/or CDPH. These agreements could include commitments that require these agencies to notify NASA of any proposed new extraction wells in the Monk Hill Subarea, and that NASA, in coordination with the agencies, evaluate the impact of any proposed extraction wells within/near the capture zones on the implemented remedies at OU1 and OU3. In addition, NASA could conduct annual reviews of new well permits in the Monk Hill subarea as an additional control to evaluate and prevent potential exposure to site-related chemicals.

Effectiveness

ICs would be effective in limiting human exposure to chemicals in groundwater at OU1 and ensuring future effectiveness of remedies at OU1 and OU3. Groundwater extraction within the Monk Hill subarea is subject to the adjudicated water rights enforced by the Raymond Basin Management Board and CDPH drinking water permits. Establishing MOAs between NASA and agencies such as the Raymond Basin Management Board and CDPH would help to ensure that any future consideration for additional groundwater extraction within the Monk Hill subarea is evaluated with respect to the protectiveness of the OU1 and OU3 remedies.

Implementability

Establishment of appropriate ICs is a frequent component of CERCLA remedies. The ICs could be easily implemented upon agreement of all parties involved. Enforcement of the controls is often the greatest uncertainty in the application of ICs, but this is a manageable uncertainty by

clearly documenting all ICs and ensuring frequent communication among all parties involved to uphold the established ICs.

Cost
The cost for implementing ICs consists of administrative costs associated with establishing the MOAs and costs associated with annual reviews of well permits in the Monk Hill subarea. The cost for ICs is low compared to other remedy components.

Screening Results
ICs are generally effective, implementable, and low in cost. Furthermore, they are often critical to ensuring protectiveness of the active remedy. Therefore, ICs are retained for further analysis in this focused FS.

4.2 In Situ Treatment

In situ treatment technologies consist of treating groundwater in place (in situ) to meet RGs using physical, chemical, or biological processes. An in situ remedy, if implemented, would need to address both the VOCs and/or perchlorate known to be present within OU1 and OU3. While in situ treatment at JPL could possibly be an enhancement to the existing systems, it would not be sufficient as a stand-alone remedy. Drinking water production wells would still need aboveground treatment even if in situ treatment was performed, and the type of material injected for treatment would need to be carefully considered, approved by the CDPH, and monitored to ensure that it would not adversely impact water quality at water supply wells (due to altering the groundwater chemistry).

Chemical treatments such as in situ chemical oxidation may address VOCs, but would not treat perchlorate. While in situ chemical treatment would not be effective to address all chemicals, enhanced in situ bioremediation could potentially achieve anaerobic biodegradation of both VOCs (i.e., TCE and carbon tetrachloride) and perchlorate. The area with elevated perchlorate concentrations (i.e., greater than 100 µg/L) covers approximately 24 acres, which is too large of an area to feasibly treat entirely with injections due to the depth to groundwater, geology, and existing infrastructure. However, an in situ barrier could be attempted with a series of injection points intersecting the groundwater plume downgradient of the existing OU1 interim remedy system. The width of the plume perpendicular to groundwater flow is approximately 500 feet and the depth required for injection is approximately 200 to 500 feet bgs.

Effectiveness
A pilot study was previously conducted to evaluate the effectiveness of an in situ reactive zone for treatment of perchlorate at the JPL site (Arcadis, 2004). The pilot study evaluated the effectiveness for the application of corn syrup injections to stimulate perchlorate bioremediation in anaerobic reactive zones. The pilot study demonstrated reductions in perchlorate concentrations, with some removal of VOCs within the treatment area. However, the effectiveness of in situ treatment for treatment of perchlorate on a larger scale as an in situ barrier, such as that required for full-scale treatment, has not been demonstrated at the JPL site.

As part of the Interim ROD for OU1 (NASA, 2007b), an evaluation was conducted that determined that extraction and treatment was the best option for remediation at OU1. Considering the success of the OU1 system in reducing perchlorate concentrations (i.e., influent concentrations reduced from 2,300 µg/L in February 2005 to 45 µg/L in February 2013), it is not likely that in situ treatment would reduce the remediation timeframe or life-cycle costs of the existing OU1 and OU3 systems.

Implementability
In situ remedies for treatment of perchlorate and VOCs are not well suited to the site conditions at JPL. As mentioned previously, the area with elevated perchlorate concentrations (i.e., greater than 100 µg/L) covers approximately 24 acres at a depth of approximately 200 to 500 feet bgs. The depth and extent of the chemicals in groundwater significantly complicate implementation of any in situ remedy. Additionally, the existing structures at the JPL facility limit access to areas where in situ injections would be required and the geology/lithology at JPL is not favorable for successful implementation of in situ injections. Therefore, in situ treatment is not considered implementable or cost-effective at the JPL site.

