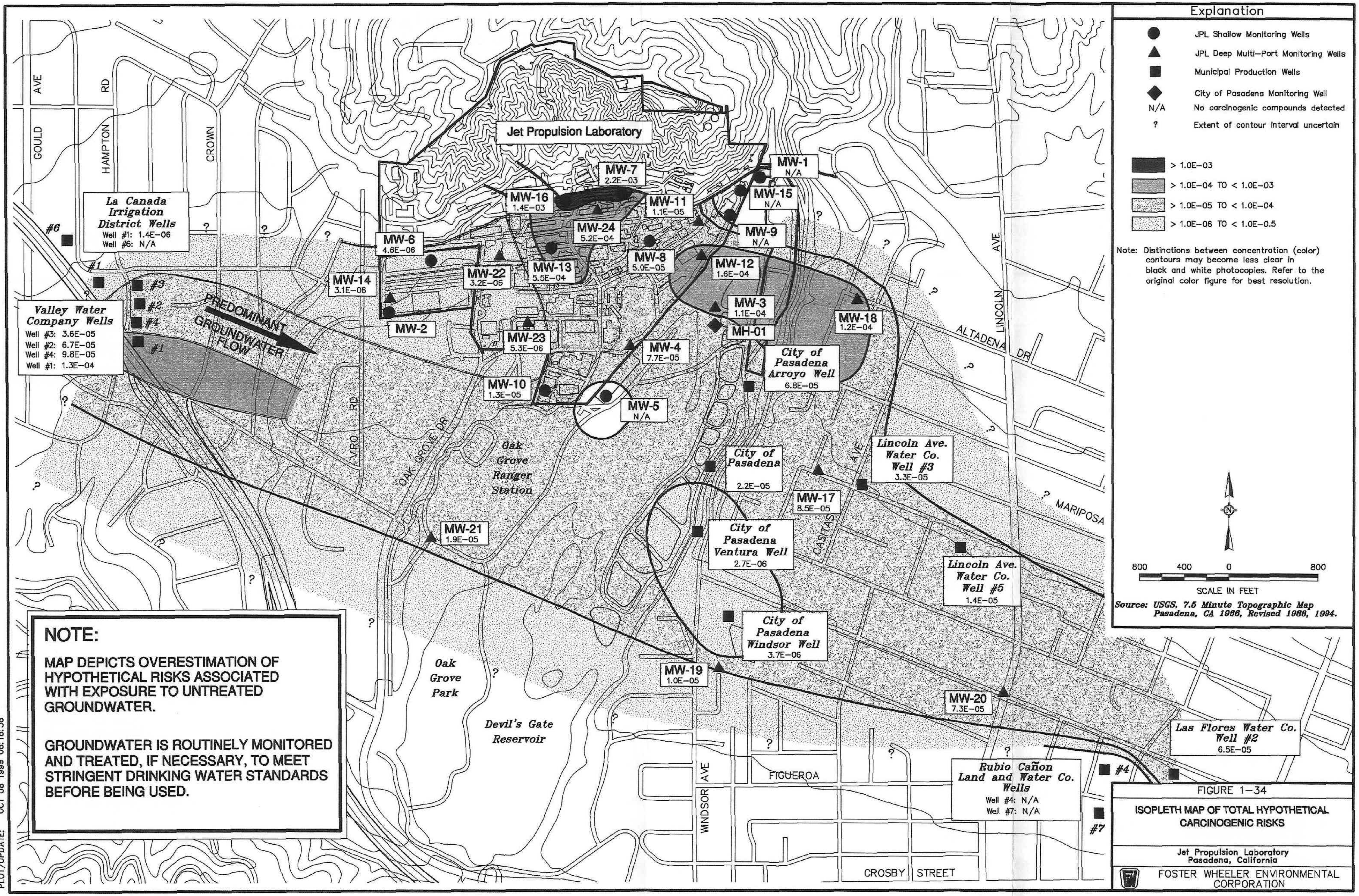
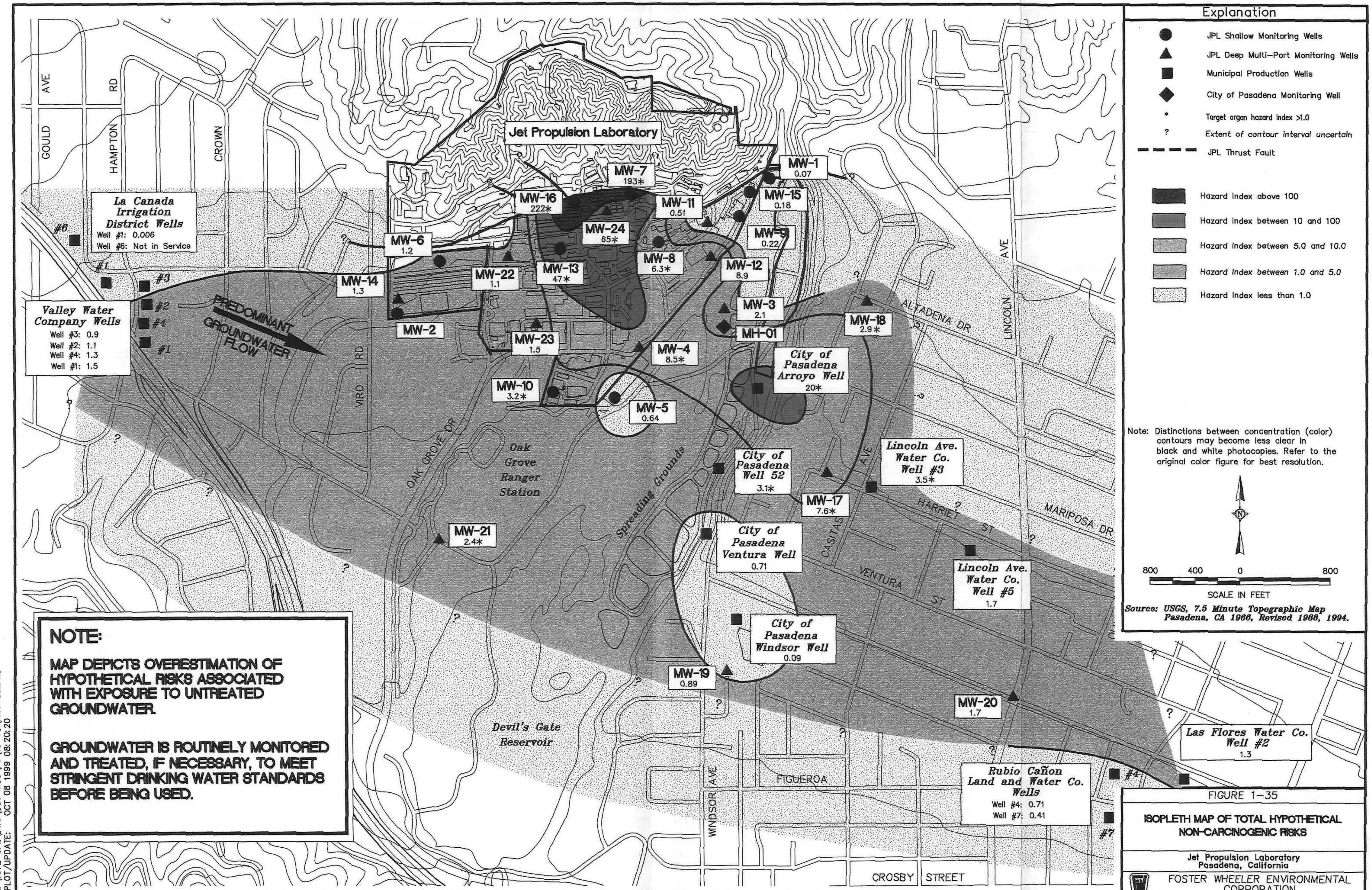


FIGURE 1-34
ISOPLETH MAP OF TOTAL HYPOTHETICAL CARCINOGENIC RISKS



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PLOT/UPDATE: OCT 08 1999 08:20:20

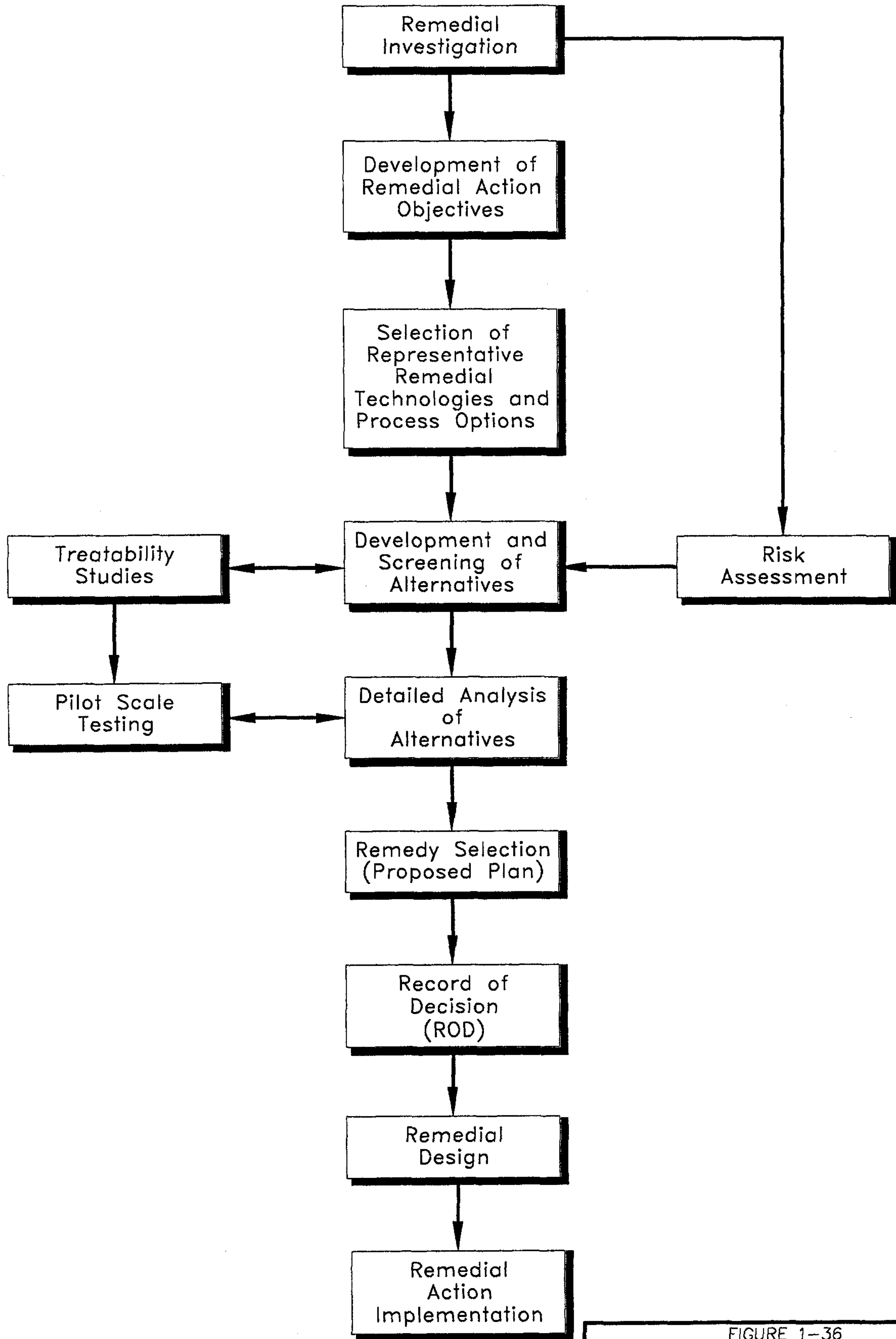

FIGURE 1-36

FLOW CHART SUMMARIZING RI/FS PROCESS

Jet Propulsion Laboratory
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\10-99\JPLFCH.DWG
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2.0 IDENTIFICATION OF POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

This section identifies potential Applicable or Relevant and Appropriate Requirements (ARARs) for the development of remedial alternatives for this FS. The identification of ARARS is a key component of the planning, evaluation, and selection of remedial actions. This section also identifies other guidance and criteria "to be considered" (TBCs) in selecting a remedy for JPL.

