

4.0 DEVELOPMENT AND SCREENING OF REMEDIAL ALTERNATIVES

In this section, potential remedial alternatives are assembled using various process options associated with SVE, which was selected as the presumptive remedy in Section 3.0 (refer to Subsection 3.3.1). The potential remedial alternatives are then subjected to a screening process in which their effectiveness, implementability, and cost are evaluated. The retained remedial alternatives are subjected to a more detailed evaluation in Section 5.0 using the nine Superfund evaluation criteria. Also included in this section is a description of the SVE pilot test conducted at OU-2, and a summary of the results.

The final configuration of the remedial alternative selected for implementation will be based on performance criteria presented in the ROD. Any additional information and data acquired during remedial design, such as from pilot testing, will also be considered when the final design is developed. The project details described in this FS are conceptual and have been assumed only for cost estimating and remedial alternative comparisons. Other technologies and configurations are possible. In accordance with EPA guidance, cost estimates developed at this stage in the FS process are approximate (plus 50 to minus 30 percent), and based on designs that are not yet well defined.

4.1 DEVELOPMENT OF REMEDIAL ALTERNATIVES

The development of alternatives must conform to requirements identified in CERCLA, as amended, and to the extent possible in the National Contingency Plan (40 CFR Part 300). 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, or 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.

These requirements will be taken into consideration in developing the alternatives for the JPL site.

For the purposes of this FS, the remedial alternatives consist of process options associated with treatment of VOC waste streams extracted via SVE. SVE is paired with the various process

options to form remedial alternatives, which are then screened on the basis of effectiveness, implementability, and cost.

As per EPA guidance, the "No Action" alternative is carried through the FS screening processes to provide a baseline for comparison with other alternatives. The "No Action" alternative consists of leaving the site "as is." Under this alternative, no remedial activities would be undertaken at OU-2 in the future, and the pilot plant currently operational would be taken off line.

Based on the analysis presented in Section 3.0 and above, the general alternatives for OU-2 at JPL include:

- No Action
- In Situ Soil Vapor Extraction

These alternatives include soil-vapor monitoring via the quarterly monitoring program (currently in place) to assess the VOC concentration trends over time.

As noted above, additional technologies that are required for treatment of waste streams from SVE are considered below. Vapors extracted from the well(s) will contain VOCs, and the vapor stream will require treatment prior to discharge to the atmosphere.

Using the EPA *Remediation Technologies Screening Matrix and Reference Guide* (EPA, 1993c), the following technologies were identified as being appropriate for VOC removal from the off-gas stream:

- Thermal Oxidation
- Catalytic Oxidation
- Carbon Adsorption
- VOC Adsorbing Resins

The choice of off-gas treatment method may depend on the concentrations of contaminants and may change if these concentrations vary by an order of magnitude, either across the site or with time.

4.1.1 Development of Alternatives

Alternatives were developed using the "No Action" alternative, and in situ SVE (the presumptive remedy) plus the possible process options for treating waste streams. As noted above, all alternatives include soil monitoring, so that the degree of remediation can be evaluated. Natural attenuation will occur regardless of human effort; therefore, it is expected to occur to some extent in each alternative as well.

Four alternatives were developed for SVE, each specifying a different process option for off-gas treatment.

The alternatives developed for consideration at JPL OU-2 are:

- Alternative 1:** No Action
- Alternative 2:** In Situ SVE Treatment
- Alternative 2a:** Thermal Oxidation Off-Gas Treatment
- Alternative 2b:** Catalytic Oxidation Off-Gas Treatment
- Alternative 2c:** Granular Activated Carbon Adsorption Off-Gas Treatment
- Alternative 2d:** VOC Adsorbing Resins Off-Gas Treatment

4.2 PILOT TEST

In situ SVE was identified during the RI stage as being a potentially feasible technology for remediation of the VOC-impacted soils in OU-2. Implementation of in situ SVE requires collection of site-specific data, typically through implementation on a field pilot scale. This was recognized by the RPMs during the RI process, and a field scale pilot test was implemented starting in April of 1998. This testing confirmed the feasibility of in situ SVE in remediating VOC-impacted soils, and provided design parameters for future full-scale implementation. Detailed descriptions of the pilot test and results obtained to date are provided in Appendix A. A summary of relevant information is provided in the following sections.

4.2.1 Test Setup

The pilot test was performed on a test vapor extraction well (VE-1) installed at the location shown in Figure 4-1 that is at the approximate center of the area with the highest VOC concentrations. The well is screened across the depth of contamination, from approximately 45 feet bgs to 185 feet bgs. It consists of three discrete casings that are screened at different depths [Screen A (44 to 84 feet bgs), Screen B (94 to 134 feet bgs), and Screen C (145 to 185 feet bgs)] as shown in Figure 4-2. This allows a better distribution of vacuum across the screened interval and allows for extraction from specific depths as opposed to the entire screened depth.