Cost
Construction of an in situ treatment barrier, as described above, would require 50 or more injection wells to adequately cover the 500 feet wide treatment zone. Installation of each injection well would cost approximately $200,000, totaling over $10M for injection wells alone. The cost for the amendment and equipment needed to inject electron donor is estimated at $1.5M, resulting in total capital costs of over $11.5M, which does not include additional costs for long-term groundwater monitoring.

Given the success of the existing OU1 remedy, and the fact that in situ treatment would not eliminate the need for aboveground treatment in OU3, it is not likely that in situ treatment would reduce the remediation timeframe or life-cycle costs of the overall remedy that was implemented as a result of the interim ROD, which means it is not a cost-effective option.

Screening Results
Given the difficulty in implementing in situ remediation at JPL, uncertainties with successful implementation, potential water quality impacts associated with altering the groundwater chemistry, and the need to use groundwater for drinking water purposes, in situ treatment is not retained for further evaluation, either as a stand-alone remedy or as an enhancement to existing response actions.

4.3 Groundwater Extraction and Ex-Situ Treatment

4.3.1 Groundwater Extraction

Groundwater extraction is the method currently used to remediate groundwater in OU1 and OU3. Extraction can establish a hydraulic gradient to contain groundwater within a treatment area and prevent vertical and/or lateral downgradient migration of chemicals in groundwater. Groundwater extraction for hydraulic containment can be accomplished in various ways, including use of extraction wells or pumping from containment trenches, depending on the depth

of groundwater to be contained. Based on the depths of impacted groundwater at the JPL site (average depth of approximately 300 to 700 feet bgs), groundwater extraction wells would be the most effective option.

Effectiveness
Groundwater extraction is a generally effective method to modify the hydraulic gradient for controlling groundwater flow or contaminant transport. This has been proven effective at the JPL site through operation of the OU1 source area treatment system, as well as the MHTS and LAWC treatment systems at OU3.

Implementability
Groundwater extraction is readily implementable, particularly given the existing interim remedies at OU1 and OU3 are already installed and operating effectively (NASA, 2012a). Treatment and disposition of the extracted groundwater is required in conjunction with the technology option.

Cost
Overall costs are highly dependent on the timeframe required for the remedy and the associated O&M costs. Given the extent of chemicals in groundwater at OU3, it is expected that implementation of this remedial option would require an extended period of operation (potentially greater than 15 years). Remedial alternatives, including groundwater extraction, typically have a relatively high present-value cost over a typical project life.
Screening Results
Groundwater extraction is retained as a representative process option for containment of groundwater because of ease of implementation and consistency with the interim remedies currently in place. Construction of the necessary equipment and infrastructure to support this technology option is already in place at the site.

4.3.2 VOC Treatment

U.S. EPA has identified air stripping and GAC as the preferred technologies to use, referring to these as “presumptive technologies,” for aboveground treatment of groundwater containing dissolved VOCs. U.S. EPA expects these technologies to be used for removal of VOCs at “all appropriate sites.”

Air stripping is the process of forcing air through groundwater containing VOCs to remove the volatile chemicals. This causes the chemicals to volatilize from the dissolved phase into the gas phase. The off-gas from the air stripper is then collected and further treated prior to discharge to the atmosphere.

GAC is a material used to remove chemicals from groundwater. The chemicals are removed from the groundwater by adsorbing onto the GAC surface. When the GAC media is spent, it can be regenerated and reused, or disposed, depending on the type of chemicals that are being treated. GAC treatment is currently in place and working effectively as part of the existing interim remedies at OU1 and OU3 (NASA, 2012a; 2013c; 2013d; 2013e).

Effectiveness
Air stripping and GAC are presumptive technologies based on U.S. EPA guidance (U.S. EPA, 1996) that are well understood methods and have been used for many years in the treatment of dissolved VOCs from drinking water and/or municipal or industrial wastewater. In addition, GAC is currently used as part of the interim remedy at both OU1 and OU3 and has proven to be an effective treatment technology for dissolved VOCs in the extracted groundwater.

Implementability
The technologies for dissolved phase VOC treatment discussed in this section are very implementable because they are well developed technologies with several vendors available to provide the equipment. GAC is currently used as part of the OU1 and OU3 interim remedies, so implementation of this technology option would include continued use of the existing equipment and infrastructure.

Cost
Given the relatively low dissolved phase concentrations of VOCs in the extracted groundwater at OU1 and OU3, GAC treatment is more cost effective than air stripping, which requires additional treatment of the VOCs that are transferred to the vapor phase.

Screening Results
In accordance with the U.S. EPA presumptive remedy guidance (U.S. EPA, 1996), as well as information obtained from on-going interim remedy treatment, GAC is retained for further evaluation as a technology option within the remedial alternatives developed in Section 5.