2.1 DEFINITION OF ARARS AND OTHER CRITERIA OR GUIDELINES TO BE CONSIDERED (TBCs)

Section 121(d) of CERCLA requires remedial actions at CERCLA sites to attain any Federal or State environmental standards, requirements, criteria, or limitations that are determined to be legally applicable or relevant and appropriate unless any such standard requirement, criterion or limitation is waived. Federal ARARs may include requirements under any Federal environmental law (e.g., the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), and the Clean Air Act (CAA)). Only promulgated, legally enforceable environmental or facility-siting laws or regulations that are identified and are more stringent or broader in scope than Federal requirements qualify as State ARARs. Several California laws give local agencies the authority to develop regulations that implement State requirements. As a result, some local regulations are also potential ARARs.

According to the National Contingency Plan (NCP) (40 CFR Part 300), "applicable," "relevant and appropriate," and "TBCs" are defined as follows:

- **Applicable requirements** are those standards, requirements, criteria, or limitations in regulations promulgated by Federal or State agencies and in Federal or State statutes that specifically address a substance, remedial activity, location, or other circumstances found at a CERCLA site.
- **Relevant and appropriate requirements** are those standards, requirements, criteria, or limitations promulgated under Federal or State law that, while not "applicable" to a substance, remedial activity, location, or other circumstances at a CERCLA site, address situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.
- **TBCs** consist of advisories, criteria, or guidance developed by Federal agencies, states, or local agencies, which are not set forth in regulations or statutes and which may be useful in developing CERCLA remedies. They are not legally binding and do not have status as potential ARARs.

The hazardous substances present, the remedial actions contemplated, the physical characteristics of the site, and other appropriate factors are considered when determining whether a requirement is "applicable" or "relevant and appropriate."

Pursuant to CERCLA §121 and the NCP, only substantive requirements are ARARs. In addition, under CERCLA §121(e), Federal, State, and local permits are not required for those portions of a CERCLA response action that are conducted entirely within the CERCLA site.

2.2 CLASSIFICATION OF ARARS

ARARs and TBCs can be divided into three categories: chemical-specific, location-specific, and action-specific. Each potential remedial alternative will be evaluated to determine compliance with identified ARARs or TBCs. The three ARAR and TBC categories are summarized below:

- **Chemical-specific** requirements are health- or risk-based concentration limits, or numerical values for various environmental media (i.e., groundwater, surface water, air, and soil) that are established for a specific chemical. These ARARs set limits on concentrations of specific substances, pollutants, and contaminants in the environment. Examples of this type of ARAR include State and Federal drinking water standards.
- **Location-specific** requirements set restrictions on certain types of activities based on site characteristics and location. Federal and State location-specific ARARs are restrictions placed on the concentration of a contaminant or the activities to be conducted because they are in a specific location. An example of a location specific ARAR is a prohibition on the disposal of a hazardous waste in a solid waste landfill.
- **Action-specific** requirements are technology- or activity-based requirements that are triggered by the type of remedial activities under consideration. Examples are RCRA regulations for waste treatment, storage, or disposal.

2.3 IDENTIFICATION OF POTENTIAL ARARS

Neither CERCLA nor the NCP provide explicit standards for determining whether a particular remedy will result in an adequate cleanup at a particular site. Rather, CERCLA recognizes that each site has unique characteristics that must be evaluated to determine which Federal or State requirements are ARARs.

Federal, State, and local ARARs and TBCs listed herein are based on the current set of remedial alternatives identified for JPL, on available analytical data, and on a review of potential ARARs for sites with similar circumstances.

Since a remedy for JPL has not yet been selected, all ARARs identified in this section are preliminary. A final determination of the ARARs for JPL will be included in the Record of Decision (ROD).

2.3.1 Potential Chemical-Specific ARARs

Chemical-specific ARARs are health- or risk-based concentration limits that are established for a specific chemical that may be present in the environment, or that may be discharged during remedial activities.

The primary contaminants of interest for groundwater are carbon tetrachloride, trichloroethene, 1,2-dichloroethane, hexavalent chromium, and perchlorate. The chemical-specific Federal and State ARARs that address these contaminants are discussed below:

2.3.1.1 Safe Drinking Water Act

EPA has established Maximum Contaminant Levels (MCLs) (40 CFR Part 141) under the Safe Drinking Water Act (SDWA) to protect public health from contaminants that may be found in drinking water sources. MCLs are enforceable standards that are applicable at the tap for water that is delivered directly to 25 or more people or which may be supplied to 15 or more service connections.

Under the SDWA, EPA has also designated Maximum Contaminant Level Goals (MCLGs) (40 CFR Part 141), which are health-based goals that may be more stringent than MCLs. MCLGs are based entirely on health considerations and do not take cost or the feasibility of achieving them into account. MCLGs are set at levels, including an adequate margin of safety, where no known or anticipated adverse health effects would occur. MCLs are required to be set as close as feasible to the respective MCLGs, taking into consideration available treatment technologies, analytical capabilities, and other factors (including cost). Although not legally applicable, MCLGs may be relevant and appropriate in circumstances where multiple contaminants or multiple pathways of exposure present unacceptable health risks (EPA, Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites, OSWER Directive 9283.1-2, 1988b).

The NCP (40 CFR Section 300.430(e)(2)(B)) states that remedial actions for groundwater that is a current or potential source of drinking water must generally attain MCLs and nonzero MCLGs. The groundwater at JPL is a current source of drinking water. Therefore, MCLs and nonzero MCLGs are applicable to JPL groundwater. MCLs and MCLGs for the constituents of interest and other constituents at JPL are listed in Table 2-1.

2.3.1.2 California Safe Drinking Water Act

California has established standards for sources of public drinking water under the California Safe Drinking Water Act of 1976 (Health and Safety Code §§ 4010.1 and 4026(c)). Some State MCLs are more stringent than the corresponding Federal MCLs. In these instances, the more stringent State MCLs are applicable to JPL. There are also some chemicals that lack Federal MCLs. Where State MCLs exist, they are also applicable for these chemicals. Table 2-1 lists the current promulgated MCLs for constituents of potential concern found in groundwater around JPL (identified during initial risk screening).

The California secondary MCLs contained in Title 22 CCR Section 64449 pertain to minimum aesthetic qualities of drinking water. These enforceable limits are applicable if treated groundwater is directed for domestic use. The State secondary MCLs are listed in Table 2-1.

2.3.1.3 Federal Water Pollution Control Act

Section 402 of the Federal Water Pollution Control Act [also known as the Clean Water Act (CWA)], as referenced in 40 CFR Part 122, contains the National Pollutant Discharge Elimination System (NPDES) permit requirements for discharges to waters of the United States. The substantive aspects of the NPDES requirements applicable would include specific chemical discharge limits for discharge of treated groundwater to surface waters (e.g., Arroyo Creek). Section 303 of the CWA requires states to determine beneficial uses of their waters and water quality for surface water or groundwater. The beneficial uses and water quality objectives are potential ARARs.

Section 403 of the CWA contains regulations applicable to the pretreatment of waste waters prior to discharge to Publicly Owned Treatment Works (POTWs). Specific chemical concentration limits would apply to discharges of treated groundwater to the County Sanitation District of Los Angeles County (CSDLAC).

2.3.1.4 State Water Resources Control Board, Resolution 88-63

Pursuant to Section 13000 et. seq. of the California Porter-Cologne Water Quality Act (California Water Code), the State Water Resources Board and the Regional Water Quality Control Boards are authorized to establish in water quality plans and resolutions, the beneficial uses and numerical and narrative standards to protect the quality of all waters of the State. The substantive requirements of water quality control plans and resolutions established under the authority of the State and regional water boards are legally enforceable when approved by the Office of Administrative Law and are potential ARARs if the requirements address standards, criteria, contaminants, activities, or concentrations similar to that at the site.

Resolution 88-63 (Sources of Drinking Water Policy) designates all waters of the State as drinking water except where total dissolved solids (TDS) exceeds 3,000 parts per million, the well yield is less than 200 gallons per day, or the water can not be reasonably treated for domestic use. This Resolution is applicable to surface and groundwater in the vicinity of JPL since the surface and groundwater are waters of the State and meet the requirements of "drinking water."

2.3.1.5 State Water Resources Control Board, Resolution 92-49

Resolution 92-49 (Cleanup and Abatement Policy) establishes cleanup and abatement policies and procedures for those cases of pollution wherein it is not reasonable to restore water quality to background levels. Under this policy, case-by-case cleanup levels for the restoration of water quality must, at minimum:

- Consider all beneficial uses of the waters;
- Can not result in water quality less than that prescribed by the Basin Plan and policies adopted by the State and Regional Boards; and
- Be consistent with maximum benefit to the people of the State.

Resolution 92-49 is applicable to NASA's remedial action plan for groundwater.

2.3.1.6 Los Angeles Regional Water Quality Control Board, Los Angeles River Basin Plan

The LARWQCB Basin Plan identifies beneficial uses, water quality objectives, and incorporates SWRCB Policy (Resolution 68-16) "Statement of Policy With Respect to Maintaining High Water Quality in California." The Basin Plan identifies the beneficial uses of surface and groundwater in the Los Angeles River Basin watershed and water quality objectives necessary to protect these beneficial uses. The Basin Plan requirements are relevant and appropriate to JPL.

Waters designated as Municipal and Domestic Supply have California MCLs as water quality objectives. Since the Basin Plan identifies Municipal and Domestic Supply as a potential beneficial use of the Arroyo Creek and the Monk Hill Subbasin groundwater, California MCLs are applicable to remedial actions involving discharge of treated groundwater to the Arroyo Creek or to the Monk Hill Subbasin. In addition to chemical constituents, the Basin Plan identifies other requirements (e.g., requirements concerning bacteria, coliform; bioaccumulation; chlorine; color; nitrogen; pH; etc.) that must be met for discharge to surface or groundwater. Table 2-2 contains water quality limits for discharge to the Arroyo Creek and the Monk Hill Subbasin.

2.3.2 Potential Location-Specific ARARs

Federal and State location-specific ARARs are restraints placed on the activities to be conducted because they are in a specific location. Examples of location-specific ARARs are requirements restricting actions in floodplains, wetlands, historic places, and sensitive ecosystems or habitats. Location-specific ARARs can be considered as a subset of action-specific ARARs. They do not drive the need for a CERCLA action to occur, but, if CERCLA action is otherwise appropriate, they may constrain the range of appropriate action.

2.3.2.1 Federal Facilities Compliance Act (FFCA)

The FFCA requires Federal facilities, including NASA's JPL facility, to comply with all Federal, State, and local requirements for solid and hazardous waste management.

2.3.2.2 National Historic Preservation Act

Under this statute, if a Federal undertaking affects any district, site, building, structure, or object that is listed on or eligible for listing on the National Register of Historic Places, the responsible official shall comply with the procedures for consultation and comment promulgated by the Advisory Council on Historic Preservation. NASA has an obligation to determine if any district, site, building, structure, or object listed or eligible to be listed on the National Register of Historic Places would be affected by the proposed remedial activities. It is unlikely property with historic, architectural, archeological, or cultural value, if located within the vicinity of JPL, will be impacted by remedial actions. However, a historic, archeological, architectural and cultural resource review of surrounding and on-site property must be conducted prior to implementation of remedial actions involving structure demolition, construction or intrusive groundwork.

2.3.2.3 Archaeological and Historic Preservation Act

This statute and implementing regulations establish requirements for the evaluation and preservation of historical and archaeological data that may be destroyed through alteration of terrain as a result of a Federal project or a Federally approved activity or program. This act is potentially applicable for remedial alternatives that involve construction around archaeological sites. Review of archaeological and historical data of surrounding and on-site property may need to be conducted prior to implementation of remedial actions involving structure demolition or construction or intrusive groundwork.

2.3.2.4 Endangered Species Act

This statute and implementing regulations (15 U.S.C. §§ 1531-1544, 50 CFR Part 402) prohibit any Federal activity or Federally authorized activity from jeopardizing the continued existence of any threatened or endangered species or destroying or adversely modifying the critical habitat of a listed species.

Compliance with this requirement involves consultation between EPA and the U.S. Fish and Wildlife Service, resulting in a determination as to whether there are listed or proposed species or critical habitats present at or around the site to be remediated and, if so, whether any proposed activities will impact such wildlife or habitat. Preliminary environmental studies (screening level ecological risk assessment) compiled lists of California and Federal threatened or endangered plant and animal species that could potentially occur in the topographic quadrangle map in which JPL is located (Foster Wheeler, 1996f). The Endangered Species Act is applicable if the selected remedy or implementation of the selected remedy adversely affects a threatened or endangered species or its habitat.

