Previous

The pilot study was conducted at JPL monitoring well MW-7, where 5 gallons per minute (gpm) of groundwater was produced and treated. Calgon tested a proprietary Ionic SEParation system (ISEP), which consisted of 30 columns packed with IE resin arranged in a circle on a rotating carousel. As the carousel rotates, columns are either being used for ClO_4^- adsorption, being regenerated or being rinsed. Calgon also tested a proprietary perchlorate and nitrate catalytic destruction module (PNDM) for destroying ClO_4^- in the brine, which allowed for the reuse of the brine. Calgon was on-site for approximately 5 months optimizing the ISEP system, and tested the PNDM for approximately 10 days.

The catalytic destruction module allowed for the reclamation of approximately 90% of the brine, and an overall process waste stream of approximately 0.16% of the volume of treated water. This waste was then transported off-site for disposal. Results of the Calgon study are included in Appendix C. While the costs involved with such a system are relatively high, if performance can be verified/guaranteed, the system is feasible and is capable of producing water that meets regulatory requirements with a very small waste stream. The Calgon IE system as described above is, therefore, retained as a treatment option.

It is noted that research efforts to refine IE techniques with regard to ClO_4^- removal are proceeding rapidly. While at present, the Calgon catalytic destruction module is the only known possibility for brine treatment at JPL, conventional IE (without catalytic destruction ClO_4^- in the brine) may indeed be feasible. For example, US Filter has investigated using resins recovered from other high-purity applications, which can be acquired at a relatively low cost. The system employs several resin beds in a lead-lag configuration, which is very simple in terms of O&M. In this application, spent resins are transported off-site through a service arrangement and destroyed, while a fresh bed is brought on-line (analogous to the manner in which spent LPGAC cartridges are changed out). This eliminates the need for regeneration, and hence, no brine is produced. Other potential advances in IE technology involve the development of ClO_4^--specific resins. As indicated, options for treatment involving IE resins are increasing, and decisions on IE systems should be made based on the most current information available.

Membrane Processes

Reverse Osmosis (RO) is a membrane process in which dissolved contaminants are separated from water by filtering through a semi-permeable membrane at a pressure greater than the osmotic pressure caused by the dissolved materials in the water. As water enters the RO system, it is separated into two streams. The first of these is the "permeate", which is the clean effluent that is recovered for various high-purity uses. The second is the "rejectate", which is typically a relatively small percentage of the influent flow, and contains the contaminants that have been removed by the process. The term "recovery rate" refers to the percentage of the original flow that is recovered as permeate. Similarly, the term "rejection rate" is the percentage of the original flow that is concentrated as the rejectate. As with IE, RO does not destroy ClO_4^-, rather it is collected and concentrated in the rejectate. This rejectate must then be treated or disposed of appropriately.

Although RO is capable of removing organic compounds as well, this process is much more costly for VOC treatment than air-stripping or LPGAC, and was rejected as a primary treatment technique for VOCs. However, RO is one of the few available processes with the potential ability to remove ClO_4^- from groundwater to non-detectable levels. RO is being considered only in this capacity. RO also coincidentally removes a high percentage of other dissolved constituents [including Cr(VI)].

For this FS, US Filter Corporation was subcontracted to conduct an initial, preliminary bench-scale treatability study to assess the effectiveness of using RO to remove ClO_4^- from JPL groundwater (see Appendix D). Results from this initial test showed that with only one thin-film composite membrane, approximately 80% of the influent stream was recovered as permeate, with ClO_4^- levels being reduced from approximately 800 μg/L in the influent feed to 12-16 μg/L in the permeate. The rejectate consisted of 20 percent of the influent stream and contained ClO_4^- at approximately 3600 μg/L.

With the goal of reducing the overall production of wastes, a second test was performed, again with only one membrane, to assess whether the rejectate could be further concentrated by passing it through the RO system again. The test indicated that 50% of the original rejectate could be recovered as permeate, with ClO_4^- concentrations of 17 to 18 μg/L. The rejectate from this test comprised 50% of the original influent volume (the rejectate from the initial test) and contained ClO_4^- at a concentration of 7900 μg/L.

These initial results are illustrated in the following table, using a hypothetical 100 gallons per minute (gpm) system as example:

	Permeate			Rejectate			
Treatment	**Recovery Rate**	**Amount Recovered (Permeate)**	**ClO_4^- concen-tration***	**Rejection Rate**	**Amount Rejected (Rejectate)**	**ClO_4^- concen-tration***	**Fate of Rejectate**
Initial treatment of JPL groundwater	80%	80 gpm	12-16 μg/L	20%	20 gpm	3600 μg/L	To RO unit for second pass
Second RO pass for treatment of the 20 gpm initial rejectate stream	50%	10 gpm	17-18 μg/L	50%	10 gpm	7900 μg/L	To additional treatment to destroy ClO_4^- or for appropriate disposal
Total	90% (the original 80% plus 50% of the initial rejectate)	90 gpm	12-18 μg/L	10% (50% of the initial 20% rejected--the other 50% recovered as permeate)	10%	7900 μg/L	To additional treatment to destroy ClO_4^- or for appropriate disposal

* Influent ClO_4^- concentration was approximately 800 μg/L.

The data from this preliminary study indicate that the combined permeates (from treatment of groundwater and secondary treatment of the rejectate) would have a ClO_4^- concentration slightly below the CADHS Interim Action Level of 18 μg/L, and the final rejectate would have a ClO_4^- concentration of approximately 7900 μg/L (Appendix D). However, when considering these preliminary results, it is very important to note that complete RO systems consist of multiple membranes in multiple elements, with multiple elements comprising an RO array. This preliminary test was conducted using only one membrane in one element. This is consistent with US Filter's approach to this type of early testing, which is to obtain worst case conditions for scale-up. This is done to insure that the results from the large-scale system will generally be better than the test results because the permeate from one element will be diluted by the permeates from the other elements. Therefore, based on the results of these preliminary tests, it is believed that with an appropriately configured RO system, non-detectable ClO_4^- concentrations in treated water can be readily achievable without further treatment of the permeate.

Nevertheless, US Filter performed two additional tests to investigate the potential of using additional treatment for the permeate. These tests included using a second pass RO and ion exchange (strong and weak base anion exchange resins) as potential permeate polishing techniques. Both of these tests achieved non-detect (<4.0 μg/L) ClO_4^- results in the permeate (Appendix D). Because the TDS of RO permeate is very low, IE resins used for permeate polishing become saturated with contaminant ions very slowly, and regeneration requirements of the resins are greatly minimized.

Finally, US Filter notes that while a final rejection rate of 10 percent of the original influent volume is achievable, it may be advisable to instead reject up to 15-25 percent, in order to prevent potential silica scaling. However, based on conversations with US Filter, this could be reduced depending on system specifications and discharge requirements (sewer capacities, etc.).

Based on the success of the preliminary RO studies, additional experiments were conducted to evaluate the use of biological treatment to destroy ClO_4^- in the RO rejectates. For this FS, biological treatment was also evaluated as a technique to destroy ClO_4^- in JPL groundwater. Results from biological treatment studies on both JPL groundwater and RO rejectates are summarized in the following section (Section 3.4.6.2) in more detail. Below is a brief summary of results on biological treatment of RO rejectates.

In the additional tests on RO rejectates, three bioreactor configurations were used to evaluate the propensity for biologically destroying ClO_4^- in both the primary and secondary RO rejectates (Appendices E and F). Both of these waste streams are considerably less saline than IE brine and are, therefore, more conducive to this type of treatment. It was confirmed that ClO_4^- could be biologically reduced in the primary and secondary RO rejectates to non-detect levels with residence times of less than 1 hour. See Section 3.4.6.2 below and Appendices E and F for more details. It is also noted that in two of these experiments, the reduction of Cr(VI) was evaluated and it was shown to be reduced to Cr(III), which is insoluble at near-neutral pH (Appendices E and F). If necessary, removal and disposal of Cr(III) precipitates would be addressed in the remedial design phase.

Reverse Osmosis is feasible and is retained for further evaluation, primarily for treatment of ClO_4^- [and Cr(VI) if necessary].

3.4.6.2 Biological

In this process, groundwater is extracted and pumped through vessels (bioreactors) containing microbes that are attached to, or suspended within various matrices in the vessels. The most promising applications to date include fluidized bed reactors (FBR), packed bed reactors (PBR), and continuous stirred tank reactors (CSTRs) (Girard, 1999; Logan, 1999, Coppola, 1999). While PBR systems are easier to operate, they may be prone to clogging. However, clogging is not expected to be a significant problem at JPL, since the total organic carbon (TOC) content of the groundwater is expected to be fairly low.

Treatability studies were conducted to assess initial process feasibility of FBR (see Appendix D), PBR (see Appendix E) and CSTR (see Appendix F), and to obtain preliminary information regarding potential reactor sizing. A fourth type of reactor, the matrix film biological reactor (MFBR) was also tested (see Appendix F). Results of these studies are briefly summarized as follows:

1. The PBR system was able to reduce ClO_4^- in the JPL groundwater from approximately 800 μg/L to non-detectable levels at residence times of less than 0.5 hours. In addition, the PBR reduced ClO_4^- in the primary RO rejectate from approximately 5 mg/L to nondetect levels, and in the secondary RO rejectate from approximately 10 mg/L to approximately 0.1 mg/L.
2. The FBR system performed less efficiently, and reduced ClO_4^- in a simulated JPL groundwater from approximately 1,500 μg/L to levels as low as 100 μg/L. The inability to reach non-detectable levels was attributed to difficulties associated with operation of the FBR technology at the small scale used. Larger scale piloting and full-scale FBR systems have yielded data suggesting that non-detect ClO_4^- levels are attainable.
3. The MFBR system was demonstrated to be capable of reducing ClO_4^- concentrations in the RO process waste from approximately 10 mg/L to nondetect levels. However, there were several breakthroughs. It was the opinion of Applied Research Associates, who conducted the test, that although process feasibility was demonstrated, this reactor did not perform as well as had been hoped.
4. The CTSR consistently and efficiently reduced ClO_4^- concentrations in the RO process waste from approximately 10 mg/L to nondetect levels, with residence times consistent with the CSTR system currently in use to treat process wastewater at Thiokol's production facility near Brigham City, Utah.

In these tests, process feasibility was demonstrated for treatment of groundwater and RO rejectates. Bioreactors are, therefore, feasible, and are retained.

3.4.7 Disposition of Treated Water

Options for use of the treated water include: re-use as drinking water, discharge to surface water bodies, use as irrigation water, discharge to publicly-owned treatment works (sewer), and re-introduction to the aquifer (via direct re-injection or re-infiltration through the vadose zone).

3.4.7.1 Re-Use as a Drinking Water Source

Re-use as a drinking water source recognizes the value of treated groundwater in reducing demand on the potable water supply, as well as the need to protect and comply with the rights of the local water purveyors in the area. It is assumed for this FS that, due to adjudication rights in the Raymond Basin, all water withdrawn by JPL must be used pursuant to the basin adjudication or be replaced. It is also assumed that if this is not possible, an equivalent amount must be purchased and re-introduced into the aquifer, or supplied to local purveyors to make up for lost production. An advantage of potable re-use scenarios is that the distances from treatment to potable distribution systems are generally substantially shorter than for other re-use scenarios, resulting in lower capital and maintenance costs.

A disadvantage of this option revolves around the fact that blending is the current remedial option being used for ClO_4^- control by the City of Pasadena. Potential future increases in ClO_4^- levels in the Pasadena wells could make blending insufficient to control ClO_4^- concentrations. If the ClO_4^--impacted wells are actively treated for ClO_4^- rather than merely blending, re-use as drinking water becomes a more dependable option. Hence, this option is retained for further consideration. It should be noted, however, that significant CADHS permit requirements for water purveyors (over and above those currently in place) would have to be met for this option (Section 2.0).

3.4.7.2 Discharge to Surface Water Bodies

This option involves discharge of treated groundwater to the Arroyo Seco spreading grounds, or to a new surface water body in the Arroyo which is being considered by the City of Pasadena as part of a new multi-use park area. This would require local/regional permits, including a National Pollutant Discharge Elimination System permit from the RWQCB. This option is inexpensive and moderately easy to implement. However, its effectiveness was rated low, primarily because after treatment potential residual contaminants (possibly below detection limits) may potentially impact the aquatic environment and/or sediments. Based on this reason, NASA prefers not to use this technology, and it is, therefore, eliminated at this time.

3.4.7.3 Use as Irrigation Water

This option consists of using treated water to irrigate public or private facilities such as golf courses or parks. This would require local/regional permits, including a National Pollutant Discharge Elimination System permit from the RWQCB. This option is retained at this time, pending further evaluation.

3.4.7.4 Discharge to Publicly Owned Treatment Works (Sewer)

Under this option, treated water or process waste (treated RO rejectate and/or IE brine) would be discharged to a local publicly owned treatment works via the sewer. City of Pasadena sewer lines may be used for such discharges. Preliminary discussions with the City of Pasadena Department of Public Works indicate that adequate capacity is available for discharge in the 1,000 to 2,000 gpm range, since existing pipe capacity is expected to be increased by addition of new lines in the near future. Additional discussions with Pasadena would be required after selection of the specific remedial technology. For disposal of smaller amounts of treated water, or for treated RO rejectates or IE brines, this option is potentially feasible, and is retained for further consideration in this regard.

3.4.7.5 Re-Introduction to the Aquifer

This option consists of returning treated water to the aquifer via direct injection or infiltration/percolation through the vadose zone. Based on preliminary discussions with the RWQCB, direct injection to the aquifer would require an extensive permitting process (Waste Discharge Permit). However, both options are viable, and both are retained for further consideration for disposal of water from a primary treatment system.

3.5 RETAINED TECHNOLOGIES

Table 3-6 presents a summary of the retained treatment technologies and process options. These technologies and process options are used to develop complete remedial alternatives as described in Section 4.0.