4.3.3 Perchlorate Treatment

The best above-ground perchlorate treatment approach is dependent on several factors, including the perchlorate concentrations, water quality, specific site conditions, and other considerations. Treatability testing of reverse osmosis, ion exchange, and biological treatment were conducted at NASA JPL, and a literature review to identify other potential perchlorate treatment technologies for JPL were previously conducted (NASA, 2006b).

Based on the studies conducted by JPL and others, two perchlorate treatment processes have proven to be effective at JPL and other sites: FBR and ion exchange. FBR is cost-effective for relatively high concentrations of perchlorate and at locations where continuous operation can be achieved, such as the source area beneath JPL. The FBR contains carbon particles covered with a coating of bacteria that destroy perchlorate biologically. The primary advantages of this system are the destruction of perchlorate and relatively low operational cost.

Ion exchange consists of small plastic beads, or resin, in a tank. As the water passes through the tank, perchlorate attaches to the resin. After enough perchlorate attaches to the resin, the resin is removed and sent to a licensed disposal facility, and new resin is added. Ion exchange is more cost-effective at low perchlorate levels, such as those found at OU3, and it is more appropriate for operations where the flow rate is varied. Drinking water treatment systems require varied flow rates to match potable water demand.

Effectiveness
As part of the ongoing interim remedial action, FBR has been proven to effectively treat the higher perchlorate concentrations present in the source area (OU1) groundwater. In addition, this technology destroys perchlorate through biological degradation, rather than transferring it to another media.

Ion exchange has been demonstrated to be an effective technology for treatment of low perchlorate concentrations in groundwater at OU3.

Implementability
An FBR is currently operating as part of the OU1 interim remedy, and ion exchange is being used as part of the OU3 interim remedy. Ion exchange has been used extensively by drinking water systems in California to remove perchlorate; therefore, it is the most implementable option for ex situ groundwater treatment at OU3 because other potential alternatives would require extensive testing prior to approval for use in drinking water systems. FBR at OU1 and ion exchange at OU3 are both very implementable options, as implementation of these technology options would include continued use of the existing equipment and infrastructure.

Cost
Typically FBR is a more cost-effective treatment technology for treating higher concentrations of perchlorate, and ion exchange is more cost-effective for treating lower concentrations of perchlorate in groundwater. This has proven to be true at the JPL site based on data that have been collected as part of the interim remedies for OU1 and OU3.

Screening Results
Based on the above evaluation, FBR and ion exchange are retained for further evaluation as a technology option within the remedial alternatives developed for OU1 and OU3, respectively, in Section 5.

5.0 DEVELOPMENT AND DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

In this section, remedial alternatives are developed by assembling various technologies and process options retained from Section 4.0 to address the project-specific RAOs and achieve RGs while considering site-specific conditions. Under typical FS procedures, the list of alternatives is then screened using the effectiveness, implementability, and cost criteria. However, interim remedies are currently operational at both OU1 and OU3, and results of the recent CERCLA five-year review concluded that both remedies are operating effectively and are protective of human health and the environment (NASA, 2012a). Based on this information, a limited number of alternatives are evaluated in this focused FS. Due to the limited number of alternatives, the alternative screening process has been omitted from the evaluation process and all alternatives are included for full evaluation against seven of U.S. EPA's nine evaluation criteria.

The first two evaluation criteria, overall protection of human health and the environment and compliance with ARARs, are threshold criteria. CERCLA and the NCP require that a remedial action must protect human health and the environment and comply with ARARs unless justification to waive a particular ARAR is documented in the ROD. An alternative that does not meet these threshold criteria is not considered a viable remedy. The next five criteria, long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost; are considered balancing criteria. Balancing criteria are the primary means by which alternatives that meet the threshold criteria are differentiated and compared. The final two criteria, community acceptance and regulatory agency acceptance, are considered modifying criteria, which are essentially the final test in determining that the community and regulators find a remedial alternative acceptable. These are addressed during the Proposed Plan and documented in the ROD.

The evaluation criteria are described in more detail below.

Overall Protection of Human Health and the Environment

Overall protection of human health and the environment is a threshold criterion, in that a remedial alternative must achieve this criterion to be considered viable. Evaluation of the overall protection of human health and the environment determines whether the alternative achieves adequate protection and describes how site risks are eliminated, reduced, and/or managed through treatment, engineering, or controls.

Compliance with ARARs

Compliance with ARARs also is a threshold criterion. The evaluation includes a determination of whether each alternative meets all federal, state, and local chemical-, location-, and action-specific ARARs.

Long-Term Effectiveness and Permanence

The long-term effectiveness of each alternative is evaluated based on the risk likely to be present at the site after response actions have been employed. This evaluation includes an assessment of the extent and effectiveness of controls that may be required to manage residual risk posed by treated residuals and/or untreated contaminants of concern. The evaluation of long-term

effectiveness evaluates both the magnitude of residual risk and the adequacy and reliability of controls.