2.3.2.5 Executive Order 11988 – Protection of Floodplains

In accordance with Executive Order 11988, Federal agencies are required to avoid, to the extent possible, adverse effects associated with direct or indirect development in a floodplain.

If avoidance is not possible, mitigation of the adverse effect is required. Therefore, this regulation may be applicable to NASA depending on the nature of the remedy.

2.3.2.6 Executive Order 11990 – Protection of Wetlands

Executive Order 11990 requires Federal agencies, in carrying out their responsibilities, to take action to minimize the loss, destruction, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands. After cursory review, the Arroyo Creek appears to meet the criteria of a wetland under the Clean Water Act definition, which includes areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. This provision may be applicable to NASA depending on the nature of the remedy and if formal evaluation determines the Arroyo Creek is indeed a wetland.

2.3.2.7 California Fish and Game Code

California Fish and Game Code Sections 5650, 12015, and 12016 prohibit the discharge of harmful quantities of hazardous materials into places that may deleteriously affect fish, wildlife, plant life, or habitat. These sections may be applicable if the selected remedy provides for the discharge of extracted and treated groundwater and/or any wastewater generated during the implementation of the remedy to Arroyo Creek.

Section 1900 originates from the Native Plant Protection Act and lists state-designated rare and endangered plants and provides specific protection measures for identified populations. This section may be applicable to NASA if the remedy involves the discharge of extracted and treated groundwater and/or any wastewater generated during the implementation of the remedy to Arroyo Creek and State-designated rare and endangered plants are identified within the creek.

Section 1603 of the California Fish and Game Code contains specific review procedures for any proposal to "substantially change the bed, channel, or bank of any river, stream, or bed designated by the California Department of Fish and Game. This provision may be relevant and appropriate to NASA if the remedy will create an impact to the bed, channel, or bank along the Arroyo Creek.

2.3.3 Potential Action-Specific ARARs

Action-specific ARARs are usually technology- or activity-based requirements for remedial activities. Action-specific ARARs described in this section are intended to address those actions resulting from implementation of remedial alternatives. Remedial alternatives for JPL include the construction and operation of groundwater extraction or reintroduction facilities, groundwater treatment facilities (e.g., air stripping with off-gas control), a soil gas vapor extraction system, and pipelines and other conveyance facilities needed to deliver treated water to a variety of locations. A brief description of potential action-specific ARARs is presented below.

2.3.3.1 Clean Air Act - Local Air Quality Management

One treatment technology to be evaluated for addressing VOCs in groundwater is air stripping. Air emissions from air strippers are regulated by the California Air Resources Board, which implements the Federal Clean Air Act (CAA), as well as the air pollution control requirements of the California Health and Safety Code, which includes the State's counterpart to the Clean Air Act, through local air quality management districts. Local districts may impose additional regulations to address local air emission concerns. The local air district for JPL is the South Coast Air Quality Management District (SCAQMD). The SCAQMD has adopted several rules that may be ARARs for air stripper emissions.

SCAQMD Regulation XIII, comprising Rules 1301 through 1313, establishes new source review requirements. Rule 1303 requires that all new sources of air pollution in the district use best available control technology and meet appropriate offset requirements. Emissions offsets are required for all new sources that emit in excess of one pound per day.

SCAQMD Rule 1401 requires that best available control technology for toxics be employed for new stationary operating equipment, so that the cumulative carcinogenic impact from air toxics does not exceed the maximum individual cancer risk limit of 10 in 1 million (1×10^{-5}). Contaminants such as carbon tetrachloride and trichloroethene found in the JPL groundwater are air toxics subject to Rule 1401.

SCAQMD Rule 401 limits visible emissions from a point source. Rule 402 prohibits discharge of material that is odorous or causes injury, nuisance, or annoyance to the public. Rule 403 limits downwind particulate concentrations. SCAQMD Rules 401, 402, and 403 may also be ARARs for NASA depending on the remedy selected.

2.3.3.2 Federal Water Pollution Control

The California Regional Water Quality Control Board (RWQCB) is authorized by the EPA to administer the requirements of the Federal Water Pollution Control Act (also known as the Clean Water Act). The RWQCB regulates discharges to surface and groundwater through the issuance of National Pollutant Discharge Elimination System (NPDES) permits and Waste Discharge Requirements (WDR). In issuing an NPDES or WDR, the RWQCB considers the beneficial uses and water quality objectives for the affected water body as well as existing water quality data and mixing and dilutionary effects.

As discussed in Section 2.3.3.3, water quality objectives for Arroyo Creek and for groundwater in the vicinity of JPL are presented in the RWQCB Los Angeles Region Water Quality Control Plan (Basin Plan). The Basin Plan water quality objectives for the Arroyo Creek and the substantive aspects of the RWQCB's NPDES, WDR and other RWQCB requirements are applicable if the selected remedy provides for the surface or subsurface discharge (e.g., reintroduction) of extracted groundwater.

2.3.3.3 California Porter-Cologne Water Quality Act

California's Porter-Cologne Water Quality Act incorporates the requirements of the CWA and implements additional standards and requirements for surface waters and groundwaters of the State. This Act gives authority to the Los Angeles RWQCB to formulate and enforce a water quality control plan for its region. In response, the RWQCB has adopted the Los Angeles Region Water Quality Control Plan (Basin Plan). The Basin Plan identifies the beneficial uses of surface and groundwaters in the Los Angeles River watershed and water quality objectives necessary to protect these beneficial uses.

As stated in the Basin Plan, the beneficial uses for the Arroyo Creek include:

- Municipal and domestic supply – Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply.
- Groundwater recharge – Uses of water for natural or artificial recharge of groundwater for purposes of future extraction, maintenance of water quality, or halting of saltwater intrusion into freshwater aquifers.
- Industrial service and process supply – Uses of water for industrial activities that depend primarily on water quality.
- Wetland habitat – Uses of water that support wetland ecosystems, including, but not limited to, preservation or enhancement of wetland habitats, vegetation, fish, shellfish, or wildlife, and other unique wetland functions which enhance water quality, such as providing flood and erosion control, stream bank stabilization, and filtration and purification of naturally occurring contaminants.
- Water contact and non-contact recreation – Uses of water for recreational activities involving proximity to water and body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, fishing, hiking, picnicking, camping, sun bathing, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
- Cold fresh water habitat – Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
- Warm fresh water habitat – Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
- Wildlife habitat – Uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife, or wildlife water or food sources.

Waters designated as Municipal and Domestic Supply have California MCLs as water quality standards. The Basin Plan identifies Municipal and Domestic Supply as a potential beneficial use of the Arroyo Creek. Therefore, California MCLs are applicable to any remedial action that involves the discharge of any water to the Arroyo Creek and the Monk Hill Subbasin. Additional water quality objectives for the Arroyo Creek are identified in Table 2-2.

Provisions of the Porter-Cologne Act also apply to the discharge of water directly to aquifers. Specifically, Section 13540 of the Porter-Cologne Act states that "no person shall construct, maintain or use any waste well extending to or into a subterranean water bearing stratum that is used or intended to be used as, or is suitable for, a source of water supply for domestic purposes. Notwithstanding the foregoing, when a regional board finds that the water quality considerations do not preclude controlled recharge of such stratum by direct injection, and when the State Department of Health Services, following a public hearing, finds the proposed recharge will not impair the quality of water in the receiving aquifer as a source of water supply for domestic purposes, recycled water may be injected by a well into such stratum. The State Department of Health Services may make and enforce such regulations pertaining thereto, as it deems proper." This provision of the Porter-Cologne Act may be applicable to the reintroduction of treated groundwater into the Monk Hill Subbasin aquifer.

2.3.3.4 State Water Resources Control Board, Resolution 68-16

The Basin Plan also incorporates the State Water Resources Control Board (SWRCB) policy "Statement of Policy with Respect to Maintaining High Water Quality in California" (Resolution 68-16). Resolution 68-16 requires that existing water quality be maintained unless it is demonstrated that a change will benefit the people of California, will not unreasonably affect present or potential uses, and will not result in water quality less than prescribed by other State policies. Any activity that may increase the volume or concentration of a waste discharged to surface or groundwater is required to use the "best practicable treatment or control." Resolution 68-16 may be applicable if the selected remedy provides for the discharge of extracted groundwater to the Arroyo Creek or to the Monk Hill Subbasin

2.3.3.5 Resource Conservation and Recovery Act and the California Hazardous Waste Management Program

The Federal Resource Conservation and Recovery Act (RCRA) establishes requirements for the management and disposal of hazardous wastes. In lieu of the Federal RCRA program, the State of California is authorized to enforce its Hazardous Waste Control Act, and implementing regulations (California Code of Regulations (CCR) Title 22, Division 4.5), subject to the authority retained by EPA in accordance with the Hazardous and Solid Waste Amendments of 1984. California is responsible for permitting hazardous waste treatment, storage, and disposal facilities within its borders and carrying out other aspects of the Federal RCRA program. Some of the Title 22 regulations may be ARARs if the selected remedy for JPL results in the generation, storage, treatment, or disposal of hazardous wastes.

2.3.3.6 Clean Water Act and County Sanitation District of Los Angeles County (CSDLAC) Wastewater Ordinance

Under 40 CFR Part 403, standards are set to control the discharge of pollutants to publicly owned treatment works (POTWs). These standards are implemented by the local POTW, which is the County Sanitation District of Los Angeles County (CSDLAC) for JPL. In addition to the general standards and requirements in the CWA, the CSDLAC Wastewater Ordinance specifies additional limitations, standards, and requirements for the discharge of wastewater that may be applicable to NASA, depending on the remedy selected. Fees for sewer connections and wastewater strength and flow may also be applicable.

2.3.3.7 Toxic Injection Well Control Act

Section 25159.24 of the California Health and Safety Code states that any injection well used to inject contaminated groundwater that has been treated and is being reinjected into the same formation from which it was withdrawn for the purpose of improving the quality of the groundwater in the formation is exempt from the toxic injection well control act standards if the method is part of a remedial program initiated in response to an order or action required by a Federal or State agency. Remedial actions conducted under a ROD for JPL are exempt from the requirements of the Toxic Injection Well Control Act, and it is not considered an ARAR for the purposes of this FS.

2.3.3.8 California Water Well Standards

Section 4016(a) CCR requires all wells designed, located and constructed to produce drinking water to be constructed under this provision. An amended permit application is also required by a public water supply system prior to the addition of a new source of supply. Section 4014 requires that the Department impose permit conditions necessary to assure a reliable supply of pure, wholesome, and potable water from the new facilities. The design, location and construction standards would be applicable to NASA only if NASA decides to provide treated groundwater as drinking water. The conditions necessary to ensure the quality of the water would be applicable to entities that function as the drinking water purveyor or supplier.

2.3.3.9 Public Water Supply Regulations

Section 64650 of Title 22 CCR contains specific microbiological contaminant treatment requirements for a water purveyor using an approved surface water or groundwater under the direct influence of surface water for public use. This provision is applicable if groundwater (which is under the direct influence of surface water) is treated and is proposed for utilization as a source of domestic supply.

2.4 IDENTIFICATION OF GUIDANCE AND CRITERIA TO BE CONSIDERED (TBCs)

Other standards, criteria, or guidance to be considered are Federal, State, or local advisories or guidance that do not have the status of potential ARARs. If there are no specific Federal or State ARARs for a particular chemical or remedial action, or if the existing ARARs are not considered sufficiently protective, then guidance or advisory criteria may be identified and used to ensure the protection of public health and the environment. TBCs may provide health effects information, technical information on performing or evaluating site investigations or remedial actions, and useful policies for dealing with hazardous substances.