TABLES

TABLE 3-1

SUMMARY OF CONSTITUENTS OF POTENTIAL CONCERN
JET PROPULSION LABORATORY

Constituent of Potential Concern[1]	Maximum Exposure Point Concentration[2]		Maximum Detected[3]			Cancer Risk Based on Maximum Exposure Point Concentration	Non-Cancer Risk (Hazard Quotient) Based on Maximum Exposure Point Concentration	Maximum Contaminant Level (MCL)[5]	MCL Goal (MCLG)	Constituent of Interest
	Value	Well	Value	Well	Frequency of Detects					
Volatile Organic Compounds										
Carbon Tetrachloride	150 μg/L	MW-7	150 μg/L	MW-7	67/278	2.0E-03	98	0.5 μg/L	0 μg/L	Yes
Trichloroethene	29 μg/L	MW-13	29 μg/L	MW-21-1	74/278	2.8E-05	1.8	5.0 μg/L	0 μg/L	Yes
Tetrachloroethene	3.7 μg/L	MW-7 and MW-21[9]	4.4 μg/L	MW-21-4	71/278	8.6E-06	0.04	5.0 μg/L	0 μg/L	No
1,2-Dichloroethane	2.1 μg/L	MW-16	2.1 μg/L	MW-16	15/278	1.3E-05	0.28	0.5 μg/L	0 μg/L	Yes
1,1-Dichloroethene	2.6 μg/L	MW-16	2.6 μg/L	MW-16	18/278	5.8E-05	0.11	6.0 μg/L	7 μg/L	No
Chloroform	43 μg/L	MW-16	43 μg/L	MW-16	126/278	8.1E-05	1.7	100[8] μg/L	None	No
Bromodichloromethane	0.44 μg/L	MW-17	0.9 μg/L	MW-17-3	12/278	5.2E-06	0.008	100[8] μg/L	None	No
Inorganic Constituents										
Perchlorate	1,230 μg/L	MW-16	1230 μg/L	MW-16	76/214	N/A	160	18[6] μg/L	None	Yes
Hexavalent Chromium	0.041 mg/L	MW-13	0.045 mg/L	MW-13	13/278	2.6E-04	0.50	None	None	Yes
Arsenic	0.004 mg/L	MW-3	0.01 mg/L	MW-3-5	6/278	9.2E-05	0.90	0.05 mg/L	None	No
Lead	0.0032 mg/L	MW-14[9]	0.028 mg/L	MW-14-5	18/278	N/A	6.2 μg/dl[4]	0.015[7] mg/L	0 μg/L	No
Nitrate	19 mg/L	MW-14[9]	19 mg/L	MW-14-1	233/263	N/A	0.80	10 mg/L	10 mg/L	No

Notes:

(1): As determined during baseline risk assessment screening completed during the RI (Foster Wheeler Environmental, 1999).
(2): Determined for baseline risk assessment using 95% upper confidence limit (UCL) (or maximum detected value if 95% UCL was higher) for most recent year of RI data (1997).
(3): From most recent year of RI data (1997).
(4): Estimated 99th percentile blood lead level for a child receptor in micrograms/deciliter. Threshold level is 10 μg/dl.
(5): Lowest state or Federal MCL listed.
(6): California State Interim Action Level.
(7): Action level, treatment and public notification triggered.
(8): MCL is for total trihalomethanes which includes chloroform, bromoform, bromodichloromethane and dibromochloromethane.
(9): Considered upgradient JPL monitoring well.

TABLE 3-2

SUMMARY OF REMEDIATION GOALS FOR CONSTITUENTS OF INTEREST JET PROPULSION LABORATORY

Constituent of Interest	Remediation Goal	
	Re-Introduction to Aquifer(1)	Domestic Supply(1)
Volatile Organic Compounds		
Carbon Tetrachloride	<0.5 µg/L	<0.5 µg/L
Trichloroethene	<5.0 µg/L	<5.0 µg/L
1,2-Dichloroethane	<0.5 µg/L	<0.5 µg/L
Inorganic Constituents		
Perchlorate	<18 µg/L(2)	<18 µg/L(2)
Hexavalent Chromium	<15 µg/L(3)	<15 µg/L(3)

Notes:

(1): Lowest of California or Federal EPA MCL value.
(2): California State Interim Action Level (non enforceable).
(3): Based on an EPA acceptable cancer-risk target level.

TABLE 3-3

SUMMARY OF GENERAL RESPONSE ACTIONS
JET PROPULSION LABORATORY

General Response Actions	Representative Associated Technology Types	Description
No Further Action	None	Current remedial activities (Section 1.2.6) will continue. Provides baseline for evaluation of all other alternatives.
Limited Action	Remediation by Monitored Natural Attenuation, Groundwater Monitoring	Consists of remediation by natural means (natural attenuation), in conjunction with groundwater monitoring to assess the process. Groundwater monitoring may also be implemented in conjunction with other technology types to monitor the extensiveness of the plume, and to assess/verify remediation effectiveness.
Institutional Controls	Use Restrictions, Alternate Water Supplies	Administrative means are used to limit the public's exposure to contaminated groundwater.
Containment	Capping, Vertical Barriers, Hydraulic Control	Use of physical barriers or controls to minimize or eliminate contaminant migration.
Collection	Extraction Wells, Subsurface Drains	Extracting impacted groundwater from the aquifer for purposes of treatment or containment.
Treatment	*In-situ*, *Ex-situ* Treatment	Treatment of impacted groundwater either in place, or at the surface in conjunction with some form of collection technique. Treatment technology options may include physical, chemical, or biological processes.
Disposition of Treated Water	Discharge to Surface Water Bodies or Sewer; Re-introduction Back into Aquifer; Use as Drinking Water or Irrigation Water	Disposition of treated groundwater after ex-situ treatment includes discharge to surface water bodies, re-introduction to the aquifer, and re-use for irrigation or as drinking water.

TABLE 3-4

SUMMARY OF IDENTIFICATION AND PRELIMINARY SCREENING RESULTS OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS JET PROPULSION LABORATORY

(Shading indicates technology or process option which has been eliminated)

Medium	General Response Actions	Remedial Technology Types	Process Options	Screening Comments
Groundwater	No Further Action	Current Remedial Activities	N/A	Retained to provide baseline for comparison with other actions.
	Limited Action	Remediation by Monitored Natural Attenuation (MNA)	N/A (Contaminated levels are lowered through naturally-occurring processes)	Retained.
		Groundwater Monitoring	N/A	Retained to monitor plume status and effectiveness of remedial actions.
	Institutional Controls	Use Restriction	Regulatory Restrictions on Quality and Fate of Groundwater	Retained-Applies to treatment and disposal processes.
		Alternate Water Supplies	Install New Supply Wells, Purchase water from other sources	Retained.
	Containment	Capping	Asphalt, Concrete, Clay, Other Low Permeability Materials	Eliminated-Not effective. Does not address exposure points, does not treat contaminant, technically infeasible.
		Vertical Barriers	Slurry Walls, Sheet Pile, Impermeable Membranes	Eliminated-Not effective. Groundwater and contamination are too deep, does not treat contaminants.
		Hydraulic Control	Extraction/ Re-introduction Wells	Retained.
	Collection	Extraction Wells	Pumps	Retained.
		Subsurface Drains	Interceptor Trenches	Eliminated-Not effective or implementable. Groundwater and contamination are too deep.
	Treatment	*In-situ* Physical	Air Sparging, Dual Phase Extraction	Eliminated-Not implementable. Groundwater and contamination are too deep, contaminated area too extensive.
	Treatment[1]	*In-situ* Chemical	Reactive Walls	Eliminated-Not implementable. Groundwater and contamination are too deep, contaminated area too extensive.
			Injection of Oxidizing/Reducing Agents	Eliminated-Not effective or implementable. Groundwater and contamination are too deep, contaminated area too extensive, reducing agents ineffective in lab studies for ClO_4^-.

TABLE 3-4

SUMMARY OF IDENTIFICATION AND PRELIMINARY SCREENING RESULTS OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS JET PROPULSION LABORATORY

(Shading indicates technology or process option which has been eliminated)

Medium	General Response Actions	Remedial Technology Types	Process Options	Screening Comments
Groundwater	Treatment[1]	*In-situ* Biological	Oxygen Enhancement	Eliminated-Not effective. Contaminants present generally not biodegraded under aerobic conditions.
			Co-metabolic Processes (methane or propane sparging)	Eliminated-Groundwater and contamination are too deep, contaminated area too extensive.
			Reductive Processes	Eliminated-Not effective. Groundwater and contamination are too deep, contaminated area too extensive.
		Ex-situ Physical	Carbon Adsorption	Retained for VOCs only.
			Air Stripping	Retained for VOCs only.
			Ion Exchange	Retained for ClO_4^- only[1]
			Reverse Osmosis	Retained for ClO_4^- only[1]
		Ex-situ Chemical	UV Oxidation	Eliminated-Not cost effective at required flowrates.
			Treatment with Oxidizing/Reducing Agents	Eliminated-Effectiveness unknown, not cost effective at required flow rates.
			Electrochemical Reduction	Eliminated-Effectiveness unknown, not cost effective at required flow rates.
		Ex-situ Biological	Bioreactors	Retained for ClO_4^- only[1]
	Disposition of Treated Water	Reuse as a drinking water source	N/A	Retained.
		Disposal to surface water bodies	N/A	Eliminated-Potential for impact to aquatic environments and/or sediments unknown.
		Disposal as irrigation water	N/A	Retained.
		Disposal to Sewer	N/A	Retained.
		Re-introduction to the Aquifer	N/A	Retained.

Notes:

(1): Treatment technologies retained for ClO_4^- are assumed to be applicable for Cr(VI) based on chemical similarities (see text, Section 3.3.6).

TABLE 3-5

SUMMARY OF FINAL SCREENING OF RETAINED TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER JET PROPULSION LABORATORY

General Response Actions	Remedial Technology Types	Process Options	Effectiveness	Implementability	Cost	Comments
No Further Action	Current Remedial Activities	N/A	High for VOCs, currently high for ClO_4^-	Easy	Low	Retained per CERCLA guidelines. However, if perchlorate levels rise in the downgradient water supply wells, the effectiveness would be reduced significantly, since the well(s) may have to be shut down; this in turn could increase the potential for impacting further down-gradient wells.
Limited Action	Monitored Natural Attenuation (MNA)	NA (Contaminant concentrations are lowered through naturally-occurring processes)	Moderate	Easy	Low	Retained - Evidence suggests that MNA is not effective enough to provide primary remediation mechanism, but is retained in a "polish"-type role.
	Groundwater Monitoring	Sample and analyze groundwater	Needed to Monitor Remediation	Easy	Low	Retained for monitoring of remediation, but not as a stand-alone technology.
Institutional Controls	Use Restrictions	Regulate water use and quality	Moderate	Easy	Low	Already in place.
	Alternate Water Supplies	Purchase water from other sources	Moderate	Easy	High	Retained, but not as a stand-alone technology.
		New extraction wells	Moderate	Easy	High	Retained.
Containment	Hydraulic Control	Pumping of various extraction wells	High	Easy	Low to High	Retained.
Collection	Extraction Wells	Pumps	High	Easy	Low/Moderate	Retained.

TABLE 3-5

SUMMARY OF FINAL SCREENING OF RETAINED TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER JET PROPULSION LABORATORY

General Response Actions	Remedial Technology Types	Process Options	Effectiveness	Implementability	Cost	Comments
Treatment, *ex-situ*	Physical	Carbon adsorption	Moderate/High	Easy	Moderate	Retained for VOC treatment.
		Air-stripping	High for VOCs	Easy	Moderate	Retained for VOC treatment.
		Ion exchange	High for Perchlorate	Easy	High capital and operating costs	Retained for perchlorate treatment.
		Reverse osmosis	High for Perchlorate	Easy	High capital costs, Moderate operating costs	Retained for perchlorate treatment.
	Biological	Bioreactor	High for Perchlorate	Moderate/Easy	Low	Retained for perchlorate treatment.
Disposition of Treated Water	Reuse as a Drinking Water Source	N/A	High	Easy	Low	Retained.
	Disposal as Irrigation Water	N/A	Moderate	Moderate	High	Retained.
	Disposal to Publicly Owned Treatment Works (Sewer)	N/A	High	Variable, depends on flow rates	Moderate	Retained for potential discharge of treated process water.
	Re-introduction to the aquifer	Re-injection wells	High	Moderate	High	Retained.
		Infiltration wells	High	Moderate	High	Retained.

Notes:

N/A: Not applicable.

TABLE 3-6

SUMMARY OF RETAINED TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER JET PROPULSION LABORATORY

General Response Actions	Remedial Technology Types	Process Options
No Further Action	None	Current remedial activities (Section 1.2.6)
Limited Action	Monitored Natural Attenuation	NA (Contaminant concentrations are lowered through naturally-occurring processes)
	Groundwater Monitoring	Sample and analyze groundwater to monitor remediation.
Institutional Controls	Use Restrictions	Ensure that there is no uncompensated loss from the aquifer.
		Restrictions on contaminant concentrations following treatment.
	Alternate Water Supplies	Purchase water from other sources.
		Install new extraction wells.
Containment	Hydraulic Control	Removal and replacement of water via extraction and re-introduction wells.
Collection	Extraction	Removal of water via extraction wells.
Treatment, *ex-situ*	Physicochemical	Carbon Adsorption (VOCs).
		Air Stripping (VOCs).
		Ion Exchange (ClO_4^-).
		Reverse Osmosis (ClO_4^-).
	Biological	Bioreactor (ClO_4^-).
Disposition of Treated Water	Re-use	Use treated water for irrigation or supply to purveyors for municipal consumption.
	Re-introduction to Aquifer	Return treated water to the aquifer via re-injection or infiltration wells.
	Disposal to Publicly-Owned Treatment Works	Discharge treated process wastewater to sewer.