Reduction in Toxicity, Mobility, or Volume through Treatment
This criterion addresses the regulatory preference for remedial actions that permanently and significantly reduce the toxicity, mobility, or volume of contamination through treatment. The evaluation includes an assessment of the anticipated efficiency of the remedial alternative at reducing the risk associated with contaminants of concern at the site.

Short-Term Effectiveness
Short-term effectiveness is an assessment of the effects of the alternative during the construction and implementation phase. This criterion includes an evaluation of potential impacts to the community, site workers, and the environment during remedy execution to achieve short-term protection and the time required to achieve RGs.

Implementability
Implementability is evaluated in a manner that encompasses both the technical and administrative feasibility of implementing a remedial alternative. It incorporates an evaluation of the technical difficulties associated with construction and operation of the remediation system, the reliability of the chosen technologies, and the ease of implementing additional remedial action if anticipated or necessary. This criterion also includes an assessment of the ability to resolve administrative issues; procure treatment, storage, and disposal services; and the availability of equipment and labor to implement all facets of the remedial alternative.

Cost
Costs are calculated for each alternative using primarily available historic information based on past operation of the interim remedies. If needed, a variety of other cost-estimating techniques can be used, including, but not limited to, vendor information, cost-estimating guides (e.g., RS Means cost guides), and engineering judgment.

Community Acceptance
This criterion evaluates the issues and concerns the general public may have regarding each remedial alternative. In accordance with U.S. EPA guidance (1998), this will be addressed in the ROD, once community comments on the focused FS and Proposed Plan are received and addressed.

Regulatory Agency Acceptance
This criterion evaluates the technical and administrative issues and concerns that federal, state, or other agencies may have regarding each remedial alternative. In accordance with U.S. EPA guidance (1998), this will be addressed in the ROD once agency comments on the focused FS and Proposed Plan are received and addressed.

5.1 Alternative 1: No Action

In accordance with the requirements of the NCP and CERCLA, the No Action alternative is presented and carried through the FS to serve as the baseline condition on which to compare other remedial alternatives. This alternative would entail no active remediation of groundwater at OU1 or OU3. Monitoring would also not be a component of this alternative. No periodic reviews would be conducted to evaluate the protectiveness of this alternative. There would be no costs associated with implementing this alternative.

Overall Protection of Human Health and the Environment
The No Action alternative would prevent use of OU3 groundwater as a drinking water source and may result in migration of chemicals if the PWP and LAWC wells in the Monk Hill subarea are not operating. In addition, while there is no direct exposure pathway to human or ecological receptors at OU1 or OU3, groundwater monitoring and modeling have demonstrated that chemicals present in groundwater could migrate downgradient impacting other water purveyors. Under the No Action alternative, no remedial action would be completed to reduce chemicals in groundwater at OU1 or OU3, and no monitoring would be conducted. Based on this information, the No Action alternative would not be protective of human health.

Compliance with ARARs
There is no need to identify ARARs for the No Action alternative because ARARs apply to "any removal or remedial action conducted entirely on-site" and "no action" is not a removal or remedial action (CERCLA sec. 121[e], 42 U.S.C. § 9621[e]). CERCLA Section 121 (42 U.S.C. § 9621) cleanup standards for selection of a Superfund remedy, including the requirement to meet ARARs, are not triggered by the No Action alternative. Therefore, a discussion of compliance with ARARs is not appropriate for the No Action alternative.

This alternative would not meet the threshold criterion of overall protection of human health and the environment and does not trigger an ARARs determination. In addition, the No Action alternative would not meet the RAOs. Therefore, an analysis of the balancing criteria is not required.

5.2 Alternative 2: Groundwater Extraction with Aboveground Treatment and ICs

Alternative 2 is comprised of groundwater extraction, aboveground treatment, and discharge of treated water, consistent with the current interim remedies. Currently, there are three treatment systems operating at the JPL site: (1) the OU1 source area treatment system, (2) the OU3 MHTS, and (3) the OU3 LAWC treatment system. Alternative 2 also includes the addition of various formalized ICs (i.e., in addition to the adjudicated water rights currently in place and enforced by the Raymond Basin Management Board) to ensure impacted groundwater within the JPL site is not utilized without appropriate evaluation and/or treatment. In addition, this alternative includes continuation of the routine groundwater monitoring program to monitor remedy performance and effectiveness.

Based on the concentration of chemicals to be treated (higher concentrations at the source area in OU1 and lower concentrations downgradient at OU3), the technologies selected as part of the interim remedies to achieve the aboveground treatment are different for OU1 and OU3. Also, the end use of the treated groundwater from OU1 and OU3 are different. Treated groundwater from OU1 is reinjected into the aquifer and treated groundwater from OU3 is used by PWP and LAWC for drinking water.