The test consisted of applying a vacuum on various combinations of these casings, monitoring flow rates and VOC concentrations in extracted vapors, and measuring vacuum responses in the soil vapor monitoring wells surrounding VE-1. Locations of the wells that were monitored are shown in Figure 4-1. As noted in the RI report (Foster Wheeler, 1999b), each well consists of multiple soil vapor sampling tips at various depths. These wells were also monitored for VOCs as part of the ongoing soil vapor monitoring program, which provided additional information in terms of SVE effectiveness. A vacuum blower was used to extract soil vapors from VE-1, and

the vapors were treated with four vapor-phase granular activated carbon (GAC) vessels as shown in Figure 4-3.

The test consisted of a short-term portion (Tests 1 and 2) from April 1998 to June 1998, and a long-term portion (Test 3) beginning in November 1998 (this test is ongoing).

4.2.2 Test Results

The test results indicated that SVE is indeed a feasible technology for remediation of the VOC-impacted soils at OU-2. Following are some of the key results of the pilot test:

- All three screens were able to extract significant quantities of soil vapor with flow-rates ranging from 157 to 174 cfm from each screen at vacuums ranging from 44 to 80 inches of water.
- Vacuum responses were noted as far as 771 feet away from the extraction well. Normalized vacuum responses of greater than or equal to 1 percent of the exerted vacuum were observed at least 460 feet away.
- A 75 percent reduction in CCl_4 (the primary constituent of interest) levels was observed approximately 450 feet away from the extraction well in Zone 4 (approximately the bottom 50 feet of the vadose zone). In Zones 2 and 3, 75 percent reductions in CCl_4 levels were observed 550 and 425 feet away from the extraction well, respectively.
- VOC concentrations in the extracted vapor were reduced by over 95 percent over the duration of the test.
- VOC removal rates of up to 0.10 lbs/hr were noted for CCl_4 , with an overall removal of approximately 180 lbs of CCl_4 between May 1998 and October 1999.
- Total VOC removal rates of up to 0.11 lbs/hr were noted, with an overall removal of approximately 200 lbs between May 1998 and October 1999. An additional 850 lbs of VOCs (total) may have been removed on two separate occasions.

4.2.3 SVE Effectiveness

As noted above, vacuum responses were noted as far as 700 feet away from VE-1 during the early portions of the test, indicating a ROI of at least 700 feet. This is somewhat higher than the typical ROI at most sites (10 to 200 feet depending on soil type). This led to an extension of the test from an originally intended duration of 10 weeks, to approximately 12 months. Furthermore, the observation of vacuum responses does not necessarily imply that remediation (i.e., removal of VOCs) is occurring within the area encompassed by the ROI. Hence, the actual changes in VOC levels in the various soil-vapor monitoring probes were evaluated over time to provide a better measure of SVE effectiveness. This effectiveness was measured in terms of the radius of remedial influence (RORI), which is defined as the distance (from the extraction well) which significant reduction in VOCs (as evidenced by soil vapor levels) is observed.

Four soil-vapor monitoring events (May/June 1998, October 1998, March 1999, and October 1999) were used to evaluate SVE effectiveness. It is noted here that two events were actually conducted in May/June 1998. However, because they were conducted only one month apart, they were considered together for the purpose of assessing SVE effectiveness, and the highest concentration for each sampling probe was used. VOC levels (CCl₄ and Freon) for the four events for selected soil vapor monitoring probes are shown on Figure 4-4. Based on Figure 4-4, VOC levels have reduced significantly as a result of the SVE pilot test. Contours for CCl₄ and Freon are shown in Figures 4-5 and 4-6, respectively, for the four events. These figures also reflect the significant reduction in VOC levels as a result of the pilot test.

As shown in Appendix A, reductions of greater than 50 percent were observed as far as 340 and 380 feet away from the extraction well for Freon in Zones 3 and 4. The corresponding distance for Freon in Zone 2 is greater than 1,000 feet. The effectiveness for CCl₄ is greater than for Freon, with a 75 percent reduction occurring at approximately 550, 425, and 450 feet for Zones 2, 3, and 4, respectively. To be conservative, a RORI of 400 feet is assumed.

4.3 SCREENING OF REMEDIAL ALTERNATIVES

In this section, the remedial alternatives listed above are described and evaluated on the basis of effectiveness, implementability, and cost, the same criteria used in Section 3.3. The focus of the following screening is enlarged to include the effects of the remedial process on its surroundings as well as its technical feasibility. Alternatives with favorable composite evaluations will be retained for further consideration during the detailed analysis presented in Section 5.0.