4.0 DEVELOPMENT AND SCREENING OF REMEDIAL ALTERNATIVES

In this section, remedial alternatives that meet the RAOs are assembled using the treatment technologies and process options that were retained in Section 3.0. A remedial alternative represents a "complete" remedial action, consisting of a specific combination of the retained treatment technologies and process options to address all aspects of remediation. These aspects include extraction, hydraulic control, treatment, and final disposition of treated water. As was carried out for the treatment technologies and process options, the potential remedial alternatives are also subjected to a screening process based on effectiveness, implementability, and cost. The objective of this evaluation is to develop the alternatives in sufficient detail and to narrow the field of appropriate alternatives while preserving an adequate range of remedial options for subjection to a more detailed evaluation using nine Superfund evaluation criteria in Section 5.0. Also included in this section are descriptions of the use of the JPL three-dimensional groundwater model to estimate required groundwater extraction rates for various remedial alternatives.

The final configuration of the remedial alternative selected for final implementation will be based on performance criteria that will be described in the Record of Decision (ROD) and potentially on additional information and data acquired during potential additional pilot studies and/or remedial design. The project details described in this FS (e.g., treatment process details, treatment facility locations and pipeline routes) are conceptual and have been assumed only for cost estimating and remedial alternative comparisons. Other treatment technologies and configurations are possible. Uncertainty about project details is not expected to preclude estimation of costs within the range of uncertainty specified by EPA guidelines.

4.1 DEVELOPMENT OF REMEDIAL ALTERNATIVES

Remedial alternatives are combinations of General Response Actions (GRAs) which include: collection, treatment, and use of disposal options, as well as institutional controls, and monitoring strategies. In Section 3.0, technologies and process options were screened and retained on the basis of applicability to the JPL site. In this section, the retained technologies and process options are summarized and in the following section (Section 4.2) the technologies and process options are assembled into remedial alternatives. The remedial alternatives are then screened on the basis of effectiveness, implementability and cost.

The development of alternatives must conform to requirements identified in CERCLA and in the National Contingency Plan (NCP). CERCLA Section 121(b) identifies the following statutory preferences when developing and evaluating remedial alternatives:

- Remedial actions that involve treatments that permanently and significantly reduce the volume, toxicity, and mobility of contaminants or hazardous substances are preferred over alternatives that only prevent exposure.

- Off-site transport and disposal of hazardous substances or contaminated materials without treatment is considered the least favored remedial action for sites where practical treatment technologies are available.
- Remedial actions using permanent solutions, innovative treatment technologies, or resource recovery technologies shall be assessed.

Based on these statutory preferences, remedial alternatives are developed to meet the following criteria to the extent practicable:

- The remedial alternative is protective of human health and the environment.
- The remedial alternative attains remediation goals (chemical-specific ARARs, etc.) and can be implemented in a fashion consistent with location- and action-specific ARARs.
- The remedial alternative uses permanent solutions and innovative treatment technologies to the maximum extent practicable.
- The alternative developed is capable of achieving a remedy in a cost-effective manner.

4.1.1 Summary of Retained Technologies and Process Options

The various collection, treatment, and disposal options, as well as institutional controls, monitoring options, and monitored natural attenuation retained in Section 3.0 are briefly summarized below. These technologies and process options will be assembled into remedial alternatives in the following sections.

4.1.1.1 Collection Options

Extraction via pumping is the only collection option considered feasible at JPL for meeting the RAOs established in Section 3.1. Extraction via pumping is expected to provide a means to implement treatment as well as hydraulic capture of contaminants. The following general extraction options were considered for the FS:

- On-site pumping at rates and locations designed to achieve on-site contaminant source reduction.
- On-site pumping at rates and locations designed to achieve on- and off-site plume containment/remediation.
- Off-site pumping at rates and locations designed to achieve on- and off-site plume containment/remediation.

Various combinations of extraction via pumping were incorporated into the alternatives, and were modeled in order to investigate flow rates needed to bring about capture of contaminants for treatment, and limitation of migration (discussed below, Section 4.2.1).

4.1.1.2 Treatment Options

The primary constituents of interest in the JPL groundwater include: three VOCs (carbon tetrachloride [CCl_4], trichloroethene [TCE], and 1,2-dichloroethane [1,2-DCA]), and perchlorate

(ClO_4^-), an inorganic, oxyanionic compound, which have been detected above regulatory levels. As noted in Section 3.1.1, hexavalent chromium [Cr(VI)] is also considered a constituent of interest, but was detected in a localized area on-site, at very low concentrations (Section 1.0). Because the behavior of Cr(VI) in groundwater is similar to that of ClO_4^-, these two compounds 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) present on-site would also be treated via the same processes. If Cr(VI) becomes an issue during the implementation phase of any treatment activities (e.g. is present in water extracted for treatment at levels above the treatment goal), the treatment(s) selected for ClO_4^- can be optimized for Cr(VI) based on current treatment knowledge.

As also noted in Section 3.1.1, low concentrations of several other VOCs, including tetrachloroethene (PCE), 1,1-dichloroethene (1,1-DCE), and chloroform, were detected in several JPL monitoring wells during the RI. These VOCs have not been detected above regulatory limits during the JPL RI, and are not designated as primary constituents of interest for this FS. These VOCs, however, are subject to the same treatment techniques as CCl_4, TCE and 1,2-DCA (the primary VOCs of interest). In this FS, VOC treatment is focused primarily on CCl_4, TCE and 1,2-DCA, and based on their similar properties, it is assumed that the small amounts of other VOCs present (notably PCE) will also be removed via the same treatment processes.

Several *ex-situ* process options were retained in Section 3.0 for developing alternatives, as listed below:

- Air-stripping for VOCs.
- Liquid phase granular activated carbon (LPGAC) for VOCs (ranked lower than air-stripping).
- Ion exchange (IE), for ClO_4^- [and potentially Cr(VI)].
- Reverse osmosis for ClO_4^- [and potentially Cr(VI)].
- Biotreatment (bioreactor) for ClO_4^- [and potentially Cr(VI)].

In addition to these process options, blending of water from different water supply wells to reduce the perchlorate concentrations to acceptable levels for municipal consumption is an accepted practice.

4.1.1.3 Disposition of Treated Water

The water rights in the Raymond Basin are adjudicated. It is assumed for this FS that all water withdrawn from the aquifer by JPL must be delivered to a purveyor with water rights or returned to the aquifer. It is also assumed that if this is not feasible or possible, an equivalent amount of water must be purchased and supplied to local purveyors or re-introduced into the aquifer to replace the water withdrawn. In addition, it appears at this time that it may not be possible to treat ClO_4^- to meet remediation goals without generating a waste stream that cannot be returned to the aquifer, and therefore, some off-site disposal options for process waste have also been retained. Depending upon the quantity and quality of treated water or waste streams generated, options for disposition of treated water include:

- Re-use as drinking water.
- Return to the aquifer via infiltration or re-injection.
- Supply as irrigation water.
- Discharge to publicly owned treatment works (sewer).
- Transport off-site.

As mentioned, these options are specific to the quantity and quality of treated water and/or waste streams, based on the type of treatment used. Given the variation in treatment options within the alternatives, specific options regarding the fate of the treated water may also vary. For this FS, re-introducing treated water to the aquifer appears to be the most likely scenario that would be utilized in the near term (potentially up to 3 years or more after the ROD is accepted). This is due to the extensive regulatory requirements imposed to provide water to water purveyors, which is the next, most likely scenario for disposition of treated water. Re-introduction of treated water to the aquifer is therefore used in the development of alternatives for comparative purposes.

4.1.1.4 Groundwater Monitoring

Groundwater monitoring will be used to assess the progress of remediation. The long-term quarterly groundwater monitoring program currently in place at JPL is comprehensive in scope (Foster Wheeler, 1996a), approved by the regulatory agencies (EPA, DTSC, and RWQCB), and is expected to be adequate for monitoring water quality within the aquifer during remedial activities. Monitoring will also be conducted at the municipal production wells as currently required by the CADHS.

4.1.1.5 Institutional Controls

Applicable institutional controls include use restrictions and provision of alternate water supplies as described below.

Use restrictions already exist through adjudication of water rights, which are administered through the Raymond Basin Management Board. These restrictions preclude private withdrawal of groundwater. Use restrictions are also applied through CADHS regulations to insure acceptable water quality for water extracted by local water purveyors and supplied for domestic consumption.

Provision of alternate water supplies involves construction of new water supply wells in non-impacted areas of the aquifer, or purchasing water from alternate water purveyors, such as the Metropolitan Water District (MWD).

4.1.1.6 Monitored Natural Attenuation (MNA)

MNA was retained in Section 3.0 for use in conjunction with other active remediation activities, or as a follow-up to remediation that has been implemented. MNA was not retained as a primary remedial mechanism.

4.2 DEVELOPMENT AND SCREENING OF REMEDIAL ALTERNATIVES

In this section, the treatment technologies and process options retained from Section 3.0 and summarized above have been combined into remedial alternatives. Each of the remedial alternatives developed is described and preliminarily evaluated on the basis of effectiveness, implementability, and cost. The screening process is intended to reduce the number of potentially feasible alternatives by evaluating the advantages and disadvantages with respect to these criteria. Alternatives with the most favorable composite evaluation with respect to the screening factors will be retained for further consideration during a detailed analysis presented in Section 5.0. The three evaluation criteria are discussed below:

Effectiveness—Each alternative will be evaluated as to its effectiveness in providing protection of human health and the environment, and the degree to which it will reduce toxicity, mobility, and volume of contamination. Both the short-term and the long-term effectiveness components will be reviewed. In addition, attainment of ARARs by the alternatives is evaluated as part of the effectiveness criterion.

Implementability—The implementability evaluation is used to assess both the technical and administrative feasibility of each alternative, particularly with respect to construction, operation, and maintenance of various systems, as well as permitting. In addition, the availability of the technologies involved in a remedial alternative will be considered.

Innovative technologies will be considered favorably in the screening process if they offer the potential for better treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs than demonstrated technologies. Technical implementability criteria include the following:

- The ability to construct and operate technologies within site-specific and technology-specific regulations and constraints. Technical aspects considered include operation, maintenance, monitoring, and post-implementation support.
- The extent of administrative coordination required to substantively comply with permit requirements and the coordination required with other governmental agencies.
- The availability of key components of the alternative and the time required for installation and attainment of the desired results.

Cost—During the alternative screening, order-of-magnitude cost comparisons are used to eliminate alternatives that have much higher costs and do not provide a comparative increase in protection with respect to other alternatives. This approach may also be used in choosing among similar alternatives that provide comparable protection. Both capital and operation and maintenance (O&M) costs are considered. The order-of-magnitude cost estimates were obtained by contacting vendors, and referencing other feasibility study cost estimates.

4.2.1 Groundwater Modeling

Because the depth and areal extent of contamination preclude *in-situ* treatment techniques, the treatment technologies and process options retained in Section 3.0 point to groundwater extraction and *ex-situ* treatment (pump-and-treat) as the leading remedial response action with merit for the JPL site. The development of alternatives therefore involve various pump and treat scenarios. A groundwater flow model was developed to simulate potential remediation alternatives. Model results were primarily used to help develop and evaluate the flow rates required for each alternative. This section describes the general configuration and application of the model. A detailed description of model development and calibration is presented in a *Report on the JPL Groundwater Model* included as Appendix G. Specific applications of the model to each remediation alternative are discussed in the descriptions of the alternatives, which are presented in Section 4.2.3 below.

The JPL groundwater model was generated using the finite-difference modeling software MODFLOW (USGS, 1984). To adequately simulate the complex subsurface conditions and hydraulic influences at the JPL site, a six-layer, three-dimensional, transient flow model was constructed. The model consists of six aquifer layers with five intervening low-permeability interfaces representing aquitard horizons between aquifer layers. Areally, the model covers approximately nine square miles; the 101- by 96-cell model grid extends well beyond JPL property boundaries to include municipal production wells and major hydrologic features of the Raymond Basin which could potentially influence groundwater flow beneath the JPL facility.

Two main data sources provided guidance in selecting model input parameters and hydraulic properties of the aquifer: the Raymond Basin Project for the City of Pasadena (CH2MHill, 1990 and 1992) and data collected as part of the JPL RI. The Raymond Basin Project produced a basin-wide data set and a regional two-dimensional groundwater flow model. The JPL RI results provided site-specific data from borings, geophysical logs, groundwater monitoring wells, and aquifer tests. Municipal water well construction and production information was obtained primarily from Raymond Basin Watermaster reports.

The three-dimensional flow model was calibrated to transient conditions over the 16-month period from August 1995 to December 1996. This time period was selected because, at the time, it contained the maximum amount of groundwater elevation data available from the JPL deep multi-port monitoring wells. Sixteen stress periods were modeled, one for approximately each month of the calibration period. Model calibration continued, adjusting hydraulic properties and recharge values in an iterative fashion, until satisfactory agreement between observed and modeled groundwater elevations was obtained.

The calibrated groundwater model is used primarily to assess groundwater pumping rates estimated to achieve adequate contaminant capture zones for each remedial alternative. For each alternative modeled, groundwater extraction rates were varied until the desired capture was achieved. All scenarios modeled included the use of infiltration wells on-site as the disposal method for the treated water. It is noted that other disposal options are possible, however, it is believed that re-infiltration represents a worst-case scenario in terms of having a negative effect on extraction wells maintaining desired capture zones.

Possible ranges in groundwater conditions were incorporated in this FS by presenting modeling results for each remedial alternative twice: once at a time of high groundwater levels and once at a time of low groundwater levels. The months of March and September were selected to represent times of high and low groundwater, respectively. Table 4-1 summarizes the pumping schedules of nearby municipal wells, as provided by the Raymond Basin Management Board, used during all model simulations. The model results presented in this report represent the final outcomes for each remedial alternative at the two different times of the year for each of the three aquifer layers identified beneath JPL in the RI (Section 1.0). It is important to note that to effectively model the large groundwater mound at the mouth of the Arroyo Seco, an east-west trending fault was placed immediately south of the mound by the groundwater modelers (Appendix G).