For OU1, Alternative 2 consists of groundwater extraction wells, GAC treatment to remove VOCs, FBR treatment to remove perchlorate, and reinjection of treated water. For OU3, the alternative consists of groundwater extraction from existing production wells, GAC treatment to remove VOCs, ion exchange treatment to remove perchlorate, and the treated water is disinfected and utilized as potable water with the PWP and LAWC distribution systems.

The operating strategy (e.g., flow rates and groundwater extraction well locations) and aboveground treatment technologies applied in these treatment systems could change in the future, with involvement and concurrence from the regulatory agencies, to ensure treatment is accomplished in the most cost effective manner. Some examples of these types of changes include:

- Influent perchlorate concentrations in the OU1 source area could decrease to a point where it is more cost effective to treat source area groundwater using ion exchange rather than using the FBR.
- New wells are added to one or more of the systems to improve chemical mass removal or system reliability.
- Concentrations in the OU1 source area are reduced to a point where residual levels of VOCs and perchlorate are more cost-effectively addressed by the OU3 systems.

A groundwater monitoring program is currently in place and groundwater monitoring would continue until RAOs are achieved. The existing JPL monitoring well network is sufficient to monitor the three dimensional extent of the chemical plumes in OU1 and OU3. A total of 25 monitoring wells are currently sampled on either a quarterly or semi-annual basis (NASA, 2013a), including well MW-25 located downgradient of OU3 near the Sunset Reservoir wells. Fifteen of the 25 wells in the JPL groundwater monitoring network are multi-level wells that monitor up to five zones within the aquifer. Altogether, there are 82 discrete sampling locations. In addition, the JPL monitoring well network is supplemented by performance data from production wells in the Monk Hill Subarea. For example, NASA funds weekly monitoring for perchlorate at RCL&W#4 and RCL&W#7. The location and frequency of monitoring may change in the future with concurrence from the regulatory agencies based on changing site conditions over time.

Raymond Basin adjudication (enforced by the Raymond Basin Management Board) and CDPH permitting effectively manage extraction of groundwater from the basin that could potentially present an unidentified exposure route or undermine the effectiveness of the containment provided by this remedial alternative. Even so, under Alternative 2, ICs would be established to further restrict groundwater extraction that could result in unidentified exposure to chemicals in

groundwater at OU1 or OU3, or that could negatively impact the OU1 or OU3 remedy. ICs could consist of MOAs or other agreements with the Raymond Basin Management Board and/or CDPH requiring these agencies to notify NASA of any proposed new extraction wells in the Monk Hill Subarea, and that NASA, in coordination with the agencies, evaluate the impact of any proposed extraction wells within/near the capture zones on the implemented remedies at OU1 and OU3. In addition, NASA could conduct annual reviews of new well permits in the Monk Hill subarea as an additional control to evaluate and prevent potential exposure to site-related chemicals.

The final component of the remedy in this alternative includes continuation of Five-Year Review evaluations in accordance with CERCLA requirements. In support of the five-year reviews, annual reviews of new well permits issued in the Monk Hill subarea would be performed to determine if they may adversely impact protection of human health or effectiveness of the remedy. Locations where well permits or other related information may be reviewed include the CDPH, Los Angeles County Public Health Department, City of Pasadena well permitting desk, the State Water Resource Control Board, and the California Department of Water Resources. These, and other resources as appropriate, would be reviewed on an annual basis to determine if new wells have been installed or proposed that would require further evaluation with respect to the OU1 and OU3 remedies.

Overall Protection of Human Health and the Environment

This proposed remedial alternative is designed to contain and treat chemicals in the source area groundwater to prevent further migration of source area chemicals that will adversely impact the downgradient drinking water supply. Monitoring results show that there has been a decreasing trend in perchlorate and VOC concentrations in the extracted groundwater over the duration of the OU1 system operation, and the system has consistently treated these chemicals to below the discharge criteria (NASA, 2012a). Based on this information, the existing treatment system at OU1 is considered protective of human health and the environment.

Similarly, stable or decreasing trends have been noted in perchlorate and VOC concentrations at the OU3 LAWC treatment system since it began operation in 2004 and at the MHTS since it began operation in 2011. Both systems have consistently treated chemicals in the extracted groundwater to concentrations below the MCLs (NASA, 2012a). Based on this information, the existing MHTS and LAWC treatment systems at OU3 are considered protective of human health and the environment.