2.4.1 State Action Levels (ALs)

The State has developed numerical criteria known as Action Levels (ALs) for selected chemicals in drinking water for which MCLs have not yet been established. Although drinking water ALs are not specifically listed in laws or regulations, they are derived by the California Department of Health Services (CADHS) under the "general protection of the public provision" in the California Safe Drinking Water Act and the California Porter-Cologne Water Quality Act. Drinking water ALs developed by CADHS are often referenced by the RWQCB as action-specific, non-promulgated limits for contaminants in wastewater discharge. The RWQCB incorporates ALs as part of their site-specific conditions, and frequently specifies in NPDES permits that groundwater treatment system discharges be required to meet ALs if the wastewater is discharged to a storm drain or flood channel. NPDES permits are required by the Federal CWA for certain offsite wastewater discharges and, although a permit is not required for an onsite CERCLA response action, onsite discharge should comply with substantive discharge criteria. Discharge criteria are usually based on the Basin Plan, treatment technology limitations, and case-by-case conditions. .

2.4.2 Federal Guidance Documents

Many of the procedures and standards to be used in a CERCLA action are set forth in guidance documents issued by EPA. A list of the types of guidance that are TBCs is included in the preamble to the NCP, 55 Federal Register 8765 (March 8, 1990). That guidance, along with current updates of and additions to that guidance, will be considered in this FS and in selecting and implementing the remedy at JPL.

2.4.3 Health Effects Advisories: Chemical-Specific TBCs

Health Advisories, Drinking Water Exposure Limits, and ALs are potential TBCs for NASA. EPA's Office of Drinking Water has developed Health Effects Advisories (HEAs) for certain chemicals. HEAs serve as guidance and are not legally enforceable standards. The advisories may provide the best available standard for a particular chemical if no enforceable standard exists. HEAs describe contaminant concentrations at which adverse health effects would not be anticipated to occur over specific exposure durations from exposure to the contaminants in drinking water. HEAs are developed for 1-day, 10-day, longer term (approximately 7 years), and lifetime exposures, based on non-carcinogenic endpoints of toxicity. If EPA determines that MCLs are not protective, the HEAs may be TBCs. A final determination will be made in the ROD.

2.4.3.1 Policies, Guidance, and Local Requirements

Los Angeles County Well Standards

The substantive aspects of the permitting and installation requirements of the Los Angeles County groundwater well standards should be considered for the remedial action at JPL.

CSDLAC Policy

The CSDLAC policy is to accept groundwater only as a last resort. This policy is contained in Section 305 of the CSDLAC Wastewater Ordinance (November 1, 1989) and in "Guidelines for the Discharge of Rainwater, Storm Water, Groundwater, and Other Water Discharges."

Some remedial alternatives considered reduce concentrations of nitrates, metals, perchlorate, and/or TDS in the extracted and treated groundwater. These same treatment processes, however, generate a concentrated waste stream that potentially could be discharged to the CSDLAC.

Policy Memo 97-005, California Department of Health Services

Department of Health Services, Policy Memo 97-005: Policy Guidance for Direct Domestic Use of Extremely Impaired Sources. This Policy Memo, dated November 5, 1997, only applies to water purveyors who produce water from impacted aquifers for domestic use. While NASA is not a water purveyor, this policy must be considered by NASA for any alternative involving treating groundwater prior to transfer to a water purveyor by NASA. The permitting process is extensive and may require up to 3 years to complete. The process is intended to assure the health risk of using an impacted source is known, minimized, and considered acceptable. The process includes a source water assessment, characterization of water quality, effective treatment and monitoring programs, human health risk assessment, identification of alternative drinking water sources, completion of a California Environmental Quality Act (CEQA) review, and a public hearing. Municipal production wells that are currently producing from impacted aquifers are exempt from obtaining this permit as long as they meet current permit requirements and CADHS drinking water standards. If the current treatment process being used must be modified in any way, or if a municipal production well that is currently producing needs to be shutdown due to rising contaminant levels, a permit may be required pursuant to the requirements of this policy before production can begin again.

2.5 RAYMOND BASIN REPORT OF REFEREE

In 1944, an official safe yield determination for the Raymond Basin was made and presented in "Report of Referee" by the California Department of Public Works as Ordered by the Supreme Court of California. The safe yield was revised upward in 1954 in a second Report of Referee (Report). The Report presents adjudicated apportionment of rights to groundwater withdrawal within the Raymond Basin. The impact of contaminated groundwater withdrawal, treatment and potential reintroduction by NASA must be evaluated in light of the conditions set forth in the Report and the requirements in the Court's Order.

TABLES

TABLES

TABLE 2-1

SUMMARY OF CHEMICAL SPECIFIC ARARs FOR CONSTITUENTS OF POTENTIAL CONCERN JET PROPULSION LABORATORY

Constituent of Potential Concern[1]	Maximum Contaminant Level (MCL)		MCL Goal
	State	Federal	
Volatile Organic Compounds			
Carbon Tetrachloride	0.5 µg/L	5.0 µg/L	0
Trichloroethene	5.0 µg/L	5.0 µg/L	0
Tetrachloroethene	5.0 µg/L	5.0 µg/L	0
1,2-Dichloroethane	0.5 µg/L	5.0 µg/L	0
1,1-Dichloroethene	6.0 µg/L	7.0 µg/L	7.0 µg/L
Chloroform	None	100 µg/L[2]	None
Bromodichloromethane	None	100 µg/L[2]	None
Inorganic Constituents			
Perchlorate	18 µg/L[3]	None	None
Hexavalent Chromium	None	None	None
Arsenic	0.05 mg/L	0.05 mg/L	None
Lead	0.015 mg/L[4]	None	0
Nitrate	1.0 mg/L	1.0 mg/L	1.0 mg/L
California Secondary MCLs			
Aluminum	0.2 mg/L		
Color	15 units		
Copper	1.0 mg/L		
Corrosivity	non-corrosive		
MBAS (Methylated Blue Activated Substance)	0.5 mg/L		
Iron	0.3 mg/L		
Manganese	0.05 mg/L		
Odor Threshold	3 units		
Silver	0.1 mg/L		
Turbidity	5 units		
Zinc	5.0 mg/L		
MTBE (methyl-tert-butylether)	0.005 mg/L		
TDS (Total Dissolved Solids)	500-1000 mg/L[5]		
Chloride	250-500 mg/L[5]		
Sulfate	250-500 mg/L[5]		

1: Identified during initial risk screening (Foster Wheeler, 1999)
2: MCL is for total trihalomethanes which include chloroform, bromoform, bromodichloromethane, and dibromochloromethane
3: Interim Action Level
4: Action Level
5: Recommended and Upper Ranges

TABLE 2-2

LOS ANGELES RIVER BASIN PLAN DISCHARGE LIMITS

	TDS	Chloride	Sulfate	Boron	Nitrate	Bacteria, Coliform	Chlorine	Fluoride	DO (Dissolved Oxygen)
Arroyo Creek (surface water)	300 mg/L	15 mg/L	40 mg/L	None	45 mg/L	< log mean 200/100 mL	< 0.1 mg/L	NA	> 7.0 mg/L
Monk Hill Sub-Basin (groundwater)	450 mg/L	10 mg/L	100 mg/L	0.5 mg/L	45 mg/L	< 1.1/100 mL	NA	2.0 mg/L	NA

3.0 IDENTIFICATION, SCREENING, AND EVALUATION OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

The primary objective of this FS is to develop, evaluate, and compare remedial alternatives that meet ARARs to address contaminated groundwater at JPL. Prior to development of remedial alternatives, treatment technologies and process options with potential applicability for treating contaminated JPL groundwater are identified, screened and evaluated. The steps involved in this process (in general accordance with EPA guidelines, EPA, 1988a) are listed below:

1. Establishment of Remedial Action Objectives (RAOs), based on the constituents of interest, ARARs, exposure pathways, and target treatment goals established to protect human health and the environment.
2. Identification of General Response Actions (GRAs) to meet the RAOs.
3. Preliminary identification of treatment technology types and process options appropriate for each response action.
4. Screening and evaluation of treatment technologies and process options for implementability, effectiveness and relative costs for achieving the RAOs.

In Section 4.0, the selected treatment technologies and process options are combined into comprehensive remedial alternatives, which are then evaluated with regard to implementation, effectiveness, and cost. Alternatives that are retained in Section 4.0 are evaluated in detail in Section 5.0.

3.1 DEVELOPMENT OF REMEDIAL ACTION OBJECTIVES

RAOs consist of media-specific goals for protecting human health and the environment. RAOs should be as specific as possible, but not so specific that a reasonable range of remedial alternatives cannot be developed. The RAOs take into account the nature, extent, and migration of contamination, and potential exposure pathways and remediation goals defining acceptable contaminant levels. RAOs also consider contaminant levels and exposure routes, rather than contaminant levels alone, because protectiveness may be achieved by reducing exposure (EPA, 1988a). Listed below are the JPL groundwater constituents of interest, exposure pathways, and remediation goals that will be used to develop the RAOs.

3.1.1 Constituents of Interest

The results of the human health risk assessment conducted as part of the RI (Foster Wheeler, 1999) indicated that exposure to untreated JPL-impacted groundwater could pose a risk to human health. An initial list of Constituents of Potential Concern (COPCs) in JPL-impacted groundwater was identified based on the results of an initial human health risk screening (Foster Wheeler, 1999). These constituents are shown in Table 3-1. Based on results of the final human health risk assessment and an evaluation of ARARs (Section 2.0), a few of the initially identified

COPCs were shown to be present in groundwater at concentrations above acceptable risk levels. These constituents are identified as the constituents of interest for developing remediation goals and RAOs for the JPL site. The constituents of interest are divided into two groups as follows:

1. Organic constituents
2. Inorganic constituents

These are discussed in more detail in the following sections.

3.1.1.1 Organic Constituents

The organic constituents of interest for JPL are the volatile organic compounds (VOCs) CCl_4, TCE and 1,2-DCA (Table 3-1). All three VOCs were detected at levels above MCLs, but only CCl_4 and TCE had maximum potential cancer and non-cancer risk values outside EPA's range of acceptable risks.

Four additional VOCs were identified as constituents of potential concern (COPCs) during early baseline risk assessment screening including PCE, 1,1-DCE, chloroform and bromodichloromethane (Table 3-1). However, all of these constituents were detected at levels below State and Federal drinking water standards (MCLs) and had potential maximum cancer risk levels that fell within EPA's range of acceptable risk. All of these chemicals also, with the exception of chloroform, had potential maximum non-cancer risk levels (reflected by the "hazard quotient") that fell below EPA's threshold level of 1.0. The maximum non-cancer risk from chloroform slightly exceeded EPA's threshold in only one well (MW-16, hazard quotient = 1.7). Based on the isolated occurrence of the slightly elevated non-cancer risk, chloroform is not considered a health or environmental risk. However, it is important to note that all treatment techniques discussed in this FS for VOCs in groundwater will also treat chloroform.

3.1.1.2 Inorganic Constituents

The inorganic constituents of interest for JPL are ClO_4^- and Cr(VI) (Table 3-1). The maximum cancer-risk value for Cr(VI) and the maximum non-cancer risk value for ClO_4^- are outside EPA's range for acceptable risk. ClO_4^- is also present at levels above its interim action level (IAL) for drinking water (18 µg/L). An MCL has not been established for Cr(VI) or for ClO_4^-.

Three additional inorganic constituents, arsenic (As), lead (Pb) and nitrate, were identified as COPCs during early baseline risk assessment screening (Table 3.1). Maximum risk values for As and Pb, both naturally occurring elements, were within EPA and California ranges for acceptable risk. Lead was detected above its action level [0.15 milligrams/liter (mg/L)] in only one of 278 samples (1997-1998). This was in well MW-14, along the western/ upgradient edge of JPL. Arsenic was not detected above its MCL at JPL.

The maximum risk calculated for nitrate (a non-carcinogen) at JPL is below EPA's threshold level of 1.0. However, nitrate was detected above its MCL along the western/upgradient portion of JPL. It is believed the elevated levels of nitrate in the groundwater are the result of the historic use of cesspools and septic systems in the La Cañada-Flintridge community upgradient of JPL.

3.1.2 Exposure Pathways

It was concluded in the human health risk assessment (Foster Wheeler, 1999) that exposure to JPL contaminants through exposure to untreated groundwater does not occur because residents in the vicinity of JPL do not, and in the future will not, have access to untreated JPL-impacted groundwater. It is important to note that impacted groundwater is located in a deep aquifer, and local water purveyors treat groundwater, as necessary, to meet stringent State and Federal drinking water standards prior to distribution. Thus, there is no complete pathway for residential exposure to untreated JPL-impacted groundwater. However, pursuant to regulatory guidance and direction from EPA and California DTSC risk assessors, conservative hypothetical scenarios were evaluated where residents could be exposed to untreated groundwater (Section 1.2.8).