4.2.2 Current Remedial Activities/Proposed Pilot Study

As discussed in Section 1.0, remedial activities in the form of extraction and treatment of VOC-impacted water by nearby water purveyors are already occurring. The extracted water is also being treated for ClO_4^- by blending. As discussed in Section 3.0, at this time there does not appear to be a clear "best choice" for treatment of ClO_4^-, and a pilot study is therefore being planned at JPL. Both the current remedial activities, and the proposed pilot study have significant bearing on the various remedial alternatives being considered for JPL, and are therefore discussed below.

4.2.2.1 Current Remedial Activities

As discussed in Section 1.0, the current on-going remedial activities consist of treatment of groundwater extracted from the City of Pasadena (Pasadena) wells and the Lincoln Avenue Water Company (Lincoln) wells for VOCs. Two of the currently pumping City of Pasadena wells have shown detectable levels of ClO_4^-, which have been successfully addressed so far by blending with non-impacted water from other wells.

Figure 4-1 shows the locations of the four Pasadena wells and the two Lincoln wells near JPL. These six wells have the capacity to extract up to approximately 8,500 gpm. However, the Lincoln wells are typically off for approximately 6 months per year and the Pasadena wells are off for approximately 1 month per year. As discussed in the RI and in Section 1.0, the Pasadena wells have a significant impact on groundwater flow directions in the aquifer beneath and immediately downgradient of JPL due to their relatively large flow rates and near-continuous operation. As discussed in Section 1.0, these wells are to a great extent capturing the off-site VOC plumes. As shown on Figures 1-31, 1-32, and 1-33, the City of Pasadena wells create a large zone of depression and affect the local groundwater flow direction. These wells, when pumping, create a hydraulic barrier for contaminant migration and also induce flow towards the production wells. To a large extent, the ClO_4^- plume is also being captured. This effectiveness may be limited in part due to the fact that wells showing high ClO_4^- levels will eventually be shut down, thereby limiting capture.

Thus, a collection technology has essentially been implemented for VOCs. The water extracted from the City of Pasadena wells is treated for VOCs using air stripping followed by vapor phase carbon, while the water from the Lincoln wells is treated for VOCs using LPGAC. Both treatment technologies are feasible options for treating VOC-impacted water. The effectiveness of these treatment technologies has been confirmed, since the water from the Pasadena and Lincoln wells has been consistently treated to acceptable VOC levels, as evidenced by CADHS reports. Similarly, water from wells containing ClO_4^- has been blended with water from other non-impacted wells to reach acceptable ClO_4^- levels. The treated water from the Pasadena and Lincoln wells is being appropriately used for drinking water supply.

Therefore, the current on-going remedial activities at the Pasadena and Lincoln wells are:

1. Effective in meeting the RAOs of (a) preventing exposure of the public to the constituents of interest in the groundwater, (b) reducing the potential impact of contaminant migration on downgradient supply wells, and (c) leading towards eventually attaining remediation goals.
2. Implementable, and in fact, have been implemented.
3. Cost effective, based on the fact both air stripping and carbon are effective technologies that are commercially available from a wide range of vendors.

Thus, the current on-going remedial activities meet the three screening criteria (effectiveness, implementability, and cost) mentioned earlier. Based on the fact that current on-going remedial activities were designed to address VOC-impacted groundwater, the remedial alternatives developed for JPL, and discussed in detail in this FS, are primarily geared toward capturing and treating ClO_4^-. However, all groundwater extracted for ClO_4^- treatment will also be treated for VOCs.

4.2.2.2 Proposed Additional Pilot Study

While VOCs are easily removed from groundwater, removal of ClO_4^- is relatively difficult and expensive. The effectiveness of various ClO_4^- treatment technologies has not been adequately established over time, and preferred treatments generate a ClO_4^--rich waste stream, the volume of which increases proportionally with the volume of water treated. It therefore became apparent that the major issues in implementing remedial alternatives at JPL would revolve around ClO_4^- treatment at the large flow rates anticipated to bring about ClO_4^- plume capture around JPL.

With regard to ClO_4^- treatment, three technologies were retained in Section 3.0: IE, RO, and biotreatment. These technologies have been demonstrated to be feasible in a small-scale field study [IE (ISEP+), Appendix C] or bench-scale studies (RO and biotreatment, Appendices D, E, and F), but full-scale, long-term performance details are still largely unknown. In addition, because of the current regulatory climate regarding the fate of groundwater treated for ClO_4^-, it is possible that a combination of treatment technologies would be preferred to any one technology alone to ensure treatment goals are met. For these reasons, a 500-gpm pilot study is proposed to be conducted by NASA at JPL to evaluate treatment trains potentially involving various combinations of IE (likely ISEP+) and RO preceded by air stripping for VOC removal, and potentially followed by LPGAC as a final "polish". The proposed pilot study will involve a single extraction well located in the north-central portion of the site. Additional parameters to be addressed in the pilot study may include evaluation of infiltration efficiencies of treated water back into the aquifer and the zone of influence of the extraction well. These data will be useful to successfully implement a large-scale ClO_4^- treatment plant. Figure 4-2 shows a potential process flow schematic for the pilot study.

For this FS, it is assumed that results from the pilot study will be used to determine which ClO_4^- treatment process option and/or combination of treatment process options will ultimately be selected for a potential full-scale system, as well as the feasibility of on-site re-infiltration for the disposition of treated water. For the purposes of costing for this FS, air stripping for VOCs followed by RO and biotreatment of RO rejectate, and air stripping for VOCs followed by IE and catalytic destruction of brine (ISEP+) are assumed to be the two primary technologies of choice for VOC/ClO_4^- treatment. It is also assumed for the FS that the wastes from IE and RO treatment processes will be discharged to the sewer.

In the following discussions of the alternatives, both of these treatment scenarios are incorporated into each alternative. Because final selection of treatment technologies will be completed in the design phase (based on pilot study results), treatment parameters were not used to distinguish between alternatives.

With regard to potentially large extraction/treatment flows, treatability study results for IE have indicated that with the Calgon ISEP+ system [IE plus the perchlorate/nitrate destruction module (PNDM)], brine volumes are sufficiently small (up to 0.16% of influent flow) such that discharge to the sewer poses no foreseeable problems. Treatability study results for RO indicate that rejectate volumes may range from 10 to 25% of influent flow. For this FS it is assumed that the rejection rate will be 20%, the rejectate will be treated biologically to destroy ClO_4^-, and the treated rejectate will be discharged to the sewer. While discharge of ClO_4^- to the sewer is not regulated at present, NASA is currently not considering discharging process wastewater containing ClO_4^- to the sewer.

As indicated in Section 3.4.7.4, present Pasadena sewer capacity is adequate to accommodate the proposed discharges of RO rejectate, or could be sufficiently upgraded through expansion of current piping. If, for whatever reason, it was determined during the design phase that discharges to the sewer were not preferred, several other options are possible. First, the treated RO rejectate could be recombined (following disinfection) with the permeate, which essentially eliminates production of process wastewater. The final disposition of treated water in this case (RO permeate combined with biotreated, disinfected rejectate, 100% of influent flow) could potentially be re-introduced to the aquifer, and/or re-used as irrigation water. It is assumed that this option precludes re-use as drinking water due to the fact that the CADHS is currently not issuing permits for provision of biotreated water for domestic consumption. If this option is not practicable, the volume of rejectate could be reduced through intensifying the RO process, further concentrating the rejectate. It should also be noted that, if domestic consumption is not selected as the final disposition of treated water, straight biological treatment of groundwater (without IE or RO) is a cost effective approach. While technically feasible, implementation of this approach at JPL is dependent largely on space limitations.

4.2.3 Description and Screening of Alternatives

Some comments regarding the approach used in developing remedial alternatives for JPL are relevant here. As mentioned above, after screening treatment and process options in Section 3.0, it became apparent that groundwater extraction and *ex-situ* treatment (pump-and-treat) is the only option with merit at JPL. This FS, therefore, focuses on comparing various pump-and-treat strategies as to their potential effectiveness in meeting RAOs. Because current on-going remedial activities are meeting RAOs (protecting human health and limiting contaminant migration) with regard to VOCs (Section 4.2.2), it is not necessary to consider pump-and-treat alternatives with respect to the VOC plumes only. However, as noted previously, ClO_4^- currently has the potential to migrate toward unprotected, non-impacted production wells, and therefore requires additional remedial action. Outlined in the following list are general pump-and-treat approaches that were considered in developing the remedial alternatives primarily for the remediation of ClO_4^- at JPL. Importantly, the current remedial activities are included and considered an integral component of each approach. The remedial alternatives developed for JPL groundwater include:

1. No Further Action.
2. On-site source reduction.
3. ClO_4^- plume remediation via on-site pump and treat activities.
4. ClO_4^- plume remediation via off-site pump and treat activities.
5. ClO_4^- plume remediation via a combination of on- and off-site pump and treat activities.
6. ClO_4^- plume control only via off-site pumping (assumes ClO_4^- treatment not sufficiently developed for large-scale implementation).

A summary of the alternatives developed for JPL, which would be considered in conjunction with current on-going remedial activities, is presented in Table 4-2. A description of each alternative is provided in the following sections, along with a discussion of the results of the screening evaluation. A screening matrix, presented in tabular form, summarizes effectiveness, implementability, and cost for each alternative. A summary is then presented indicating whether or not the alternative will be retained for further detailed analysis in Chapter 5.0. As previously mentioned, the objective of this analysis is to narrow the field of alternatives while preserving an adequate range of options to evaluate more completely. For this FS it is assumed for all disposition options for treated water, that treatment will be required to lower contaminant concentrations in the treated water to below MCLs for VOCs, the CADHS IAL for ClO_4^-, and the risk-based level calculated for Cr(VI) (Table 3-2). Finally, MNA was retained for use in conjunction with all active remediation activities, and as a follow-up to remediation that has been implemented (Section 4.1.1.6). It is noted here that, although MNA is not considered a primary component of the remedial alternatives, naturally-occurring mechanisms (particularly dilution and dispersion) are expected to contribute to the overall remediation process and are, therefore, included within the framework of each alternative. A conceptual schematic diagram of the different alternatives is presented in Figure 4-3.

4.2.3.1 Alternative 1: No Further Action

The No Further Action alternative is evaluated for this FS in accordance with CERCLA protocol (EPA, 1988a) as a basis to compare all other alternatives.

Description

The No Further Action alternative stipulates that no additional remedial activities would be implemented by NASA. Under this alternative, the Pasadena and Lincoln wells would continue to pump in accordance with current practices, and VOC treatment systems (air-stripping at the Pasadena wells and LPGAC treatment at the Lincoln wells) and blending practices to address ClO_4^- would continue.

Screening Evaluation

Advantages and disadvantages of the No Further Action alternative are summarized below:

SCREENING OF ALTERNATIVE 1: NO FURTHER ACTION		
	Advantages	**Disadvantages**
Effectiveness	VOC-impacted groundwater adequately treated to protect human health and the environment. Off-site VOC plumes adequately contained.	Does not directly address ClO_4^-, other than by blending. Is currently protective of human health and the environment, however, potential rises in ClO_4^- levels could make this alternative ineffective.
Implementability	Easy to implement.	
Cost	No incremental capital costs at the present time.	Costs may increase significantly if conditions change, particularly with respect to ClO_4^-.
	Preliminary estimate of O&M costs: $11,598,889 (30-year period, present worth)	

Conclusion

The No Further Action alternative represents the baseline by which all other remedial alternatives are compared. Thus, as required, the No Further Action alternative will be carried into the detailed evaluation in Section 5.0.

4.2.3.2 Alternative 2: On-Site Contaminant Source Reduction

Under Alternative 2, on-site contaminant source reduction would be conducted via pump-and-treat activities. This alternative is expected to result in significant on-site contaminant removal, and limitation of further off-site contaminant migration through hydraulic control. As indicated in Section 1.2.5, a significant portion (over 70%) of the ClO_4^- in groundwater is estimated to be in on-site groundwater. Thus, on-site source reduction can be expected to greatly limit future ClO_4^- migration into off-site groundwater. A similar effect, albeit to a lesser extent since it is estimated most of the VOCs are present in off-site groundwater (Section 1.2.5), can be expected for the VOCs also. The extraction flow rate for this alternative is expected to be on the order of 500 gpm, which is in the same range as the proposed pilot study (Section 4.2.2).

Description

Alternative 2 would consist of the following components (in addition to current remedial activities):

1. A new extraction well installed on-site in the north-central portion of the site, which is the area of highest contamination.
2. A treatment system for VOCs and ClO_4^- [and potentially Cr(VI)].
3. One or more infiltration wells on-site to re-introduce the water to the aquifer after treatment.
4. Conveyance piping to convey extracted water from the extraction wells to the treatment area, treated water to the infiltration wells, and potentially wastes to the sewer.

Details regarding extraction, treatment, disposition of treated water and waste, and conveyance are given below, and the locations of the major components required for Alternative 2 are shown in Figure 4-4.

Extraction

Water will be extracted from a new extraction well located in the north-central portion of the site (Figure 4-4) from Aquifer Layers 1 and 2 only, as no ClO_4^- or VOC contamination exists in Aquifer Layer 3 at this area of the site. Using the groundwater model described above, flow rates of 250 gpm, 500 gpm, and 750 gpm were modeled (Appendix H). It was estimated that a flow rate of 500 gpm would be required to capture the major portion of the on-site ClO_4^- plume, which is present in Aquifer Layers 1 and 2. Capture zones for this scenario for Aquifer Layers 1 and 2 are shown on Figures 4-5 and 4-6 for the dry period of the year; and on Figures 4-7 and 4-8 for the wet period of the year.

The estimated total mass of the primary constituents of interest in both on- and off-site groundwater, and the estimated total mass of the primary constituents of interest located within the proposed on-site source-reduction area (see Table 1-8) are provided in the following table:

Constituent of Interest	Total estimated mass of constituent in on- and off-site JPL groundwater	Mass estimated of constituent in proposed source reduction area
CCl_4	102 lbs	37 lbs
TCE	143 lbs	11 lbs
ClO_4^-	1299 lbs	948 lbs

Thus, based on the estimated mass of the primary constituents of interest beneath the north-central portion of the site, source-reduction activities would be beneficial, particularly for the removal of ClO_4^-.