Compliance with ARARs

Compliance with ARARs also is a threshold criterion. This proposed remedial alternative would comply with all ARARs identified for this remedial action (Section 3.4). Discharge requirements for all treatment systems have been consistently achieved, as documented in the routine operating reports and recent five-year review (NASA, 2012a). Further, concentrations of TCE in treated water from the MHTS and LAWC treatment systems have been non-detect, demonstrating that these systems will continue to achieve the TCE MCL in the future regardless of any potential change to the MCL. Concentrations in the groundwater have been shown to be decreasing over time, demonstrating that achieving MCLs within the aquifer can be achieved. In

addition, all waste disposal for the OU1 and OU3 interim remedies would continue to be conducted in accordance with disposal requirements identified as part of the ARAR evaluation.

Long-Term Effectiveness and Permanence

Overall, there has been a general decreasing trend in perchlorate and VOC concentrations in the extracted groundwater over the duration of system operation for the source area treatment system at OU1. Based on the current data trends in the treatment plant influent and source area groundwater monitoring wells, it is estimated that it may take another 10 to 15 years to achieve RGs within the OU1 source area. Limited data are available at this time to evaluate long-term trends for the LAWC treatment system and MHTS at OU3, although chemical concentrations are anticipated to decrease as OU1 source area is remediated. Based on removal of three pore volumes of groundwater within the boundary of the JPL chemical plume, it is estimated that it may take another 15 to 20 years to achieve RGs in JPL groundwater (OU3).

At OU1, concentrations of TCE within the treatment zone (i.e., MW-7, MW-13, MW-16, and MW-24) are now below the state and federal MCL (5.0 μg/L), and concentrations of carbon tetrachloride are near the state MCL of 0.5 μg/L (maximum concentration of 0.7 μg/L in one treatment zone monitoring well). Perchlorate concentrations in MW-7 and MW-24 have declined from 13,300 μg/L and 4,880 μg/L to concentrations of 35.0 μg/L and 9.9 μg/L, respectively. These data demonstrate that operation of the OU1 treatment system has significantly reduced the chemical concentrations within the source area. The overall reduction in chemical mass within the source area will improve the effectiveness and efficiency of the off-facility (OU3) remedy. Routine monitoring and maintenance of the treatment system will ensure that the system continues to operate effectively.

At OU3, groundwater extraction and treatment removes target chemicals from the aquifer being used by the local community (LAWC and the City of Pasadena) for drinking water, and provides hydraulic control to prevent the migration of chemical mass in groundwater. The monitoring data obtained to date indicate that the system is operating as intended, with perchlorate and VOC levels below detection limits following ion exchange and GAC treatment.

At the LAWC treatment system, influent perchlorate concentrations have shown a generally decreasing trend from 2004 through 2009. However, perchlorate concentrations increased during 2010 and early 2011 because LAWC#3 concentrations increased slightly and LAWC#5 was offline or operating only intermittently. Current perchlorate concentrations at LAWC are approximately 19 μg/L.

Overall, influent concentrations of TCE from LAWC #3 and LAWC #5 have decreased over time, with concentrations now consistently below 5 μg/L. Influent concentrations of carbon tetrachloride have shown an increasing trend; however, current concentrations are relatively low, < 0.5 μg/L and 1.7 μg/ in LAWC #3 and LAWC #5, respectively.

The perchlorate, TCE, and carbon tetrachloride levels in LAWC#3 and LAWC#5 are expected to continue to decrease over time now that the MHTS is operating with extraction wells located upgradient of the LAWC wells (i.e., in between the JPL Facility and the LAWC wells). The

LAWC system has operated effectively, removing perchlorate and VOCs to below detectable levels after ion exchange and GAC treatment.

In addition, routine monitoring is conducted at the RCL&W Association production wells, which are located downgradient of the LAWC wells. The highest detection of perchlorate in these wells was 3.1 μg/L, and no TCE or carbon tetrachloride has been detected in the RCL&W Association wells. Data from the RCL&W Association wells demonstrate that operation of the OU3 interim remedy is effectively preventing further migration of chemicals in groundwater.

Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion addresses the regulatory preference for remedial actions that permanently and significantly reduce the toxicity, mobility, or volume of contamination through treatment. The FBR, which treats perchlorate from source area groundwater at OU1, meets the U.S. EPA preference for reduction in toxicity, mobility, and volume by permanently destroying the perchlorate through biological treatment. At OU3, perchlorate is not permanently degraded, but rather mobility and volume of the chemical is reduced through adsorption of perchlorate onto the ion exchange resin, resulting in clean groundwater. Similarly, the mobility and volume of VOCs is reduced through treatment at OU1 and OU3 by adsorption onto the GAC media, resulting in clean groundwater. Spent ion exchange and GAC media is properly disposed in accordance with Federal laws at approved facilities.

Short-Term Effectiveness

Because the treatment systems included in this remedial alternative were previously installed as part of the interim remedies, short-term impacts associated with this remedial alternative are limited to continued operation of these systems. Potential short-term impacts to the community are primarily related to truck traffic associated with occasional system maintenance (e.g., GAC and ion exchange media change out). Other community impacts may include noise associated with pump operation or other infrequent maintenance activities, such as well rehabilitation. These short-term impacts are mitigated to the greatest extent possible through the use of sound dampening engineering controls where required by the treatment system designs.