Although no exposure pathways to untreated impacted groundwater currently exist, contaminants are migrating toward municipal production wells, which could potentially create situations where current treatment technologies may need to be modified or where new treatment technologies may need to be implemented.

3.1.3 Remediation Goals

Remediation goals are target treatment levels based on acceptable exposure levels that are protective of human health and the environment. Remediation goals are developed primarily by considering ARARs.

The California Porter-Cologne Act states that fluids injected in a waste well must not impair the quality of water in the receiving aquifer. Treated water that may be reintroduced into the aquifer must meet this ARAR.

Treated water to be used for domestic supply must meet MCLs. MCLs are Federally enforceable national Primary Drinking Water Regulations for drinking water systems. More stringent California MCLs are similarly enforceable. The MCLs are set to be protective of human health as well as being feasible. If non-zero MCLGs are established and are relevant and appropriate, they are to be retained as remediation goals for remedial actions for potential sources of drinking water. If non-zero MCLGs are not available, MCLs will be retained (NCP, 40 CFR 300.430[e][2]). If an MCL or MCLG does not exist, a cancer-risk level or chronic health advisory value will be used (EPA, 1988a).

Hexavalent chromium does not have an MCL or an MCLG. The remediation goal for Cr(VI) in drinking water was, therefore, calculated to be 15 μg/L using a risk-based approach. This level corresponds to a cancer risk value of 1.0E-04 (i.e., 1 in 10,000 increase in chance of getting cancer). EPA considers a cancer risk of 1.0E-04 to be an acceptable target-level of risk. A review of non-cancer hazard index values calculated for Cr(VI) indicates that the non-cancer hazards are negligible, and, therefore, were not considered further because a treatment goal based on non-cancer risks would be higher than 15 μg/L.

Remediation goals for the JPL constituents of interest are included in Table 3-2.

3.1.4 Remedial Action Objectives (RAOs)

RAOs consist of goals for protecting human health and the environment from exposure to untreated JPL-impacted groundwater.

The RAOs for JPL reflect EPA's regulatory goal that contaminated groundwater be returned to its beneficial uses wherever practicable or, if restoration is deemed impracticable, "to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction." (40 CFR Section 300.430[1][a][iii][F]).

Based on nature, extent, potential migration of contamination, and potential for human and environmental exposure, the RAOs for JPL groundwater are:

1. Continue current activities designed to prevent exposure of the public to untreated JPL-impacted groundwater.
2. Minimize contaminant migration from more highly contaminated portions of the aquifer to less contaminated areas of the aquifer (both horizontally and vertically).
3. Reduce the potential impact of contaminant migration on downgradient water-supply wells.

3.2 GENERAL RESPONSE ACTIONS

This section identifies general response actions (GRAs) to address the RAOs identified in Section 3.1. Table 3-3 presents GRAs that are potentially feasible at the JPL site, with some representative technology types listed, as well as a brief explanation of each GRA. These were selected from a comprehensive list of GRAs typically considered for the remediation of hazardous waste sites (EPA, 1993). The following discussions briefly describe the types of GRAs for which potential remedial technologies and process options have been identified for the site.

No Action - No Action generally refers to a scenario under which the current status of the site would not change. At JPL, remediation activities are currently on-going (air stripping for VOCs and blending for ClO_4^- at Pasadena wells, and liquid phase granular activated carbon (LPGAC) for VOCs at Lincoln wells, see Section 1.2.6), and No Action is, therefore, characterized as No "Further" Action in this FS. No "further" remedial activities would, therefore, be undertaken to reduce the volume, mobility, or toxicity of the contaminants in the groundwater.

Limited Action - A Limited Action response generally refers to a scenario in which limited action is taken, such as groundwater monitoring to demonstrate no further impacts, or monitoring the natural attenuation of contaminants.

Institutional Controls **-** Institutional Controls are administrative means that are used to limit the public's exposure to contaminated media. Controls could include deed and use restrictions to limit access to or use of contaminated media. Use restrictions for groundwater may include provisions for alternative drinking water supplies.

Containment **-** Containment actions use physical barriers or controls to minimize or eliminate contaminant migration. These may be vertical or horizontal. Common vertical containment technologies generally include slurry walls (or similar technologies), and hydraulic control. Slurry walls serve to halt or divert sub-surface flow, whereas hydraulic control generally involves using extraction and injection wells to create hydraulic barriers that control groundwater flow. Common horizontal containment technologies include surface barriers such as caps to limit migration of contaminants due to infiltration.

Collection **-** Collection actions consist of extracting impacted groundwater by means of extraction wells or subsurface drains.

Treatment **-** Treatment of impacted groundwater at the site can include in-situ and ex-situ treatment technologies. These technologies may be physical, chemical, or biological treatments. Ex-situ treatment technologies are normally associated with various forms of collection technologies.

Disposal/Re-use **-** Disposal of treated groundwater after *ex-situ* treatment typically includes disposal to surface water bodies, re-introduction to the aquifer, and re-use for irrigation or as drinking water. Waste streams from various treatment processes are typically discharged to the sewer, or transported off-site.

3.3 IDENTIFICATION AND PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

This section provides a brief description of a variety of remedial technologies and corresponding process options that could potentially satisfy the RAOs for the site. These technologies and process options (summarized in Table 3-4) were subjected to a preliminary screening based on technical feasibility. Technical feasibility is a determination of whether a technology can reasonably be implemented at the site (EPA, 1988a). Based on this criterion, a number of technology types and associated process options were retained for further evaluation, as shown in Table 3-5. The retained technology types and associated process options were subjected to a more in depth screening, based on effectiveness, implementability, and cost, as discussed in Section 3.4.

Following is a description of a variety of technology types and associated process options identified for the site, along with relevant preliminary screening comments.

3.3.1 No Further Action

As discussed in Section 1.2.6, remedial activities are currently being conducted at the Pasadena and Lincoln production wells [air stripping or liquid-phase granular activated carbon (LPGAC) for VOCs and blending for ClO_4^-]. With "No Further Action", these activities would continue to occur. As per EPA guidance, No Further Action will be carried through to the end of this FS to allow for comparison with other alternatives.

3.3.2 Limited Action

Limited action technologies with potential application to JPL include monitored natural attenuation and groundwater monitoring, and are described below.

3.3.2.1 Monitored Natural Attenuation

Remediation by monitored natural attenuation (MNA) involves relying on naturally occurring processes to reduce contaminant concentrations to acceptable levels. MNA may be feasible at JPL in a limited role in combination with other technologies and is retained at this time.

3.3.2.2 Groundwater Monitoring

Groundwater monitoring is not a treatment technology by itself, however it is used to assess changes in contaminant concentrations in groundwater plumes over time. It is used in conjunction with other technologies such as MNA, collection or treatment to assess and verify remediation effectiveness. Groundwater monitoring is retained for such a role.

3.3.3 Institutional Controls

Institutional controls with potential application to the JPL site include use restrictions and alternate water supplies, as described below.

3.3.3.1 Use Restrictions

This allows for restrictions to help prevent or reduce public contact with impacted groundwater. This includes the current regulatory restrictions regarding the quality and fate of all water that is extracted from the Raymond Basin. The CADHS has strict standards for the quality of water used for domestic purposes, which all water purveyors must meet. This technology is already in place, and is, therefore, retained.

3.3.3.2 Alternate Water Supplies

This consists of providing alternate locations for water supply wells in areas of the aquifer that are not expected to be impacted by site contaminants, or of purchasing water from alternate water purveyors, such as the Metropolitan Water District (MWD). This technology is feasible, and is retained for further consideration.

3.3.4 Containment Technologies

Containment technologies with potential application to JPL include surface capping, vertical barriers and hydraulic control, and are described below.

3.3.4.1 Capping

This technology consists of installing a relatively impermeable barrier over contaminated soil to prevent further impact to contaminated groundwater, and to prevent contact with receptors. Options for capping include asphalt, concrete, clay, or other low-permeability materials. This technology is not applicable to the JPL site due to a number of reasons:

1. The contamination is already present at significant depth so that a cap will not prevent infiltration to, and migration from, a source close to the groundwater surface.
2. The groundwater is generally very deep (hundreds of feet below ground surface). The only recognized exposure point for human or other ecological receptors is through domestic consumption of untreated water though municipal production wells (in actuality, this never occurs, as the water is treated to meet strict drinking water standards prior to distribution). Therefore, there is no contact with receptors that capping technology could address.
3. Although the site is mostly paved and developed, the areal extent of impacted groundwater is large, and complete capping is technically infeasible.
4. Capping does not actually treat the contaminants.

Hence, capping is eliminated from further consideration.

3.3.4.2 Vertical Barriers

Vertical barriers are subsurface barriers that limit or control groundwater flow. These barriers consist of a vertically excavated trench that can be filled with a slurry, usually a mixture of bentonite and excavated soil. Alternatively, sheet piles or an impermeable membrane can be inserted into the soil. These types of barriers are often used where the waste mass is too large for practical treatment, or where mobile contaminants pose an immediate threat to down-gradient groundwater. Because the depth to groundwater at JPL ranges up to approximately 275 feet, and VOC contamination is found at depths ranging to 500-600 feet, implementation of this technology would be exceedingly difficult, costly, and impractical. Furthermore, while the technology is generally effective in limiting contaminant mobility, the long-term effectiveness is questionable because contaminants are not degraded or removed, and slurry walls may degrade or deteriorate over time.

Hence, vertical barriers are eliminated from further consideration.

3.3.4.3 Hydraulic Control

Hydraulic control is defined here as extracting and possibly re-introducing groundwater using strategically placed extraction and injection/infiltration wells to reverse or alter existing groundwater flow patterns, thereby inhibiting migration of contaminants. Re-introduction can be accomplished by either direct re-injection into the aquifer or indirectly via re-infiltration through the vadose zone. Extracted water is typically treated prior to re-introduction so that remediation is achieved in conjunction with hydraulic control. In the event that treatment is not feasible, impacted water can be extracted and re-introduced up-gradient in an effort to create a "closed system".

Inhibition of contaminant migration is an important consideration with regard to a variety of remedial actions. Thus, various applications of hydraulic control are retained for further consideration.

3.3.5 Collection Technologies

Two types of collection technologies were considered: extraction wells and subsurface drains.

3.3.5.1 Extraction Wells

This technology consists of using wells screened within the portion of the aquifer containing contamination to extract contaminated water for treatment and create hydraulic control of contaminant migration. This is a feasible means of collection, and is retained as an applicable technology.

3.3.5.2 Subsurface Drains

This technology consists of constructing a horizontal drain at depth and collecting contaminated water that flows into the drain. Based on the depth to groundwater at JPL, this technology would be extremely impractical and difficult to implement. Therefore, subsurface drains are eliminated from further consideration.

3.3.6 Treatment Technologies (*In-situ*)

These technologies consist of treating groundwater in place (*in-situ*) to meet remediation goals using physical, chemical or biological processes. Process options include air-sparging, dual phase extraction, reactive walls, addition of oxidizing or reducing agents, biological oxidation through oxygen enhancement, and stimulation of biological co-metabolic processes. It is noted here that the constituents of interest present in the JPL groundwater include VOCs, ClO_4^-, and to a lesser extent (on-site only), Cr(VI) (Section 1.2.5).

The properties of VOCs that affect their removal from groundwater are well known. Conversely, ClO_4^- has only recently been identified as an environmental contaminant and less is known regarding its behavior in environmental systems. Treatment techniques to remove it from contaminated groundwater are relatively new and untested. A summary of currently known information regarding ClO_4^- in environmental systems is presented in Appendix B. It is known that because of its non-volatile, relatively non-reactive nature, ClO_4^- behaves much differently than VOCs in groundwater. Perchlorate is not subject to the same remedial techniques as VOCs.

Appendix B also presents the results of some initial laboratory studies conducted for JPL to evaluate different treatment methods for ClO_4^-.

With regard to chromium (Cr), the predominant form of Cr(VI) in environmental systems is the chromate ion (CrO_4^{2-}) (Losi, et al., 1994). Like ClO_4^-, CrO_4^{2-} is a negatively charged oxyanion, is considered mobile in soil/water systems, and can be transformed via biological and/or non-biological reduction reactions to less toxic forms (Losi, et al., 1994). However, the impact of Cr(VI) at JPL is considerably less than that of ClO_4^-, and is limited to a very localized area on-site.