Treatment

The treatment system would potentially incorporate various components of RO and IE as determined by the proposed pilot study (Section 4.2.2.2). The system would be sized for an average flow of 500 gpm. For the purposes of this FS, it is assumed the treatment system would be located along the southeastern edge of JPL (refer to Figure 4-4).

Disposition of Treated Water

Treated water would be returned to the aquifer via infiltration wells (refer to Figure 4-4) located in the western portion of the site. It is assumed treated waste from IE (approximately 0.1 gpm from ISEP+) and/or treated rejectate from RO (approximately 100 gpm) would be discharged to the sewer. Since the volume of water not returning to the aquifer is minimal (potentially 100 gpm if RO is used), it is anticipated that the Raymond Basin will not impose any restrictions on this alternative. Should restrictions be imposed, it is assumed for this FS that arrangements with Raymond Basin will have to be made to replace or pay for this volume of water.

Conveyance

Conveyance would consist of piping from the extraction well to the treatment system, and then to the infiltration well(s). Additional piping would be required from the treatment system to the sewer for the RO and IE wastes. This is shown on Figure 4-4.

Screening Evaluation

Advantages and disadvantages of Alternative 2 are summarized below.

SCREENING OF ALTERNATIVE 2: ON-SITE SOURCE REDUCTION		
	Advantages	**Disadvantages**
Effectiveness	Significantly reduces the volume of ClO_4^- contamination with a relatively low flow rate.	Does not significantly reduce the mobility and volume of off-site ClO_4^-.
Implementability	Equipment readily available. VOC treatment technologies are easy to implement.	ClO_4^- treatment techniques are not well established over the long-term. Infiltration efficiencies not well understood (to be determined during pilot study). Space restrictions on JPL property may require special equipment designs. Piping from the on-site well across JPL would have to be installed below grade, which could pose serious problems in light of the numerous utilities at JPL, many of which may be critical to JPL operations.
Cost	**Preliminary estimate of capital costs: $ 7,670,299** **Preliminary estimate of O&M costs: $24,429,604 (30-year period, present worth)**	

Conclusion

Alternative 2 is implementable, and because extraction is applied in the on-site source area where contaminant concentrations are the highest, the costs will be relatively low compared to alternatives requiring significantly higher flow rates to extract areas of the plume less impacted. In addition, this alternative has the potential to remove over 70% of the total ClO_4^- estimated to be present in the JPL-impacted groundwater, and thereby significantly inhibit ClO_4^- migration towards downgradient production wells. Removal of VOCs from the source area would also be accomplished. Alternative 2 therefore has a very high potential for accomplishing significant remediation at relatively low cost. Alternative 2 does not, however, directly reduce the volume of downgradient ClO_4^-, or limit its migration, and therefore receives a moderate rating for effectiveness. Nevertheless, removal of significant amounts of ClO_4^- from the source area combined with the current remedial activities (VOC treatment and blending for ClO_4^-) has the potential to mitigate the problem, and Alternative 2 is retained for detailed analysis in Section 5.0.

4.2.3.3 Alternative 3: Plume Remediation with On-Site Pump-and-Treat Activities

Alternative 3 consists of extracting water from wells on JPL property to capture the on- and off-site ClO_4^- plume, in conjunction with the current remedial activities for VOC removal. These extraction wells would have to be pumped at a rate that causes reversal of flow towards JPL and away from Pasadena production wells, as opposed to the current flow towards the Pasadena wells.

Description

Alternative 3 would consist of the following components (in addition to current remedial activities):

1. Three new extraction wells on-site to intercept the ClO_4^- (and VOC plumes).
2. A treatment system for VOCs and ClO_4^- [and potentially Cr(VI)].
3. On-site infiltration wells (up to eight wells potentially) to re-introduce treated water back to the aquifer.
4. Conveyance piping to convey extracted water to the treatment plant, treated water to the infiltration wells, and wastes to the sewer.

Details regarding extraction, treatment, disposition of treated water and wastes, and conveyance are given below, and the assumed locations of the major components of Alternative 3 are shown in Figure 4-9.

Extraction

Water will be pumped from three new extraction wells located in the north-central and southeastern portions of the site (Figure 4-9). Using the groundwater model described above, combined flow rates of 5,000 gpm, 6,000 gpm, and 7,000 gpm were simulated to evaluate the potential for capturing the off-site plume through on-site pumping activities (Appendix H). Capture zones for the 7,000 gpm combined flow simulations are shown for Aquifer Layers 1, 2, and 3 on Figures 4-10, 4-11, and 4-12 for the dry period of the year; and on Figures 4-13, 4-14, and 4-15 for the wet period of the year. The information presented in these figures suggests that, even at the high flow rate of 7,000 gpm, sufficient capture of the off-site plume cannot be expected with on-site wells only.

Treatment

The treatment system would be as described for the proposed pilot study (see Figure 4-2). For Alternative 3, it is assumed the system would be sized for 7,000 gpm. The location of the treatment system is shown in Figure 4-9.

Disposition of Treated Water

Treated water would be returned to the aquifer via newly constructed infiltration wells (refer to Figure 4-9) located in the western portion of the site. Treated waste from IE (approximately 11 gpm from ISEP+) and treated RO rejectate (approximately 1,400 gpm) would be discharged to the sewer. It is assumed for this FS that a volume of water equal to that discharged to the sewer would need to be purchased (probably from MWD) and supplied to the appropriate purveyor.

Conveyance

Conveyance would consist of piping from the extraction wells to the treatment system, and then to the infiltration wells as shown in Figure 4-9. Additional piping would be required from the treatment system to the sewer for the RO and IE waste.

Screening Evaluation

Advantages and disadvantages of Alternative 3 are summarized below:

SCREENING OF ALTERNATIVE 3: PLUME REMEDIATION WITH ON-SITE PUMPING		
	Advantages	**Disadvantages**
Effectiveness	Effective for removal of on-site ClO_4^- and VOCs.	Not effective for complete capture of off-site ClO_4^- plume. ClO_4^- treatment options are not well established over the long-term at this scale.
Implementability	Equipment readily available. VOC treatment technologies are easy to implement.	Infiltration well efficiencies not well understood (to be determined during pilot study). Space restrictions on-site for large treatment equipment. Piping from on-site well across JPL would have to be installed below grade, which could pose serious problems in light of the numerous utilities at JPL, many of which may be critical to JPL operations.
Cost	**Preliminary estimate of capital costs: $46,485,108** **Preliminary estimate of O&M costs: $119,548,917 (30-year period, present worth)**	

Conclusion

Alternative 3 is favorable for removal of ClO_4^- (and VOCs) from on-site groundwater, but does not impact all of the downgradient ClO_4^-, or limit its migration, and therefore is considered moderately effective. Effectiveness of this alternative in meeting RAOs is unfavorable, as modeling results have indicated that even at a combined 7,000 gpm extraction rate, complete capture of the off-site ClO_4^- plume is not likely. Finally, Alternative 3 is relatively expensive, and because the increased expense does not appear to result in an appreciable increase in protection of human health and the environment, the expense is not justified. Since Alternative 3 receives low ratings for effectiveness as well as cost, it is eliminated from further consideration.

4.2.3.4 Alternative 4: Plume Remediation with Off-Site Pump-and-Treat Activities

Alternative 4 consists of pump-and treat activities conducted solely off-site. This alternative is expected to result in significant contaminant removal and limitation of further off-site contaminant migration through hydraulic control.

Description

Alternative 4 consists of the following components (in addition to current remedial activities):

1. Two new off-site extraction wells located to capture the ClO_4^- plume.
2. A treatment system for VOCs and ClO_4^- [Cr(VI) has not been detected in the area of the off-site ClO_4^- plume].
3. On-site infiltration wells (up to eight assumed) to re-introduce treated water to the aquifer.

4. Conveyance piping to convey extracted water from the extraction wells to the treatment area, treated water to the infiltration wells, and wastes to the sewer.

Details regarding extraction, treatment, discharge, and conveyance are given below, and the locations of the major components of Alternative 4 are shown in Figure 4-16.

Extraction

Water will be pumped from Aquifer Layers 2 and 3 (the off-site, downgradient layers with ClO_4^- contamination) from two extraction wells located off-site in the area to the southeast of JPL (Figure 4-16). Using the groundwater model described above, total combined flow rates from the two wells of 2,000 gpm, 2,500 gpm, 3,000 gpm, 3,500 gpm, and 4,000 gpm were simulated (Appendix H). A flow rate of up to 4,000 gpm was estimated to be necessary to achieve capture of the off-site ClO_4^- plume. Capture zones for the simulations for 4,000 gpm are shown for Aquifer Layers 1, 2, and 3 on Figures 4-17, 4-18, and 4-19 for the dry period of the year (September); and on Figures 4-20, 4-21, and 4-22 for the wet period of the year (March); respectively.

Treatment

The treatment system is assumed to be as described for the proposed pilot study (see Figure 4-2). For Alternative 4, the system would be designed for an average flow of 4,000 gpm. The treatment system would be located as shown on Figure 4-16.

Disposition of Treated Water

Treated water would be returned to the aquifer via newly constructed infiltration wells (refer to Figure 4-16) located in the western portion of the site. Treated waste from IE (approximately 6 gpm from ISEP+) and treated rejectate from RO (approximately 800 gpm) would be discharged to the sewer. It is assumed for this FS that a volume of water equal to that discharged to the sewer would need to be purchased (probably from MWD) and supplied to the appropriate purveyor.

Conveyance

Conveyance would consist of piping from the extraction wells to the treatment system, and then to the infiltration wells as shown in Figure 4-16. Additional piping would be required from the treatment system to the sewer for the RO and IE wastes.

Screening Evaluation

Advantages and disadvantages of Alternative 4 are summarized below.

SCREENING OF ALTERNATIVE 4: PLUME REMEDIATION WITH OFF-SITE PUMPING		
	Advantages	**Disadvantages**
Effectiveness	Effective for removal of ClO_4^-. Effectively captures off-site portion of ClO_4^- plume, preventing further significant impacts to downgradient production wells. Is protective of human health and the environment.	ClO_4^- treatment options over the long-term are not well established at this scale. Does not directly deal with on-site ClO_4^-, extending the time needed for complete ClO_4^- contamination capture.
Implementability	Equipment readily available. VOC treatment technologies are easy to implement.	Infiltration well efficiencies not well understood (to be determined during pilot study). Space restrictions on-site for large treatment equipment. Capture located near off-site municipal wells, which requires very large flow rates to inhibit ClO_4^- migration towards these wells.
Cost	**Preliminary estimate of capital costs: $29,016,663** **Preliminary estimate of O&M costs: $83,433,457 (30-year period, present worth)**	

Conclusion

Alternative 4 is reasonably implementable, and is favorable for ClO_4^- removal as well as inhibition of further downgradient migration. The relative cost of Alternative 4 is moderate. Alternative 4 is, therefore, retained for further consideration.

4.2.3.5 Alternative 5: Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-site Source Reduction

Under Alternative 5, containment and remediation of the ClO_4^- plume would be carried out through pump-and-treat activities conducted both on- and off-site. This alternative is expected to result in significant contaminant removal and limitation of further off-site contaminant migration through hydraulic control.

Description

Alternative 5 consists of the following components (in addition to current remedial activities):

1. Two off-site extraction wells to intercept the off-site portion of the ClO_4^- plume (as described for Alternative 4).
2. An on-site extraction well in the contaminant source area (as described for Alternative 2).
3. On-site infiltration wells (up to eight assumed) to return the water to the aquifer.
4. A treatment system for VOCs and ClO_4^- [and Cr(VI)] (as described in Alternative 2).
5. Conveyance piping to convey extracted water from the extraction wells to the treatment area, treated water to the infiltration wells, and wastes to the sewer.

Details regarding extraction, treatment, disposition of treated water and wastes, and conveyance are given below, and the locations of the major components involved are shown in Figure 4-23.

Extraction

Water will be pumped from two extraction wells located off-site to the southeast of JPL, and from an additional on-site well located in the contaminant source area (Figure 4-23). It is estimated using data from the groundwater model described above that a total extraction rate from the two off-site wells of 4,000 gpm (2,000 gpm for each well) would result in adequate containment of the off-site ClO_4^- plume, as described for Alternative 4. For the on-site well, it was previously estimated (Alternative 2, Figures 4-5 to 4-8) that an extraction rate of 500 gpm would be required to achieve a zone of influence necessary for capture of a major portion of the on-site ClO_4^- plume. This, however, did not account for large amounts of water that would be returned to the aquifer at the western portion of the site if infiltration was the ultimate fate of treated water from off-site extraction wells. Additional modeling of on-site source reduction pumping rates of 1,000 gpm, 1,250 gpm, 1,500 gpm, and 2,000 gpm along with the additional 4,000 gpm on-site infiltration were completed (Appendix H). Results suggest extraction rates as high as 1,250 gpm would be required for adequate on-site plume capture if on-site infiltration is carried out for water extracted from the off-site wells. This is shown for Aquifer Layers 1, 2, and 3 on Figures 4-24, 4-25, and 4-26 for the dry period of the year (September); and on Figures 4-27, 4-28, and 4-29 the wet period of the year (March), respectively.

Treatment

The treatment system is assumed to be as described for the proposed pilot study (see Figure 4-2). For Alternative 5, the system would be designed for an average flow of 5,250 gpm.

Disposition of Treated Water

Treated water would be returned to the aquifer via newly constructed infiltration wells (refer to Figure 4-23) located in the western portion of the site. Treated waste from IE (approximately 8 gpm from ISEP+) and treated rejectate from RO (approximately 1,050 gpm) would be discharged to the sewer. For this FS, it is assumed a volume of water equal to that discharged to the sewer would need to be purchased (probably from MWD) and supplied to the appropriate purveyor.