Potential impacts to site workers are associated with routine system O&M activities for the treatment systems. Potential safety concerns for site workers are also mitigated to the maximum extent practical through the use of personal protective equipment as required based on site conditions (e.g., hearing protection when working under high decibel circumstances).

Short-term effectiveness associated with the potential for unacceptable risk due to exposure to untreated groundwater would be mitigated through the existing adjudicated water rights within the basin and ICs to further restrict additional groundwater extraction within OU1 and OU3. The ICs would serve to effectively minimize the potential for unacceptable risks associated with groundwater use at OU1, and also ensure that the hydraulic containment from groundwater extraction at OU1 and OU3 remains effective by not impacting the capture zones with additional extraction or recharge from other nearby areas.

Implementability
This remedial alternative represents that which has been implemented as the interim remedial actions for both OU1 and OU3. Therefore, the administrative and technical implementability of this alternative is high. All construction activities have been completed, so implementation of this alternative includes only continued O&M of the three treatment systems (OU1 source area treatment system and OU3 MHTS and LAWC treatment systems). The treatment systems have been operating effectively, and continued operation of the systems is considered highly implementable. All required permitting is currently in place for operation of the treatment systems. In addition, the regulatory agency and community have previously accepted this alternative, further increasing the administrative implementability of this alternative.

Cost
For OU1, the annual O&M cost estimated during preparation of the interim ROD was approximately $825,000 (NASA, 2007b). Actual annual operating costs have typically ranged from approximately $800,000 to $1,000,000. This cost includes labor, materials, laboratory costs, well rehabilitation, and reporting/project management, but does not include costs associated with the routine groundwater monitoring program.

For OU3, the annual O&M costs estimated during preparation of the interim ROD were approximately $923,500 for the LAWC treatment system and $3,080,900 for the MHTS (NASA, 2007c). This cost includes labor, materials, equipment leases, electricity, laboratory costs, and reporting/project management, but does not include costs associated with groundwater monitoring. Actual costs incurred for O&M of the LAWC treatment system have typically ranged from approximately $800,000 to $900,000. Actual costs for the MHTS O&M in 2012 were approximately $3,600,000.

6.0 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section compares the relative performance of the remedial alternatives considered in Section 5 against one another based on the NCP evaluation criteria described in detail previously. This comparative analysis considers the advantages and disadvantages of each alternative and identifies key trade-offs that should be considered when selecting a remedy. This comparative analysis for the focused FS provides information for the lead agency to select the remedy which will be presented for public comment as part of the Proposed Plan and subsequently documented in the ROD.

Overall Protection of Human Health and the Environment

Although there are no human health or ecological exposure pathways for chemicals in groundwater at OU1, Alternative 1 (No Action) would not address the chemicals known to be in groundwater at OU1, and these chemicals may adversely impact the downgradient area at OU3 in terms of life-cycle costs and time of operation.

The No Action alternative is not considered protective of human health and the environment at OU3, where chemicals are present in groundwater at concentrations above the MCLs and groundwater is used as a drinking water source.

Alternative 2, groundwater extraction and ex situ treatment, has been implemented as the interim remedies at both OU1 and OU3. Data collected to date for these treatment systems have demonstrated that they can effectively treat extracted groundwater to the required discharge criteria, and that operation of the systems is resulting in decreased concentrations of chemicals within the groundwater at both OU1 and OU3. Alternative 2 is considered to have a high degree of overall protection of human health and the environment.

Compliance with ARARs

No activities are conducted as part of the No Action alternative; therefore, an ARARs determination was not conducted for this alternative.

Implementation of Alternative 2 would comply with all chemical-, location-, and action-specific ARARs identified for OU1 and OU3. Long-term groundwater monitoring data have shown that operation of the treatment systems has reduced groundwater concentrations within the treatment zone (specifically for the OU1 source area treatment system and the LAWC treatment system). This indicates that the chemical-specific ARARs identified (state and federal MCLs) can be achieved through continued implementation of this remedy. Also, all action-specific ARARs are being met, and would continue to be met, through proper system monitoring and maintenance (e.g., achieving all discharge requirements, adhering to waste disposal requirements, etc.).

Based on this evaluation, Alternative 2 meets both CERCLA threshold criteria.

Long-Term Effectiveness and Permanence
Implementation of the No Action alternative does not provide long-term effectiveness in achieving the final RAOs because no action would be completed and chemicals would remain in groundwater and drinking water.