Because their chemical properties are similar, Cr(VI) and ClO_4^- are subject to the same general treatment approaches. However, because of its predominance at the JPL site, the major emphasis in this report is placed on treatment of ClO_4^- with the understanding that Cr(VI) would also be treated via the same processes. If Cr(VI) levels become an issue during any on-site remedial implementation (e.g. is present in water extracted for treatment), the treatment(s) selected for ClO_4^- can likely be optimized for Cr(VI) based on current knowledge of the proposed treatment options. Within the following discussions, distinctions are made as necessary to differentiate whether a treatment is applicable to treating VOCs or ClO_4^- and potentially Cr(VI).

3.3.6.1 Physical Treatment

Several *in-situ* process options are potentially applicable to JPL for physical removal of contaminants from groundwater, including air-sparging and dual phase extraction.

Air Sparging

The most commonly used in-situ physical treatment technique for VOC-impacted groundwater is air sparging. It involves installation of sparging wells in the area of impact with screens below the water table. Air is sparged into these wells at sufficient pressure to cause it to enter the aquifer matrix. VOCs in the groundwater are volatilized and move into the overlying vadose zone along with the sparged air. This air is typically collected by means of another technology, soil vapor extraction (SVE). SVE consists of extracting soil vapors by applying a vacuum in the vadose zone through wells screened above the water table. The number of sparge wells required to adequately remediate impacted groundwater depends on their radius of influence (ROI). The ROI in turn depends on a number of site specific parameters, and rarely exceeds the depth of the sparge screens below the water table (usually less than 30 feet). This process does not remove ClO_4^- or Cr(VI). Based on the depths to groundwater and to contamination (several hundred feet, and up to 500-600 feet, respectively), and the extensive area of impact, this technology would be extremely difficult to implement and is, therefore, eliminated from further consideration at this time.

Dual Phase Extraction

This process uses a high vacuum system to simultaneously remove liquid and gas from low permeability or heterogeneous formations. The vacuum extraction wells are constructed with a screened interval in the zone of contaminated soil and groundwater. As the vacuum is applied, soil vapor and groundwater are extracted, and treated on the surface, usually after being separated into vapor and liquid phases. Since the contamination is present at JPL in relatively low concentrations, and generally at appreciable depth, considerable time and effort would be required to remove relatively small amounts of contaminants. Due to these conditions, the process would be very ineffective. Because of its low effectiveness, this approach is considered impractical and is eliminated at this time.

3.3.6.2 Chemical Treatment

Process options commonly associated with *in-situ* chemical treatment that are potentially applicable to JPL include reactive walls, and addition of oxidizing or reducing agents. These are described below.

Reactive Walls

This process consists of installing permeable subsurface barriers (walls) of a mixture of iron catalyst and porous media (such as sand). The contaminated groundwater passes through the wall, where it is degraded via reactions with the iron catalyst. Reactive walls can be used to treat various VOCs and possibly Cr(VI), but are presently not considered capable of treating ClO_4^- (see Appendix B). More importantly, they are generally applicable only in shallow aquifers because they must be constructed to the level of the bedrock, or an impermeable clay layer. Because of the depth to bedrock at JPL (over 1,000 feet at the southeastern portion of the study area), this technology would be extremely difficult and impractical to implement. Due to limited effectiveness, and substantial difficulties in implementation, this technology is eliminated at this time.

Injection of Oxidizing or Reducing Agents

Several geochemical oxidation processes for remediation of impacted groundwater have been identified. Most of these applications are based on injection of an oxidizer along with other reagents (which are typically proprietary) to bring about chemical oxidation of VOCs. Most of these are based on Fenton's chemistry, in which stabilized hydrogen peroxide is catalyzed by an iron compound (such as ferrous sulfate) to form hydroxyl radicals. These radicals oxidize the contaminants in the groundwater. Because of the areal extent and depth of the plumes at JPL, this technology is essentially non-implementable from an engineering standpoint, and is rejected at this time. It should be noted that several reducing agents were tested for their ability to destroy ClO_4^- in JPL groundwater. These may have been applicable for an *in-situ* injection process, but the various reducing agents tested were generally found to be ineffective (see Appendix B).

3.3.6.3 Biological Treatment

The process options generally associated with *in-situ* biological treatment include biological oxidation through oxygen enhancement, stimulation of co-metabolic processes, and stimulation of reducing conditions. These are described below.

Oxygen Enhancement

This process involves supplying oxygen to the groundwater to enhance the rate of aerobic degradation of organic contaminants by naturally occurring microbes. This is typically accomplished by sparging the affected aquifer with air, or by circulating a dilute solution of hydrogen peroxide throughout a contaminated groundwater zone. This technology also requires consideration of various aquifer conditions such as pH, the presence of nutrients, and permeability of the subsurface materials. The main organic constituents of interest at JPL are TCE and CCl_4, which are generally not considered to degrade under aerobic conditions (with the exception of co-metabolic processes-see next paragraph). It is noted that perchlorate is subject to biological destruction. However, oxygen interferes with this process, and, therefore, oxygen enhancement is not applicable to treating ClO_4^-. Because the major constituents of interest at JPL are not considered to undergo significant degradation under aerobic conditions, this technology is not considered effective and is eliminated at this time.

Co-Metabolic Processes

This process consists of injecting oxygen (or ambient air), along with methane or propane into groundwater to enhance degradation of chlorinated solvents by methanotrophic bacteria (methanotrophs) through a mechanism that has been termed "co-metabolism." This mechanism is not applicable for treating ClO_4^-. Co-metabolism is a process whereby bacteria fortuitously degrade (co-metabolize) a non-growth substrate, such as a particular chlorinated organic compound. This is accomplished via enzymes, which break down similar substrates such as methane or propane, which supplies the bacteria with energy for growth. There is no energy derived from the co-metabolized compound, and no known benefit to the organism results. The best documented example of this process is the fortuitous degradation of PCE and TCE by methanotrophs while growing on methane or propane under aerobic conditions.

The extent of chlorinated VOC contamination in the JPL aquifer is generally widely dispersed with much of the contamination found deep in the aquifer. Injection of oxygen and methane or propane in a way that achieves the necessary contact with contaminated groundwater would be very difficult. Furthermore, VOC levels are generally low (the highest recent detects reach a maximum of 150 μg/L, most other detects are well below this level). Because of "diminishing return" effects which are commonly observed with many *in-situ* bioremedial techniques, substantial time would likely be needed to achieve the necessary results. This technology is, therefore, not effective and is eliminated at this time.

Reductive Processes

This technology involves addition of a carbon source to lower the oxidation/reduction potential of the groundwater and create a reducing environment. Under these conditions, microbially mediated reductive dechlorination (for VOC remediation) and reduction of Cr(VI) to insoluble Cr(III) is known to occur via a variety of mechanisms. This technique also has the potential to reduce ClO_4^- as well, but this has not been proven at this time. In terms of implementability, this technology is not presently well developed, and is not suited to the site conditions at JPL.

In addition, due to "diminishing return" effects, which are commonly observed with many *in-situ* bioremedial techniques, substantial time would likely be needed to achieve the necessary results. Because of limited implementability and effectiveness, this technology is eliminated at this time.

3.3.7 Treatment Technologies (*Ex-situ*)

Ex-situ technologies involve pumping the groundwater out of the aquifer and treating it at the ground surface. Potentially applicable process options associated with this technology for JPL contaminants include liquid phase granular-activated carbon (LPGAC) adsorption, air-stripping, ultraviolet (UV) oxidation, ion exchange (IE), reverse osmosis (RO), treatment with oxidizing/reducing agents, electrochemical reduction, and biological treatment. Process options associated with treatment of vapor generated with air-stripping include vapor phase granular activated carbon (VPGAC), thermal oxidation, catalytic oxidation, and biofiltration. The feasibility of these options will be evaluated in the following subsections.

As mentioned previously (Section 3.3.6), ClO_4^- and Cr(VI) behavior in groundwater differs significantly from that of VOCs, and is not subject to the same remedial technologies. As in the previous discussions, distinctions are made as necessary to differentiate general applicability of a treatment to VOCs or ClO_4^- and Cr(VI).

3.3.7.1 Physical Treatment

A number of process options are available in which contaminants are removed from groundwater via physical means, including air-stripping, carbon adsorption, ion exchange, and reverse osmosis.

Air-Stripping

This process consists of passing ambient air through the contaminated water transferring VOCs into the vapor phase [ClO_4^- and Cr(VI) are not removed]. Then, after some form of treatment to remove VOCs, discharging the air back to the atmosphere. This is a feasible process and is retained for removal of VOCs[1].

Carbon Adsorption

Liquid-phase granular-activated carbon (LPGAC) adsorption is a feasible means for removing VOCs from groundwater. Carbon has also been found to adsorb ClO_4^- to a limited degree (Appendix B). However, the affinity of carbon for ClO_4^- is considered weak, and adsorption capacities are not believed to be sufficient to warrant consideration as a primary treatment. Some research is currently being conducted to investigate the use of metal-impregnated LPGAC for ClO_4^- removal (Na, et al., 1999), but the work is in its very early stages. LPGAC is also known to adsorb Cr(VI) to a limited extent. However, LPGAC is generally not considered effective, and is

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[1] As discussed in Section 1.0, air-stripping has been implemented at the four nearby City of Pasadena municipal production wells for removal of VOCs.

not commonly used for treatment of Cr(VI). LPGAC is, therefore, eliminated as a feasible option for removing ClO_4^- and Cr(VI), but is retained for treatment of VOCs[2].

Ion Exchange

Ion exchange (IE) involves the exchange of ions from solution by sorption, onto a suitable IE resin. This process is capable of removing a variety of ionic species, but is not effective for VOCs. As discussed in Appendix B, ion exchange resins are capable of removing ClO_4^- from JPL groundwater by exchanging chloride (Cl^-) from the resin with ClO_4^- in the groundwater. A pilot study was subsequently conducted at JPL by Calgon Carbon Corporation (Calgon), which involved testing the effectiveness of a proprietary IE system to treat the JPL groundwater (discussed further in Section 3.4.6). It is expected that anion exchange would be able to remove Cr(VI) as well, based on its anionic nature (see Section 3.3.6). Ion exchange is, therefore, retained as a feasible technology for removing ClO_4^- as well as Cr(VI).

Membrane Process

Membrane processes, including reverse osmosis (RO), nano-filtration (NF), and electrodialysis (ED) consist of using specialized filters and membranes to remove contaminants from water. Membrane processes have the ability to remove ClO_4^- from groundwater, and are potentially applicable to removing Cr(VI) as well. In addition, membrane processes are capable of removing various organic compounds, although they are not considered as an economical primary VOC treatment when compared with air-stripping and LPGAC. Based on input from several vendors, and a review of current ClO_4^- research activities, NF and ED are not currently considered feasible for treating large quantities of ClO_4^- impacted water. However, RO is one of only a few processes currently considered to be capable of removing ClO_4^- from groundwater at the high flow rates that may be required at JPL. RO is, therefore, retained for further evaluation for treatment of ClO_4^- and Cr(VI). VOC removal is also acknowledged to occur with RO.

3.3.7.2 Chemical Treatment

With regard to chemical treatment, a limited number of process options are considered, including ultraviolet (UV) oxidation, treatment with oxidizing or reducing agents, and electrochemical reduction. These are described below.

Ultraviolet Oxidation

This process consists of irradiating VOC-contaminated groundwater with UV light and introducing hydrogen peroxide (H_2O_2) into the water stream. The H_2O_2 breaks down, forming the OH^- radical, which completely oxidizes the VOCs. This process will not remove ClO_4^- from groundwater. With regard to VOCs, the main advantage of this process compared to carbon adsorption and air-stripping is that it destroys the VOCs, leaving no residual waste streams under optimal conditions. However there are also several major disadvantages. These include: high

[2] As discussed in Section 1.0, LPGAC has been implemented at the Lincoln Avenue Water Company municipal wells for removal of VOCs.

capital costs, the presence of suspended solids causing competition for the UV light energy which results in partial oxidation and formation of by-products for high turbidity waters, electricity–intensive operation, and significant operation and maintenance (O&M) costs. Furthermore, formation of by-products is generally expected and may themselves require further treatment. Because of these disadvantages, UV oxidation is eliminated from further consideration.