Conveyance

Conveyance would consist of piping from the extraction wells to the treatment system, and then to the infiltration wells as shown in Figure 4-23. Additional piping would be required from the treatment system to the sewer for the RO and IE wastes.

Screening Evaluation

Advantages and disadvantages of Alternative 5 are summarized below:

SCREENING OF ALTERNATIVE 5: PLUME REMEDIATION WITH OFF-SITE PUMPING PLUS ON-SITE SOURCE REDUCTION		
	Advantages	**Disadvantages**
Effectiveness	Effective for removal of ClO_4^- Designed to capture on- and off-site portions of ClO_4^- plume, preventing further significant impact to downgradient production wells. Is protective of human health and the environment.	ClO_4^- treatment options are not well established at this scale.
Implementability	Equipment readily available. VOC treatment technologies are easy to implement.	Infiltration well efficiencies not well understood (to be determined during pilot study). Space restrictions on-site for large treatment equipment. Piping from the on-site well would have to be installed below grade, which could pose serious problems in light of the numerous utilities at JPL, many of which may be critical to JPL operations. Capture located near off-site municipal wells, which requires very large flow rates to prevent ClO_4^- migration towards these wells.
Cost	**Preliminary estimate of capital costs:** **Preliminary estimate of O&M costs:**	**$38,220,419** **$106,372,874 (30-year period, present worth)**

Conclusion

Alternative 5 is reasonably implementable. Furthermore, this alternative is favorable for removal of ClO_4^- as well as inhibition of further downgradient migration, and is, therefore, considered to be effective. The cost for Alternative 5 is greater than that of Alternative 4. However, because of the potentially substantial increased effectiveness (inclusion of on-site source reduction) of Alternative 5 versus Alternative 4, Alternative 5 cannot be eliminated based on cost. Therefore, due to high ratings for implementability and effectiveness, Alternative 5 is retained for further consideration.

4.2.3.6 Alternative 6: Containment of ClO_4^- Only with Off-Site Pumping

For Alternative 6, a scenario is assumed where ClO_4^- treatment is not feasible at the high flow rates required. This scenario must be considered because of the potential technical uncertainties associated with current technologies for long-term removal of ClO_4^- from groundwater (although this will be addressed in the proposed pilot study). Alternative 6, therefore, involves treatment of VOCs, but only containment of the ClO_4^- plume through hydraulic control. This would be accomplished using off-site extraction wells, and on-site re-introduction of water into the aquifer without ClO_4^- treatment (back into the ClO_4^- plume) in an effort to create a containment loop. It is acknowledged that re-introduction of water in this type of application would not meet ARARs, however, if ClO_4^- can not be treated at the flow rates required to contain the plume, Alternative 6 may be the only option to inhibit further downgradient migration. If this were the case, attempts would be made to obtain an exemption from the ARAR for re-introduction. Furthermore, it is recognized that a complete containment loop may be difficult to maintain over long periods of time, particularly if conditions in the basin change.

Description

Alternative 6 consists of the following components (in addition to current remedial activities):

1. Two off-site extraction wells located to achieve capture of the ClO_4^- plume.
2. Treatment system for VOCs.
3. On-site infiltration wells to return the water to the aquifer.
4. Conveyance piping to convey extracted water from the extraction wells to the VOC treatment area, and VOC treated water to the infiltration wells.

Details regarding extraction, treatment, disposition of treated water, and conveyance are given below, and the locations of the major components (except locations of re-introduction wells) are similar to Alternative 4.

Extraction

Similar to Alternative 4, water will be pumped from two off-site extraction wells located in the area to the southeast of JPL (Figure 4-16). Based on results of groundwater modeling for Alternative 4, total flow rates from the two wells of 4,000 gpm were estimated to be necessary to achieve reasonable capture of the off-site ClO_4^- plume (Figures 4-17 through 4-22).

Treatment

Water from the off-site extraction wells would be treated for VOCs using air-stripping, but no ClO_4^- treatment is specified for Alternative 6 at this time.

Disposition of Extracted Water

Water from these wells (treated for VOCs but not ClO_4^-) would be re-introduced via infiltration wells located in the area of the on-site ClO_4^- plume.

Conveyance

Water from the off-site extraction wells would be pumped, treated for VOCs, and re-introduced back into the on-site ClO_4^- plume. Piping would be constructed from the extraction wells to the VOC treatment facility, and from the treatment plant to the infiltration wells.

Screening Evaluation

Advantages and disadvantages of Alternative 6 are summarized below:

SCREENING OF ALTERNATIVE 6: CONTAINMENT OF ClO_4^- WITH OFF-SITE PUMPING FOR HYDRAULIC CONTROL		
	Advantages	**Disadvantages**
Effectiveness	Reduce volume of VOCs and mobility of ClO_4^- contamination. Achieves adequate ClO_4^- plume containment.	No net removal of ClO_4^- from aquifer. May be difficult to maintain over long periods of time.
Implementability	Equipment readily available. VOC treatment technologies are easy to implement.	Must comply with substantive requirements of RWQCB waste discharge permits, since this alternative involves re-introduction of ClO_4^- to the aquifer. Infiltration well efficiencies not well understood (to be determined during pilot study). Piping from the on-site well from JPL would have to be installed below grade, which could pose serious problems in light of the numerous utilities at JPL, many of which may be critical to JPL operations. Capture located near off-site municipal wells which requires very large flow rates to prevent ClO_4^- migration towards these wells
Cost	**Preliminary estimate of capital costs: $10,011,240** **Preliminary estimate of O&M costs: $48,697,438 (30-year period, present worth)**	

Conclusion

Alternative 6 is favorable for removal of VOCs from groundwater, and containment of ClO_4^-, and would meet the RAOs regarding inhibition of contaminant migration, and to a lesser extent, elimination of potential exposure risk. This alternative receives a relatively high rating for implementability, and is relatively inexpensive. However, because effectiveness is very low, and because it appears at this time that ClO_4^- treatment is feasible at the required flow rates, this alternative is eliminated from further consideration at this time.

4.2.3.7 Summary of Screening

The results of the remedial alternative screening exercise are summarized below:

SUMMARY OF RESULTS OF THE SCREENING EXERCISE				
Alternative	Relative Rating[1]			Comments
	Effectiveness	Implementability	Cost	
1: No Further Action	3	1	1	Retained
2: On-Site Source Reduction	2	1	1	Retained
3: Plume Remediation with On-Site Pump-and-Treat Activities	3	2	3	Eliminated
4: Plume Remediation with Off-Site Pump-and-Treat Activities	2	1	2	Retained
5: Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-site Source Reduction	1	1	3	Retained
6: Containment of ClO_4^- with Off-Site Pumping and Hydraulic Control	3	2	2	Eliminated

[1]*Notes:*

1 = Favorable

2 = Moderately favorable

3 = Unfavorable

4.3 RETAINED ALTERNATIVES

The alternatives retained for further, more detailed analysis in Chapter 5.0 (in conjunction with current remedial activities) are listed below:

RETAINED ALTERNATIVES	
Alternative	Description
Alternative 1	No Further Action
Alternative 2	On-site Source Reduction
Alternative 4	Plume Remediation with Off-site Pump-and-Treat Activities
Alternative 5	Plume Remediation with Off-site Pump-and-Treat Activities Plus On-site Source Reduction

Also, as discussed in Section 4.2.2, the current on-going remedial activities meet the three initial screening criteria (effectiveness, implementability, cost) and are considered to be an integral part of each of the above alternatives that will be carried through for detailed analysis in Section 5.0. In addition, monitored natural attenuation (Section 3.4.2 and Appendix A) is retained for use in conjunction with, and as a follow-up to, the above pump and treat remediation activities.

TABLES

TABLE 4-1

SUMMARY OF MUNICIPAL PRODUCTION WELL PUMPING SCHEDULES USED DURING GROUNDWATER MODELING SIMULATIONS JET PROPULSION LABORATORY

(all rates in gpm)
(provided by the Raymond Basin Management Board)

Production Well	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
City of Pasadena												
Ventura Well	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Windsor Well	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Pasa 52 Well	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Arroyo Well	0	0	0	0	0	0	0	0	0	0	0	0
Lincoln Water Company												
Well No. 3	1,000	1,000	1,000	1,000	0	0	0	0	0	1,000	1,000	1,000
Well No. 5	1,100	1,100	1,100	1,100	0	0	0	0	0	0	1,100	1,100
Valley Water Company												
Well No. 1	1,000	1,000	1,000	0	0	0	0	0	0	0	1,000	1,000
Well No. 4	1,100	1,100	1,100	0	0	0	0	0	0	0	1,100	1,100
Rubio Canyon & Water Association												
Well No. 4	900	900	900	900	0	0	0	0	0	900	900	900
Well No. 7	1,800	1,800	1,800	1,800	0	0	0	0	0	1,800	1,800	1,800
Las Flores Water Company												
Well No. 2	600	600	600	600	600	600	600	600	600	600	600	600
La Canada Irrigation District												
Well No. 1	450	450	450	0	0	0	0	0	0	0	450	450
Well No. 6	750	750	750	0	0	0	0	0	0	0	0	0

Note: Results for September and March were used to evaluate proposed extraction rates for remedial alternatives.

TABLE 4-2

SUMMARY OF REMEDIAL ALTERNATIVES
JET PROPULSION LABORATORY

Alternative	Definition	Description(1)	Collection	Estimated Flow Rate(2)	VOC Treatment	ClO_4^- Treatment	Disposition of Treated Water	Disposal of ClO_4^- Waste Stream
1	No Further Action	No additional remediation activities are implemented by JPL.	None	NA	NA	NA	NA	NA
2	On-site source reduction pump-and-treat activities	Water is extracted from a strategically located on-site extraction well and treated for VOCs and ClO_4^-.	New, on-site extraction well	500 gpm	Air- stripping	RO/IE(3)	Re-introduce upgradient on-site	None
3	Plume remediation with on-site pump-and-treat activities only	Water is extracted from strategically located on-site extraction well(s) and treated for VOCs and ClO_4^-.	New, on-site extraction wells	7,000 gpm	Air- stripping	RO/IE(3)	Re-introduce upgradient on-site	None
4	Plume remediation with off-site pump-and-treat activities only	Water is extracted from strategically located off-site extraction well(s) and treated for VOCs and ClO_4^-.	New, off-site extraction wells	4,000 gpm	Air- stripping	RO/IE(3)	Re-introduce upgradient on-site	None
5	Plume remediation with off-site pump-and-treat activities plus on-site source reduction	Water is extracted from strategically located on- and off-site well(s) and treated for VOCs and ClO_4^-.	New, on- and off-site extraction wells	4,000 gpm, off-site wells; 1250 gpm, on-site well	Air- stripping	RO/IE(3)	Re-introduce upgradient on-site	None
6	Plume remediation for VOCs with containment for ClO_4^-, off-site pump-and-treat/containment activities	Water is extracted from strategically located off-site well(s) and treated for VOCs, but ClO_4^- treatment considered infeasible.	New, off-site extraction wells	4,000 gpm	Air- stripping	None	NA (all water considered waste)	Re-introduce on-site into ClO_4^- plume

Notes:

(1): Current remedial activities are assumed to be in conjunction with all alternatives.
(2): Based on results of modeling.
(3): To be determined at conclusion of pilot study.