Monitoring data collected over several years of operation for the OU1 source area treatment system and LAWC treatment system document decreasing data trends in both extracted groundwater and groundwater within the treatment zones as measured at various monitoring wells. Operating data have also demonstrated the consistent achievement of goals for treated groundwater (WDRs for OU1 and MCLs for OU3). Sufficient data are not yet available to perform these evaluations for the MHTS; however, monitoring data will continue to be collected for all of the systems under this alternative and the long-term effectiveness will be re-evaluated on a routine basis as part of the remedy. Groundwater monitoring data demonstrate that the plume is mostly contained by the MHTS and LAWC treatment system and that the chemicals originating from JPL have not migrated to the RCL&W Association production wells at levels exceeding the RGs. The long-term effectiveness of Alternative 2 is considered high.

Reduction in Toxicity, Mobility, or Volume through Treatment
The No Action alternative does not meet the U.S. EPA preference for remedial actions that permanently and significantly reduce the toxicity, mobility, or volume of contamination through treatment (U.S. EPA, 1988).

Alternative 2, groundwater extraction and ex situ treatment, addresses this criterion by significantly reducing the toxicity and volume of perchlorate in the source area through FBR treatment to biologically degrade perchlorate. The mobility of perchlorate in OU3, and VOCs at both OU1 and OU3, are significantly reduced through adsorption of the chemicals on the ion exchange media and GAC media, respectively.

Short-Term Effectiveness
The No Action alternative would not have any impacts to the community, site workers, and the environment during remedy execution since no action would be taken for this alternative. However, the time required to achieve RGs would be significantly greater than Alternative 2 because no treatment would be conducted.

Short-term impacts associated with implementation of Alternative 2 are limited to community impacts (primarily traffic and noise) and potential worker safety concerns during system O&M. These impacts are mitigated to the greatest extent possible through engineering controls incorporated as part of the treatment system design and worker protection through standard operating procedures for O&M.

Implementability
The No Action alternative is highly implementable from a technical perspective, as no action would be taken. However, this alternative has a low administrative implementability rating because regulatory concurrence would not be possible with chemicals in groundwater remaining within a drinking water aquifer above MCLs.

The treatment systems incorporated under Alternative 2 are highly implementable from both a technical and administrative perspective. The systems have already been constructed and are currently being operated as part of the interim remedies for OU1 and OU3. Therefore, implementation of Alternative 2 consists of continued operation of the three existing treatment systems. Administrative implementability is also considered high because the community and regulatory agencies previously reviewed this option as part of the interim remedy Proposed Plan and ROD process.

Cost

There is no cost associated with the No Action alternative.

Historical O&M data have shown that annual operating costs for the OU1 and OU3 treatment system are in line with that which was expected during the planning phase, with combined costs of approximately $6.5M, including quarterly groundwater monitoring. These costs are considered reasonable for O&M and monitoring of three large treatment systems.

Table 6-1 summarizes the comparative analysis of Remedial Alternatives 1 and 2.

Table 6-1. Summary of the Comparative Analysis

NCP Evaluation Criterion	Alternative 1: No Action	Alternative 2: Groundwater Extraction with Aboveground Treatment and ICs
Overall Protection of Human Health and the Environment	Not protective of human health and the environment because chemicals are present in groundwater above MCLs and groundwater is used as a drinking water source.	High level of overall protection of human health and the environment. Data collected to date from implementation of the interim remedial actions demonstrate that groundwater extraction with aboveground treatment is effective.
Compliance with ARARs	ARARs determination not conducted because no activities are conducted as part of this alternative.	Complies with all chemical-, location-, and action-specific ARARs identified for OU1 and OU3.
Long-Term Effectiveness and Permanence	Does not provide long-term effectiveness in achieving RAOs because chemicals would remain in groundwater at levels exceeding drinking water MCLs.	High level of long-term effectiveness and permanence, as data from operation of the interim remedial actions show that Alternative 2 is effective in containing the chemical plumes and preventing exposure to chemicals in groundwater originating from JPL, and monitoring data indicate decreasing chemical levels in the groundwater in OU1.
Reduction in Toxicity, Mobility, or Volume through Treatment	Does not meet the U.S. EPA preference for remedial actions that permanently and significantly reduce toxicity, mobility, or volume of contamination through treatment.	Reduction in mobility and/or volume of chemicals is achieved through aboveground treatment using FBR, GAC, and ion exchange.
Short-Term Effectiveness	Does not have any impacts to the community, site workers, and the environment during remedy implementation because no actions are performed.	Some short-term impacts are possible (e.g., increase in traffic and noise, site worker safety concerns); although these impacts are mitigated to the greatest extent possible.
Implementability	Highly implementable, because no action is taken.	Highly implementable (technically and administratively) because systems have already been constructed and are operating effectively, under approved interim RODs.
Cost	No cost.	Costs are estimated at approximately $6.5M per year. These costs are considered reasonable for O&M and monitoring of three large treatment systems.

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