Treatment with Oxidizing or Reducing Agents

These are similar to the *in-situ* chemical process options discussed earlier, but with treatment taking place at the ground surface. With regard to VOCs, several chemical catalysts have been used to oxidize organic compounds in groundwater. However, this process is not proven and is not suited to treating water at the large flow rates expected to be required at JPL. The process is also more expensive and difficult to operate than air-stripping or carbon adsorption. With respect to ClO_4^-, a number of chemical reducing agents (solid and soluble) were tested for their ability to reduce and destroy ClO_4^- in JPL groundwater. However, none were found to be capable of carrying out the reaction (Appendix B). Cr(VI) may be subject to chemical reduction. Cr(VI) is of relatively minor importance at JPL and is expected to be treated concurrently by whatever method is selected for ClO_4^-. These processes are eliminated at this time due to low effectiveness and high costs.

Electrochemical Reduction

Some research is currently being conducted to investigate the use of electrochemical techniques for ClO_4^- removal (Theis, et al., 1999). The effects of such a process on VOCs are not known. This work is still in an early research stage, and results are not expected to be available before a treatment option is selected for this site. Because the process is not proven (even at the bench scale), it is eliminated at this time.

3.3.7.3 Biological

Because chlorinated VOCs are generally resistant to biodegradation, biological treatment is evaluated for treatment of ClO_4^-. The process would involve extraction of groundwater, which is then pumped through vessels (bioreactors) containing microbes that are attached to, or suspended within various matrices in the vessels. A carbon source is supplied in the feed, which the microbes oxidize while breaking down the ClO_4^-. This process is one of several processes currently believed to be capable of removing ClO_4^- from groundwater and is potentially effective for removal of Cr(VI) as well (see Section 3.3.6). Although it is theoretically possible, when optimized for ClO_4^- treatment, this technology has not been shown to affect VOCs. This technology is retained for consideration of treatment of ClO_4^- and Cr(VI) at this time.

3.3.8 Disposition of Treated Water

Options for use of treated water evaluated for this FS include re-use as a drinking water source, discharge to surface water bodies, use as irrigation water, discharge to publicly-owned treatment works (sewer), and re-introduction to the aquifer. These are described below.

3.3.8.1 Re-use as a Drinking Water Source

This option would be implemented in conjunction with a collection and treatment technology, which allows for treatment of water to drinking water standards, and involves distribution of treated water via the various local water purveyors for domestic consumption. This would pertain mainly to non-biologically treated water, and would involve an extensive permitting process directed by the California Department of Health Services (CADHS). This technology is retained for further consideration.

3.3.8.2 Discharge to Surface Water Bodies

This option consists of discharging treated water to surface water bodies, such as streams, ponds, or creeks located outside the site. It would be implemented in conjunction with a collection and treatment technology and would require local/regional permits, specifically, a National Pollutant Discharge Elimination System permit from the State (RWQCB). This technology is retained at this time for further consideration.

3.3.8.3 Use as Irrigation Water

This option consists of using treated water to irrigate various facilities such as golf courses or parks. It would be implemented in conjunction with a collection and treatment technology and would require local/regional permits. This technology is retained at this time for further consideration.

3.3.8.4 Discharge to Publicly-Owned Treatment Works (Sewer)

This option consists of discharging treated water to local publicly owned treatment works (sewer) through new or existing sewer lines. It would be implemented in conjunction with a collection and treatment technology that is not expected to produce an effluent that meets drinking water, irrigation or re-introduction standards. The Los Angeles County Sanitation District has indicated that there are no limits on chemical oxygen demand, biological oxidation demand, bacterial content, or total dissolved solids (TDS) for wastewater discharged to the sewer system. This technology is retained at this time for further consideration.

3.3.8.5 Re-Introduction to the Aquifer

This option consists of returning treated water to the aquifer via direct injection or infiltration through the unsaturated zone. It would be implemented in conjunction with a collection and treatment technology. It is eliminated as a means to directly dispose of waste from a primary treatment (IE or RO waste), due to regulatory constraints involving water quality issues. It is noted, however, that biologically treated, disinfected, secondary effluent could potentially be re-introduced to the aquifer if it were blended back into the primary effluent stream, and the final stream met strict regulatory standards. Re-introduction is thus retained for further consideration.

3.4 EVALUATION OF RETAINED TECHNOLOGIES AND PROCESS OPTIONS

In this section, the retained remediation technologies and process options identified and preliminarily screened in the previous section (Section 3.3, see Table 3-4) are further evaluated based on effectiveness, implementability, and relative cost. The results of this evaluation are summarized below.

The effectiveness screening included the following criteria:

1. The reliability in meeting chemical-specific ARARs or human health-based target concentrations required to achieve remedial objectives. Technologies that do not allow the achievement of chemical-specific ARARs or do not effectively contribute to the protection of public health, welfare, or the environment at the site were eliminated.
2. The degree of permanent reduction in toxicity, mobility, and volume of contaminants achieved by the technology. Technology types and process options that permanently reduce toxicity, mobility, and volume were preferred over those that do not provide these benefits or the same degree of benefit.
3. The long-term risks as a result of treatment residuals or containment systems. Technology types and process options that have significantly lower long-term risks were preferred.
4. The risks to the public, site workers, or the environment during implementation. Technologies posing significantly smaller adverse risks during implementation were preferred.

The implementability screening included the following criteria:

1. Potential site characteristics that limit the construction or effective functioning of the technology. Technologies limited by site conditions such that their effective functioning is seriously impaired were eliminated.
2. Waste or media characteristics that limit the use or effective functioning of the technology. Technologies that are limited by waste or media characteristics such that their effective functioning is seriously impaired were eliminated.
3. The availability of equipment needed to implement the technology or the capacity of on- or off-site treatment or disposal facilities required to remediate the site. Technologies that are commercially developed and readily available were given preference over innovative technologies for which limited information is available.

Cost-screening criteria included relative capital, and O&M costs rather than specific detailed cost estimates. Cost analysis is based on engineering judgment, and the cost of each process option is evaluated relative to the cost of other process options in the same technology type. Process options with lower relative cost were preferred if the effectiveness and implementability criteria were judged to be similar.

Screening of remedial technologies was used to select those technologies most appropriate for meeting the RAOs for the site. Features common to all comparable technologies, such as routine groundwater monitoring, were not considered in the screening analysis. The screening process evaluated the major effects of the technologies, and was intended to identify and eliminate less effective or less reliable technologies.

Within a technology type, several process options may have been identified. Each identified technology process option was screened individually for effectiveness, implementability, and cost. The screening criteria were applied in a step-wise evaluation process representing the relative importance of the screening criteria to the evaluation. Process options judged to be inferior in meeting high priority criteria (Effectiveness Criterion 1 and Implementability Criteria 1 and 2) were eliminated from further screening. Those remaining process options were subjected to screening using the next screening criteria. Lower priority criteria were used primarily for differentiating among process options within a technology type.

Following is a discussion of the technology types and associated process options that were retained in the initial screening (Section 3.3), along with relevant screening comments.

3.4.1 No Further Action

As per EPA guidance (EPA, 1988a), the No Further Action scenario will be carried through to the end of this FS to allow for comparison with other alternatives. For JPL, the No "Further" Action includes current remedial activities (Section 1.2.6), which includes the air-stripping and LPGAC systems currently removing VOCs from extracted water at the City of Pasadena and Lincoln Avenue Water Company wells (respectively). ClO_4^- will also continue to be addressed through current purveyor blending practices.

3.4.2 Limited Action

Monitored natural attenuation (MNA) and groundwater monitoring were retained in the above preliminary screening, and are further discussed below.

3.4.2.1 Monitored Natural Attenuation

A discussion of the applicability of MNA at JPL is provided in Appendix A. As discussed in Appendix A, natural attenuation mechanisms may be operating in the JPL aquifer to a limited degree, but are expected to be insufficient as a primary remediation mechanism. However, MNA can be used in conjunction with other active remediation activities or as a follow-up to remediation that has been implemented, and is, therefore, retained for such a role. It could also be used for portions of a contaminant plume that are below MCLs, if active remediation were to be occurring in portions of the plume that are above MCLs. Hence, MNA is retained for further consideration.

3.4.2.2 Groundwater Monitoring

Groundwater monitoring would consist of collecting samples from some or all of the existing JPL groundwater monitoring wells/screens, and analyzing them for the constituents of interest. It would also include obtaining and assessing chemical data from analysis of nearby production well samples collected by the local groundwater purveyors. Groundwater monitoring is necessary to assess contaminant concentrations over time and to verify effectiveness of the selected remedial action(s). Groundwater monitoring by itself is not an effective technology for meeting the RAOs. However, it is considered as a component of other technologies, such as extraction, and is, therefore, retained for such a role.

3.4.3 Institutional Controls

With regard to institutional controls, alternate water supplies, as well as several applications involving use restrictions were retained as follows:

3.4.3.1 Alternate Water Supplies

Alternate water supplies, either extracted from new water supply wells (located in areas that are not impacted by groundwater contaminants) or purchased from outside water purveyors, may be necessary. Scenarios for which alternate water supplies may be needed include: (1) if any remedial action involves treatment and disposal of the extracted groundwater, or (2) if migration of JPL impacted groundwater, or implementation of a remedial technology to treat JPL impacted groundwater involves partial or complete loss of production for any of the nearby municipal production wells. Use of alternate water supplies limits human contact with contaminated water, but does not directly reduce contaminant levels or contaminant migration. However, alternate water supplies may be necessary in conjunction with various remedial actions, and is, therefore, retained.

3.4.3.2 Use Restrictions

These restrictions already exist through adjudication of water rights, which are administered through the Raymond Basin Management Board, and preclude private withdrawal of groundwater. In addition, the various local water purveyors that are currently using the aquifer as a source of drinking water are subject to CADHS regulations. These regulations stipulate acceptable water quality for the supplied water and require that contaminants are not present above their respective regulatory levels. These restrictions and regulations do not directly provide for remediation or reduction of contaminant migration. Nevertheless, these restrictions have been and will be required for protection of human health, and are retained as part of other technologies.

3.4.4 Containment Technologies

Because of the lateral and vertical extent of groundwater contamination at JPL, capping and vertical barriers were eliminated from further consideration based on non-implementability. Hydraulic control is therefore the only potentially applicable containment option (see Section 3.3).

3.4.4.1 Hydraulic Control

Extraction of water (with or without returning the water to the aquifer) from the groundwater aquifer can alter the groundwater gradient and, therefore, be used to control contaminant migration. Extracted water can also be treated prior to replacement or re-use so that remediation is achieved in conjunction with hydraulic control. Extraction wells for this purpose are typically located downgradient of contaminant source areas, and re-injection or infiltration wells may be located upgradient to allow for re-circulation of water in an effort to create what is intended to be a closed system. If hydraulic control is to be combined with remediation, extraction wells may be positioned within, or near the leading edge of the plume (or portion of the plume that exceeds regulatory limits), and re-injection or infiltration wells can be located up- or downgradient, depending on the desired effect and other local factors.

Hydraulic control is a feasible technology, either in conjunction with treatment systems, or where treatment technologies for a particular contaminant may be questionable in terms of feasibility. Hydraulic control (with or without remediation) as described above is retained for further evaluation.

3.4.5 Collection Technologies

Because of the lateral and vertical extent of contamination at JPL, horizontal drains were eliminated from further consideration because they are not implementable. However, extraction wells were identified as a potentially feasible collection technology at JPL (see Section 3.3).

3.4.5.1 Extraction Wells

Extraction wells are commonly used to influence groundwater flow, contain the migration from a specified zone, or to deliver groundwater to the ground surface for treatment. In general, extraction wells are versatile under a variety of site conditions and have design and operating flexibility. Because of the large areal extent of contamination at JPL, multiple wells, located both on- and off-site, may be necessary to maximize capture zones and achieve significant reduction in contaminant migration. Due to their ease of installation, effectiveness at other groundwater remediation sites, and relatively low capital and O&M costs, extraction wells are retained for further evaluation.

3.4.6 Treatment Technologies (*Ex-situ*)

Several *ex-situ* treatment technologies were retained as being potentially applicable to the JPL site (Section 3.3). The feasibility of these options will be evaluated in the following subsections. As explained above (Section 3.3.6), properties of VOCs differ markedly from those of ClO_4^- and Cr(VI). For this reason, treatment technologies are also different. Treatment options discussed below are screened for their ability to remove VOCs, ClO_4^-, and Cr(VI) as indicated.