FIGURES

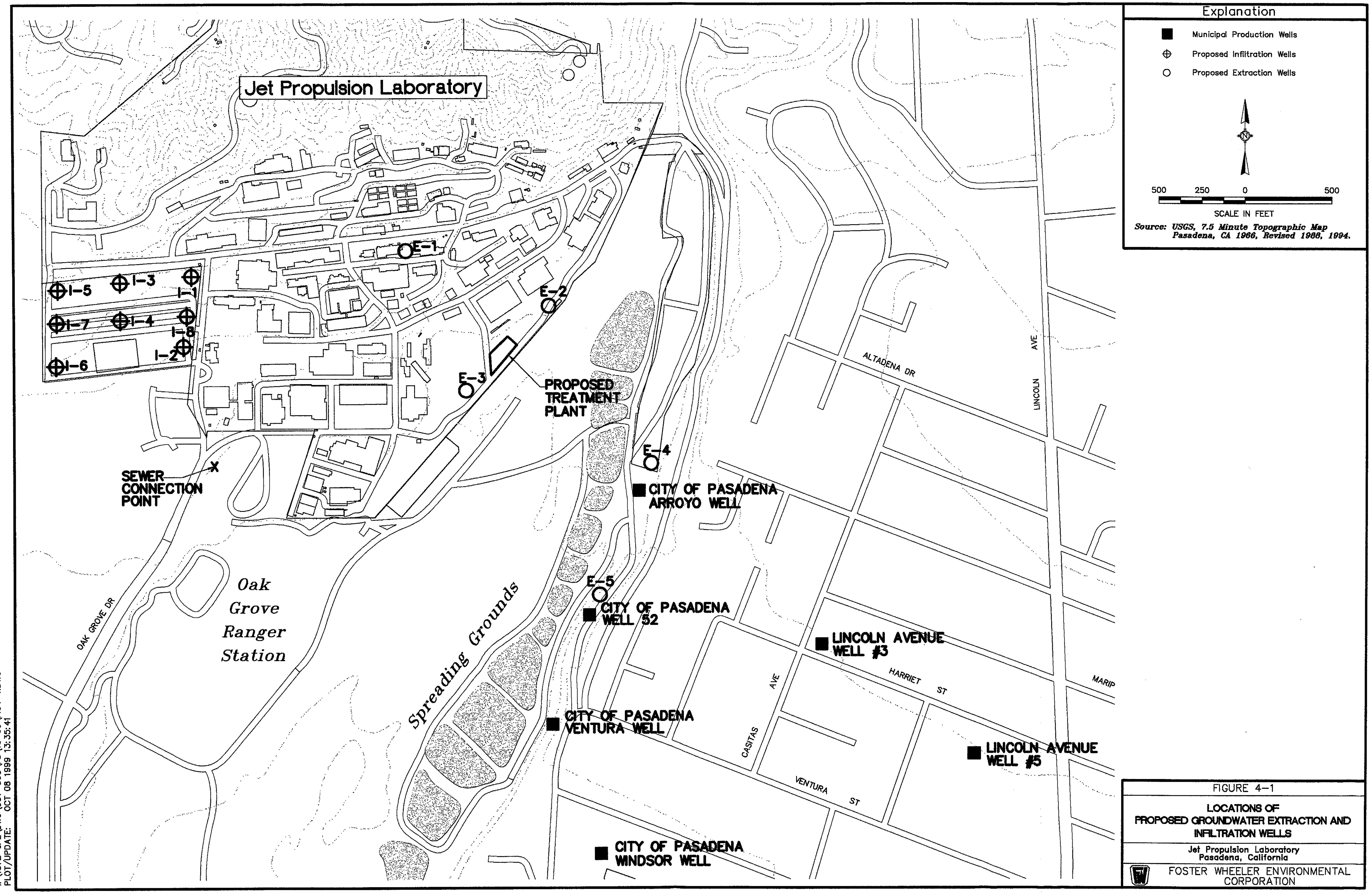

FIGURE 4-1

LOCATIONS OF PROPOSED GROUNDWATER EXTRACTION AND INFILTRATION WELLS

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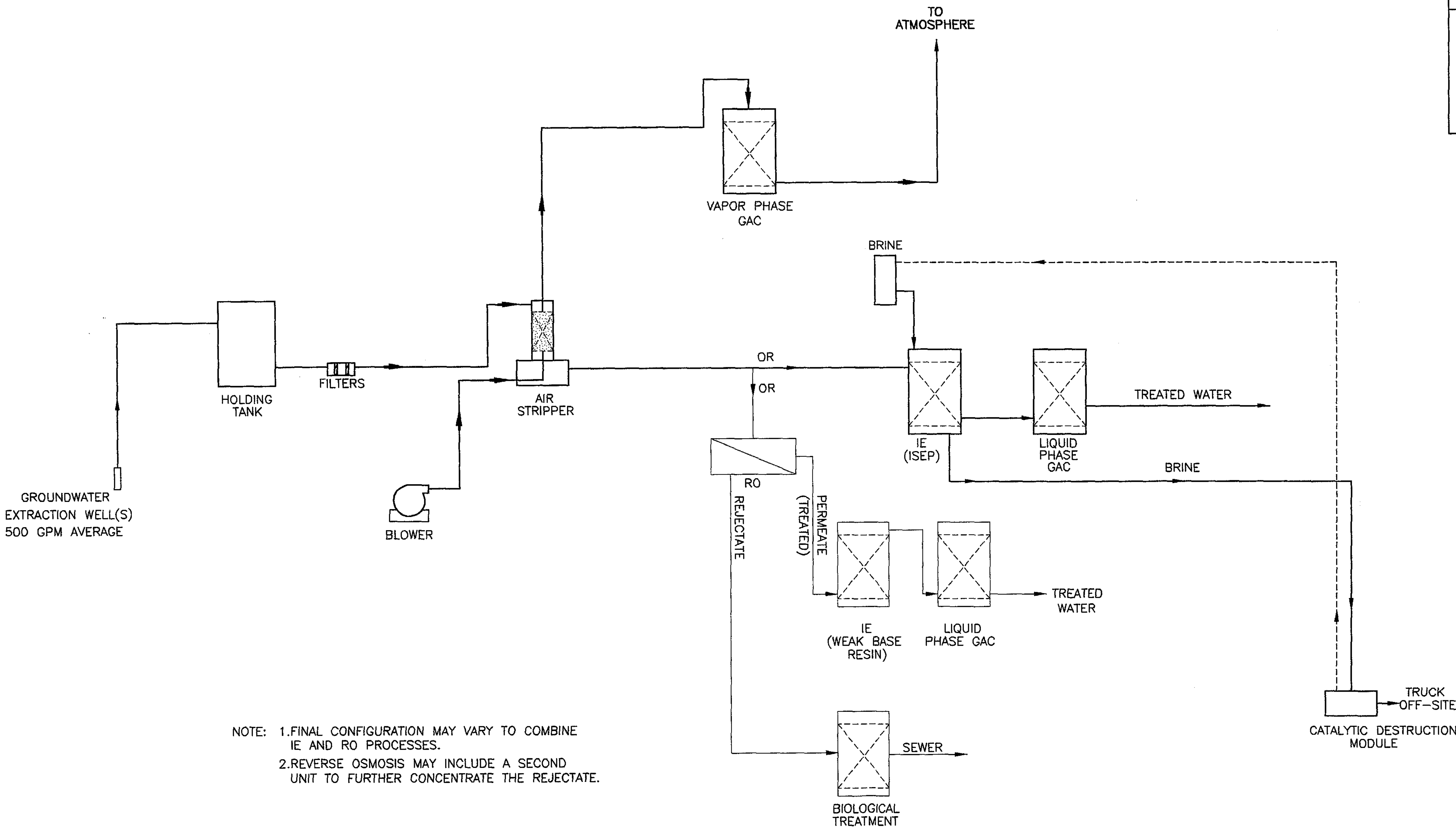
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\10-99\FIG4-1.DWG
PLOT/UPDATE: OCT 08 1999 13:35:41

Explanation

GAC	GRANULAR ACTIVATED CARBON
RO	REVERSE OSMOSIS
GPM	GALLONS PER MINUTE
IE	ION EXCHANGE



NOTE: 1. FINAL CONFIGURATION MAY VARY TO COMBINE IE AND RO PROCESSES.

2. REVERSE OSMOSIS MAY INCLUDE A SECOND UNIT TO FURTHER CONCENTRATE THE REJECTATE.

FIGURE 4-2

CONCEPTUAL SCHEMATIC DIAGRAM FOR THE PROPOSED PILOT STUDY

Jet Propulsion Laboratory
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\12-99\FIG4-2.DWG
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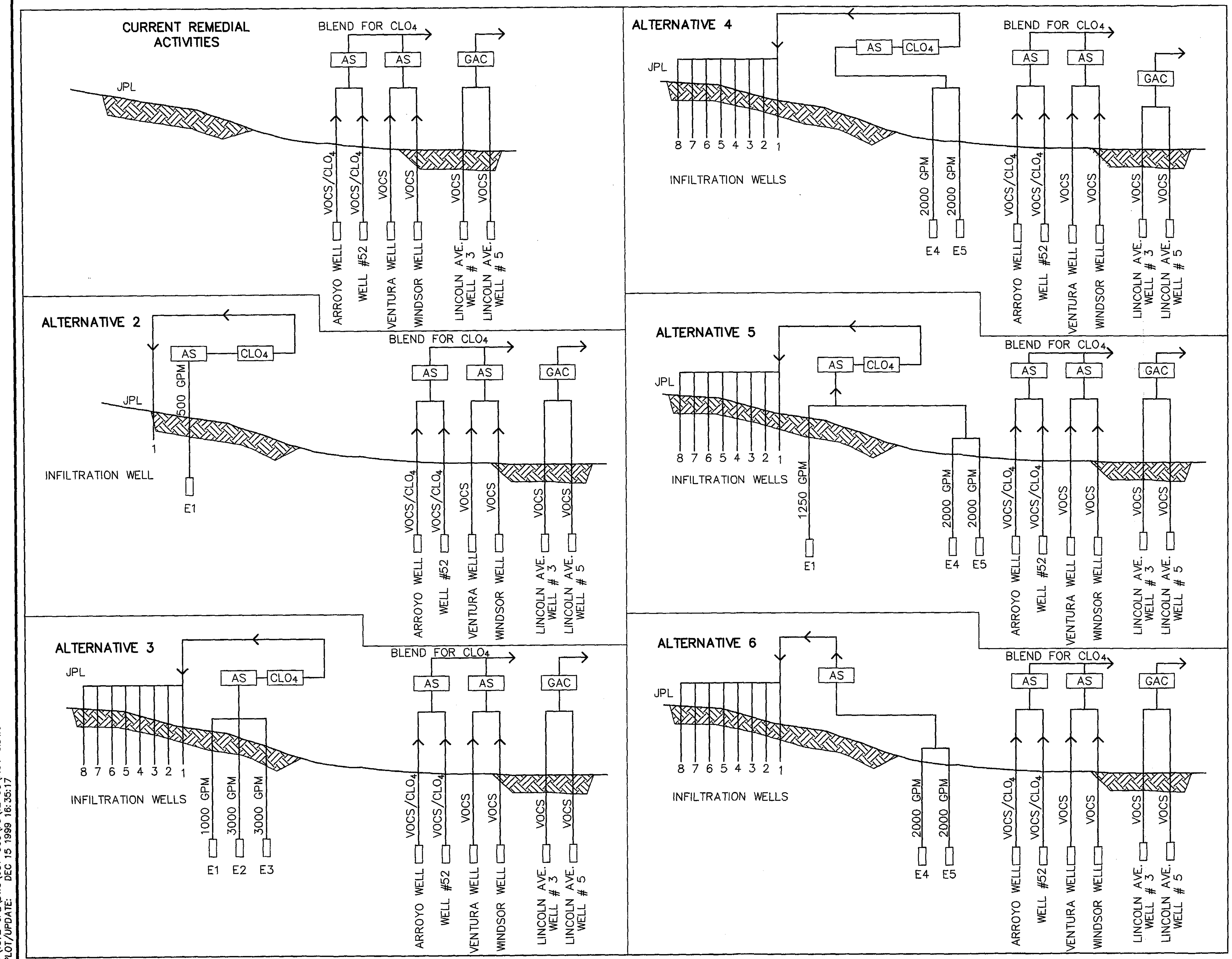

Explanation

E	EXTRACTION WELLS
VOCS	VOLATILE ORGANIC COMPOUNDS
CLO_4	PERCHLORATE
AS	AIR STRIPPING (FOR VOC REMOVAL)
GAC	GRANULAR ACTIVATED CARBON (FOR VOC REMOVAL)
CLO_4	PERCHLORATE TREATMENT (TO BE DETERMINED)
GPM	GALLONS PER MINUTE

FIGURE 4–3

SCHEMATIC DIAGRAMS OF REMEDIAL ALTERNATIVES

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Pasadena, California

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I:\1572-JPL\DWG\OU1-OU3\FS\12-99\FIG4-3.DWG
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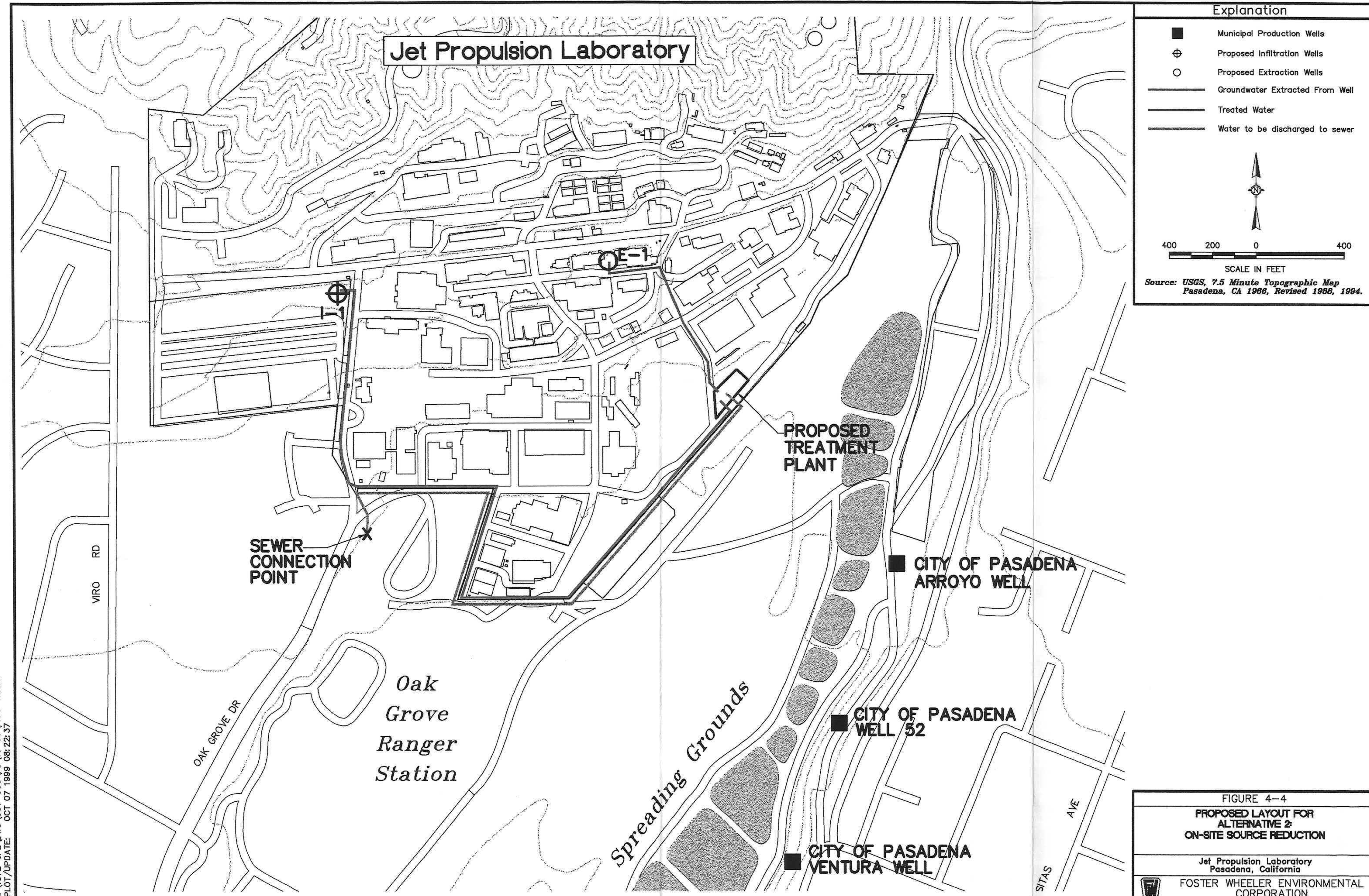