3.4.6.1 Physical Treatment

A number of process options were retained in which contaminants are removed from groundwater via physical means, including carbon adsorption, air-stripping, ion exchange, and reverse osmosis.

Air-Stripping

Air-stripping is effective in removing VOCs from water, but is not effective for treating ClO_4^-. It is noted that stripping of VOCs can also be accomplished using steam, however steam-stripping is far less implementable and more costly than air stripping. In addition, steam is typically used for less volatile compounds than the constituents of interest at JPL. Steam-stripping is, therefore, not considered further.

Air stripping is a proven technology and has been used effectively for removal of VOCs from groundwater at many sites. Contaminated water enters a stripping tower at the top and is evenly distributed across an internal packing media through distributor nozzles or weirs. A countercurrent air stream is produced by a positive pressure system that blows ambient air into the tower, while a vacuum system pulls the ambient air upward through the packing from the bottom of the tower. As the contaminated water flows countercurrent to the rising air stream, VOCs are transferred from liquid to vapor phase and enter the air stream. The VOCs are then carried by the air stream out of the tower to an off-gas treatment system. The internal packing media acts to increase the total surface area available for mass transfer of the VOC contaminants from the water and into the vapor stream. Treated water falls from the packing media into the stripper basin and exits the tower. Other potential configurations include tray air strippers and rotary-spray air strippers.

The extent of compound removal by air stripping is governed by many factors, including contaminant concentrations in groundwater, the physical properties of the contaminant, temperature of the air and water, and the air-to-water ratio. The Henry's Law constant is used to determine how easily a compound can be treated by air-stripping. The larger the Henry's Law constant, the greater the equilibrium concentration of the contaminant in the gas phase. Compounds with high Henry's Law constants are more easily removed from solution than those having lower values. VOCs typically have dimensionless Henry's Law constants greater than 0.1 (Patterson, 1985), which corresponds to high removal efficiencies.

Air stripper performance may also be adversely affected by the presence of various inorganic compounds and suspended solids in the groundwater. Groundwater with elevated hardness may result in calcium and magnesium salt deposits in the tower packing media. Elevated iron or manganese concentrations, when oxidized in the air stripper, will result in metal hydroxide precipitation, which can severely foul the packing media and reduce its effectiveness in removing VOCs. In addition, elevated total suspended solids concentrations in the groundwater can also result in deposition of solids on the tower packing and reduce liquid-to-air mass transfer. Inhibitor chemicals are often used to prevent such fouling. Groundwater at JPL generally contains low concentrations of iron and suspended solids (Table 1-3) and should not require pretreatment. Air stripping is an effective and relatively low-cost process option for removal of VOCs from groundwater and is retained for further discussion.

Off-Gas Treatment – Off-gas treatment is used to remove the contaminants from a vapor stream (e.g., air stripper off-gas) prior to discharge to the atmosphere. A variety of methods may be used to treat the off-gas:

- Thermal destruction units
  - Vapor combustion
  - Catalytic oxidation
- Carbon adsorption unit
- VOC adsorbing resins
- Vapor condensation

A determination of the most economical off-gas treatment method may change if the concentrations of contaminants vary by an order of magnitude, either across the site, or with time.

Thermal Destruction – The primary advantage of thermal destruction is that the contaminant is chemically altered so that it is no longer toxic. Vapor combustion units are typically used for contaminant concentrations greater than 12,000 parts per million by volume (ppmv); catalytic oxidation units are typically used for contaminant concentrations less than 12,000 ppmv. Vapor/liquid separators are used prior to thermal destruction units.

The advantages of vapor combustion units include simple operation and high compound destruction efficiencies. However, based on the low levels of VOCs in the JPL groundwater, off-gas concentrations will be substantially less than the 12,000 ppmv required for vapor combustion. Therefore, vapor combustion was not retained as an option for treating off-gas.

Catalytic oxidation is effective for hydrocarbon vapors at concentrations less than 12,000 ppmv, but greater than 1,000 ppmv. Recently developed catalysts permit efficient destruction of chlorinated compounds as well. The catalytic oxidation unit operates by preheating the vapor before entering a burner. The heated gas passes through a catalyst bed where it is oxidized. The catalyst accelerates the rate of oxidation and allows oxidation to occur at lower temperatures than thermal incinerators by adsorbing oxygen and the contaminant on the catalyst surface, where the reaction produces carbon dioxide, water, and hydrogen chloride gas. Catalytic oxidation of air-stripper off-gas is not retained for further evaluation because it is typically not cost effective, largely due to energy consumption and extensive operation and maintenance. Additionally, preheating the air stream for catalytic oxidation, and the need for removing hydrogen chloride from the vapor stream by scrubbing, makes this option more costly than carbon adsorption.

Carbon Adsorption – Activated carbon adsorption is the most commonly employed vapor treatment process for chlorinated VOCs. Carbon adsorption is typically used when contaminant concentrations are less than 1,000 ppmv. Although carbon adsorption has high removal efficiencies and is effective for most vapor streams, several disadvantages are associated with its use:

- The contaminants are not destroyed.
- Carbon must be regenerated either on-site or off-site, or disposed of off-site.
- Efficiency is reduced by moisture in the gas phase.

Despite its disadvantages, carbon adsorption typically compares favorably to other off-gas treatment processes due to the relatively low levels of VOCs in the JPL groundwater, and is retained for further consideration.

Synthetic Resin Adsorption – VOCs can be adsorbed using various synthetic resins in place of activated carbon. In contrast to activated carbon, which will adsorb a wide variety of chemicals, synthetic resins are designed to selectively adsorb particular chemicals or families of chemicals. In certain applications, this is advantageous because only chemicals of concern are removed. However, this may also result in synthetic resins being inappropriate or overly expensive (because additional treatment trains may be needed) for certain treatment applications where a wide variety of chemicals must be removed. Synthetic resin adsorption systems are typically constructed with on-site regenerative systems because the resins may be regenerated many times without any loss of adsorptive capacity, and because no infrastructure exists to perform off-site recycling of the resins, as is the case with activated carbon. In a regenerative system two sets of resin beds are employed: one in active adsorption service and one undergoing desorption. In the desorption process, the adsorbed chemicals are removed from the resin by heating and/or the application of a vacuum. Typically nitrogen or steam are used as the purge media. The desorbed chemicals are then condensed from the purge stream and recovered.

On-site regenerative systems using synthetic resins generally have significantly greater capital costs than typical carbon adsorption systems that employ off-site regeneration or disposal, but may have lower operating costs. Synthetic resin adsorption systems are not widely used for off-gas treatment because the high capital costs typically do not offset modest potential reductions in operating costs. Hence, this technology is eliminated from further consideration at this time.

Vapor Condensation – Vapor condensation may be used when the contaminant concentration is high and the flow rate is low. Condensation is typically accomplished by refrigeration; its effectiveness is determined by the vapor pressure and temperature characteristics of the contaminants present. Because condensation of the contaminant(s) is rarely complete, an additional method of treatment is typically required.

Because VOC concentrations in JPL groundwater are low and flow rates are expected to be high, vapor condensation is considered ineffective and is not retained for further discussion.

Liquid-Phase Granular Activated Carbon Adsorption

Liquid-phase granular activated carbon (LPGAC) adsorption consists of passing VOC-contaminated groundwater through vessels containing granular activated carbon (GAC). The VOCs are adsorbed to the carbon, which typically has capacities ranging from 0.5% to 5% depending on concentrations and other water quality parameters. LPGAC is generally considered effective for removal of all VOCs except vinyl chloride and dichloromethane, neither of which were detected in groundwater at JPL.

LPGAC adsorption is most effective for non-polar compounds of low solubility. This option is widely used for the removal of both volatile and non-volatile organic compounds. Activated carbon adsorption is most often carried out in a pressurized vessel that contains granular activated carbon. Contaminated water enters the pressurized vessel at the top and is evenly distributed over the GAC. As contaminated water flows through the activated carbon media, organic compounds are adsorbed onto the microporous surfaces of the activated carbon. When the carbon's pores are saturated with adsorbed organic compounds, the carbon must be replaced with new or thermally regenerated carbon media. Carbon regeneration frequency is a function of water flow rate, concentration of organic compounds in the feed stream, and carbon mass. Treated water flows through a collection assembly positioned at the bottom of the vessel before exiting the adsorber.

Part of the performance of activated carbon adsorbers depends on the concentration of suspended solids in the influent stream. High concentrations of suspended solids and oxidized iron will plug the carbon media and negatively affect system hydraulics as well as the adsorption process. As a result, multimedia filtration or clarification/equalization to remove suspended solids may be required as pretreatment to LPGAC. The cost involved in changing out the saturated carbon bed and its transportation/treatment/disposal as hazardous waste are negative factors in using LPGAC as a process option. In addition, some adsorption capacity is also consumed by natural organic carbon and minerals in groundwater.

Activated carbon adsorption is a surface attraction phenomenon influenced by the physical properties of the carbon and contaminant compounds. Water characteristics such as dissolved solids concentration, water temperature, and pH also have an impact. The combined quantitative effect can be expressed by the Freundlich adsorption equation, where the exponent reflects whether adsorption is favorable or not, as follows:

$$q = K * (C_f)^{1/n}$$

Where: q = the amount of compound adsorbed per unit mass of carbon

K, n = "Freundlich" parameters (empirical or by laboratory studies)

C_f = Equibrilium concentration

Because of relatively high values for the constant K (greater than 10 for most of the contaminants at JPL, and greater than 150 for TCE and PCE) it is expected that LPGAC adsorption would be

Continue

an effective groundwater treatment technique. LPGAC is therefore retained for further consideration, but because its efficiency is not optimal for treating groundwater with low VOC concentrations, such as that observed at JPL, is ranked lower than air-stripping for VOC removal.

Carbon has also been found to adsorb ClO_4^- to a limited degree, but the affinity of GAC for ClO_4^- is considered to be weak, and capacities are not known. LPGAC is, therefore, eliminated from consideration for treatment of ClO_4^-.

Ion Exchange

Ion exchange (IE) involves removing ions from solution by sorption on a suitable IE resin. This process is capable of removing a variety of ionic species, but is not effective for VOCs. Perchlorate and Cr(VI) are anionic in nature and are easily removed using various ion exchange resins. These resins contain positively charged adsorption sites, to which specific, exchangeable, anions (typically chloride) are bound. As ClO_4^--impacted groundwater is passed through the resin, ClO_4^-, as well as other anions, are sorbed to the resin. The chloride is correspondingly released into the effluent stream. In this process, the resin eventually becomes saturated with the contaminant ions, such as ClO_4^-, Cr(VI), sulfate, and nitrate, and must be regenerated. This is accomplished by using a concentrated (typically 5-10%) sodium chloride solution (brine). In this regeneration step, the brine is passed through the spent resin and removes the adsorbed ClO_4^- and other anions from the adsorption sites. The regeneration solution supplies replacement chloride ions and the resin can be reused. The ClO_4^- and other anions remain in the brine, which still must be treated or disposed of properly. A number of such regeneration cycles may be carried out before the resin needs replacement.

While IE is effective in ClO_4^- removal, the major limitation of its implementation at JPL involves disposal of the brine. The volume of brine is generally estimated at approximately 2-5 percent of the system flow rate. Because of its caustic nature, brine is considered very difficult to treat. At another southern California site where ClO_4^- was present, IE was retained based on the fact that the site had access to a local brine disposal line. This allowed for favorable economics of operating an IE system by eliminating the need to treat the brine stream. At JPL, there is no access to such a brine disposal feature. However, because it has the capability to remove ClO_4^- from water, IE is retained for further consideration as a potential component of a treatment train to address ClO_4^- and Cr(VI).

Calgon Carbon Corporation (Calgon) recently piloted a proprietary IE system to remove ClO_4^- from groundwater at JPL. The system consisted of a treatment train that included the following:

- A LPGAC system to remove VOCs prior to ClO_4^- treatment.
- An IE system which removed ClO_4^-, as well as nitrate, sulfate and other anions.
- A catalytic destruction module, which reduced ClO_4^- (as well as nitrate) in the brine.
- A nanofiltration system for removal of sulfate from the brine.