FIGURE 4-4
PROPOSED LAYOUT FOR ALTERNATIVE 2: ON-SITE SOURCE REDUCTION

Jet Propulsion Laboratory
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\10-99\FIG4-4.DWG
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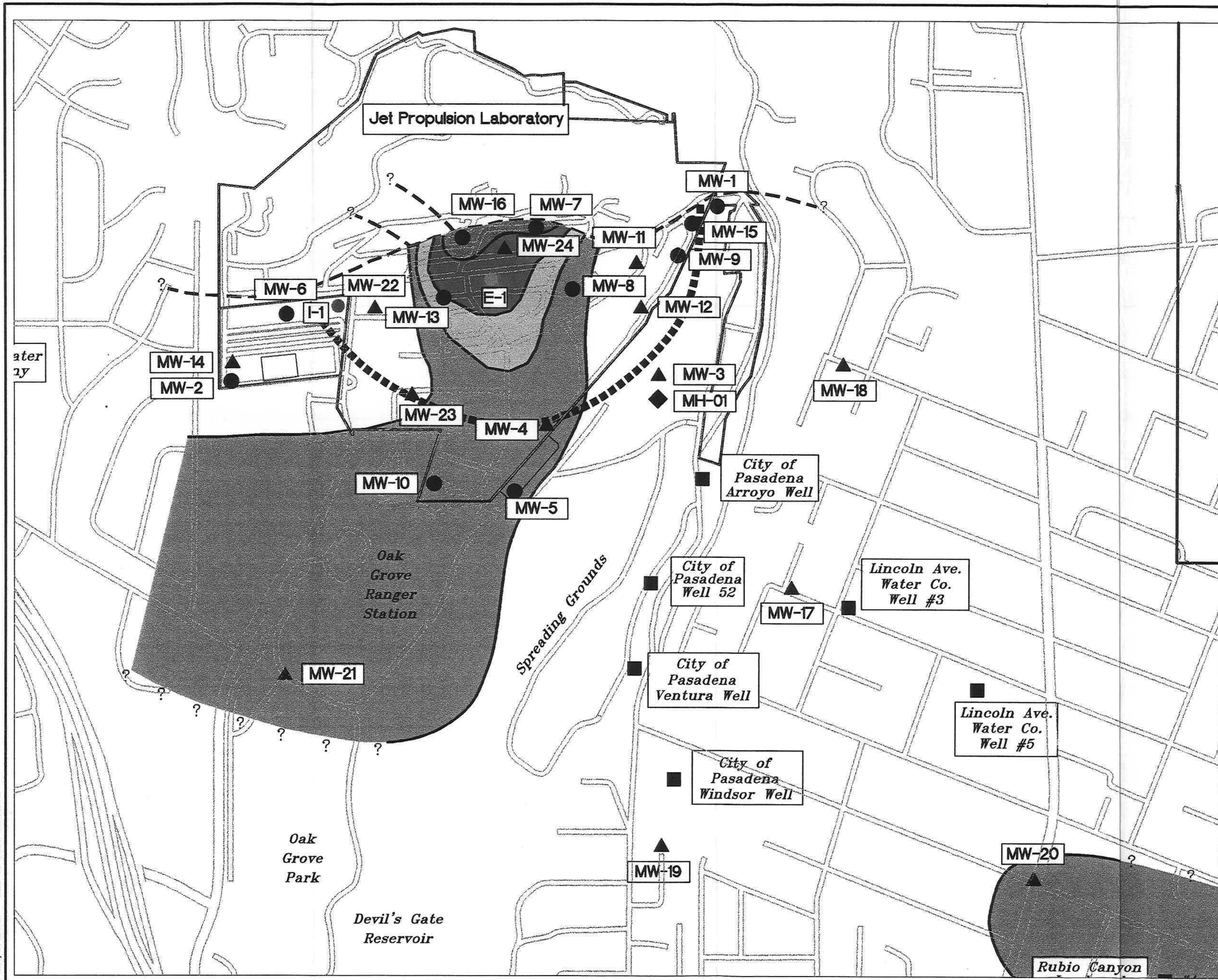

Explanation

- JPL Shallow Monitoring Wells
- JPL Deep Multi-Port Monitoring Wells
- Municipal Production Wells
- City of Pasadena Monitoring Well
- JPL Thrust Fault
- JPL Property Line

Perchlorate Plume

- Concentrations Between Detection Limit (4.0 µg/L) and IAL (18.0 µg/L)
- Concentrations 18.0 to 100.0 µg/L
- Concentrations 100.0 to 500.0 µg/L
- Concentrations Above 500.0 µg/L
- Extraction Well (500 gpm)
- Infiltration Well (500 gpm)
- Approximate zone of capture [Groundwater within the limits of this countour is captured by the extraction well(s)]

Note: Infiltration was simulated with model layer 1 only.

Note: Distinctions between concentration (color) contours may become less clear in black and white photocopies. Refer to the original color figure for best resolution.

N

600 300 0 600

SCALE IN FEET

Source: USGS, 7.5 Minute Topographic Map Pasadena, CA 1966, Revised 1988, 1994.

FIGURE 4–5

CAPTURE ZONE FOR GROUNDWATER MODEL SIMULATION OF ALTERNATIVE 2: ON-SITE SOURCE REDUCTION

(AQUIFER LAYER 1, SEPTEMBER)

Jet Propulsion Laboratory
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572–JPL\DWG\OU1–OU3\FS\12–99\FIG4–5.DWG
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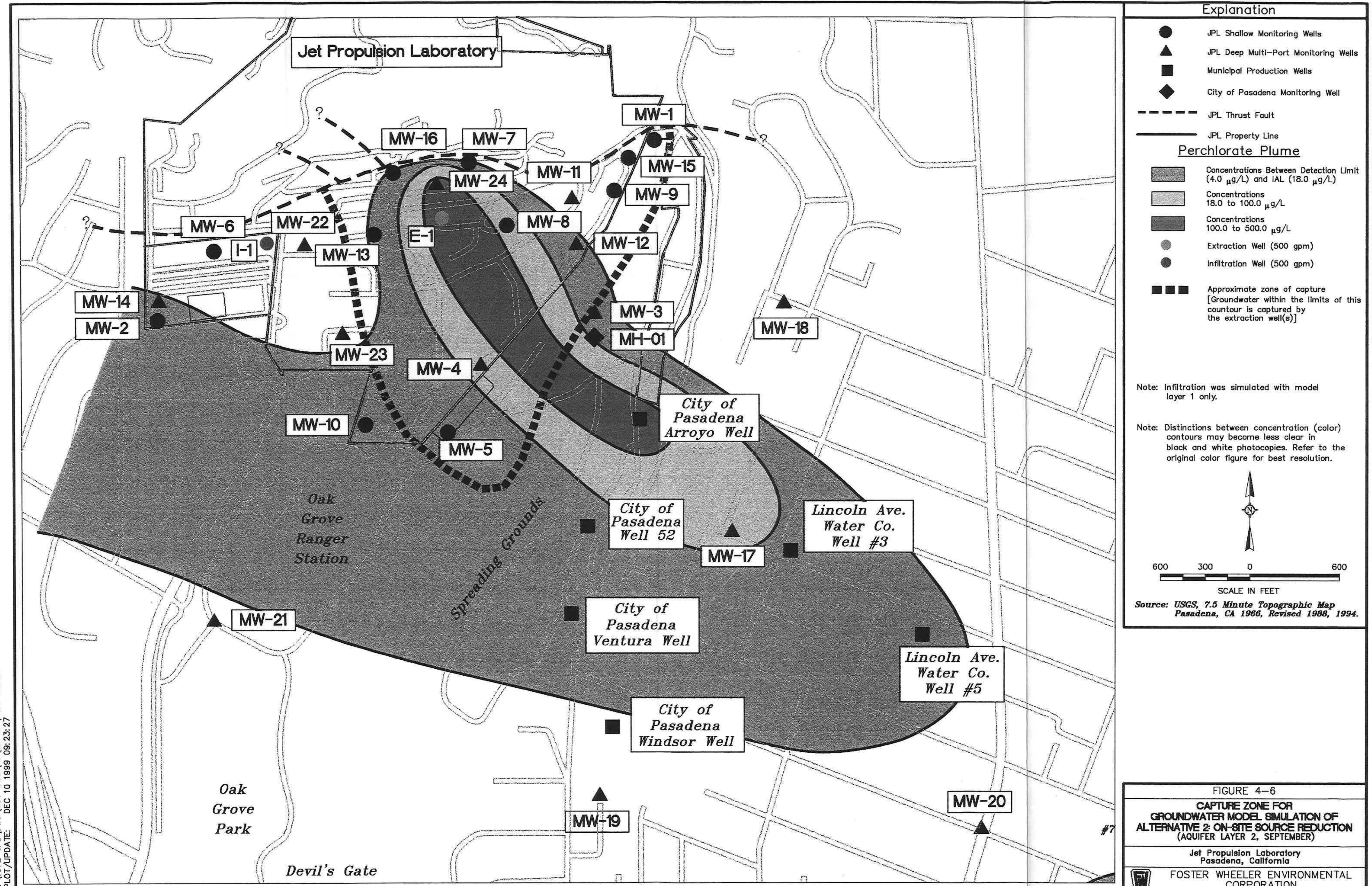

FIGURE 4-6
CAPTURE ZONE FOR GROUNDWATER MODEL SIMULATION OF ALTERNATIVE 2: ON-SITE SOURCE REDUCTION (AQUIFER LAYER 2, SEPTEMBER)
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Pasadena, California
FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\12-99\FIG4-6.DWG
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Continue

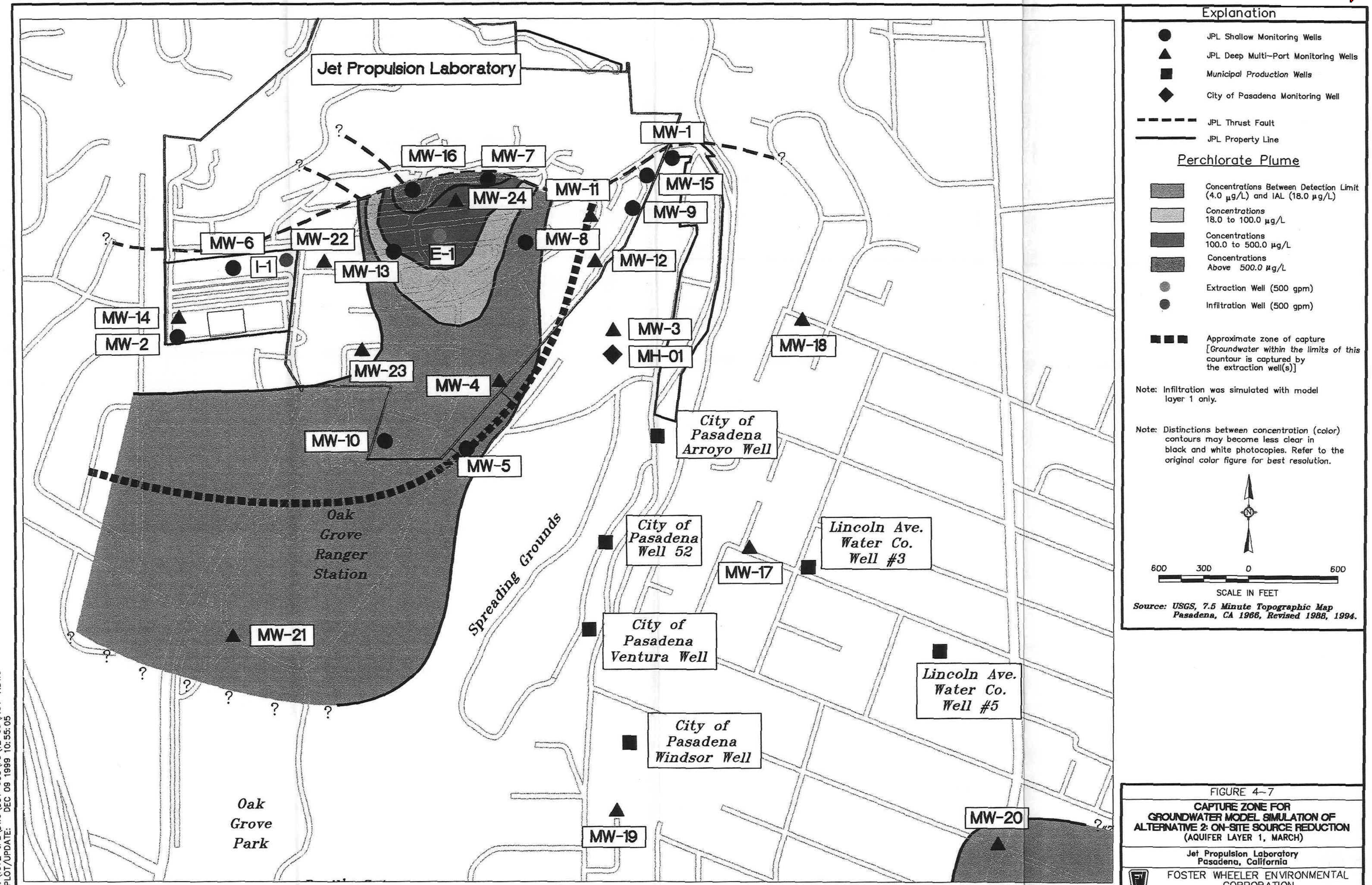

FIGURE 4-7
CAPTURE ZONE FOR GROUNDWATER MODEL SIMULATION OF ALTERNATIVE 2: ON-SITE SOURCE REDUCTION (AQUIFER LAYER 1, MARCH)
Jet Propulsion Laboratory Pasadena, California
FOSTER WHEELER ENVIRONMENTAL CORPORATION

I:\1572-JPL\DWG\OU1-OU3\FS\12-99\FIG4-7.DWG
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