Effectiveness—The effectiveness criterion evaluates the ability of an alternative to provide protection to human health and the environment. This includes both immediate and long-term considerations. According to EPA guidance (EPA, 1988a), the effectiveness screening includes the following criteria:

- The ability to protect the groundwater beneath the site, i.e., meet cleanup levels for soil that are protective of beneficial use of the groundwater.
- The degree of permanent reduction in toxicity, mobility, or volume.
- The magnitude of risks to the public, site workers, or the environment during implementation.
- The ability to attain remediation goals.

It should be noted that evaluating effectiveness with regard to direct protection of human health is not required for soils at this site because the risk assessment found no human health risks associated with surface soils [OU-2 RI report (Foster Wheeler, 1999b)]. In addition, mitigation of potential human health risks due to exposure to contaminants via groundwater is the subject of the OU-1/OU-3 FS (Foster Wheeler, 1999c).

Implementability—Implementability is a measure of both the technical and administrative feasibility of each alternative, particularly with respect to construction, operation, and maintenance. Implementability criteria include the following:

- The extent to which a process can be constructed, reliably operated, and meet technology-specific regulations
- How easily operation, maintenance, replacement, and monitoring of technical components can be achieved after the remediation period is complete.
- The difficulty in obtaining approvals from other offices and agencies.
- The availability of treatment, storage, and disposal services and capacity.
- The requirements for, and availability of, specific equipment and technical specialists.

Cost—During the alternative screening, order of magnitude cost estimates are used to provide comparisons between alternatives, rather than to define the cost of specific alternatives. The following considerations are used for the cost screening at this level:

- Comparative cost increase or decrease with respect to the benefit derived from one alternative versus another.
- Comparative capital and operation and maintenance (O&M) costs for the alternatives.

4.3.1 Alternative 1: No Action, Monitoring

The No Action alternative is evaluated for this FS in accordance with NCP protocols (40 CFR Part 300). This alternative stipulates that no additional remedial activities will be implemented by JPL. Under this alternative, no remedial activities are undertaken at the site, the current SVE pilot system is taken off-line, and a soil-vapor monitoring program is instituted to assess temporal changes in contaminant concentrations and distributions.

Advantages and disadvantages of the No Action alternative are evaluated in the following paragraphs.

Effectiveness—This alternative does not provide protection of groundwater, since there are no provisions to prevent the VOC plume from continuing to migrate to the water table. No reduction in toxicity, mobility, or volume of contaminants will result from this alternative with the exception of incidental reductions in volume or toxicity due to natural processes.

There are no risks to the public, site workers, and the environment resulting from implementation of this alternative, since no actions will take place. Remediation goals will not be met in the foreseeable future if no action is taken.

Implementability—The No Action alternative is easily implemented since no new construction is required. Soil-vapor monitoring will require field operations similar to those undertaken during

the RI and is already proven to be technically implementable at this site. In addition, soil vapor sampling tips are already in place for future soil vapor sample collection.

The No Action alternative is not likely to be acceptable to local governments and the public because the VOC plume will continue to act as a source of groundwater contamination. As discussed in the JPL OU-1 and OU-3 FS report (Foster Wheeler, 1999c), this groundwater may impact surrounding communities if no remedial action is taken.

Cost—The only costs associated with the No Action alternative are those for the soil vapor monitoring program. These fall into the O&M category, and will continue periodically for at least 5 years.

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

4.3.2 Alternative 2: In Situ SVE, Monitoring

Under Alternative 2, VOCs in the vadose zone are treated with in situ SVE. As explained in Section 3.3, in situ SVE has been identified by USEPA as a presumptive remedy for sites with VOCs present in soil. Based on discussions presented in Sections 3.3.1 and 4.2, SVE can be performed as an in situ process (thereby increasing economic effectiveness), is amenable to conditions at JPL, and has been shown to be effective at JPL in a pilot study. In situ SVE has, therefore, been selected as the presumptive remedy, and does not require further evaluation in this section. The ongoing soil-vapor monitoring program will be used to assess changes in contaminant concentrations and extent over time.

The soil vapors extracted by the SVE system constitute a waste off-gas stream, and contain the VOCs removed from the vadose zone. These VOCs must be removed before the off-gas can be discharged to the atmosphere. Four different options for vapor treatment are considered, and are evaluated in the following section.

4.3.3 Off-Gas Treatment

Alternative 2 requires off-gas treatment as part of the treatment train. Four off-gas treatment options are evaluated in the following subsections to determine which are most appropriate at this site.

4.3.3.1 Alternative 2a: Thermal Oxidation Off-Gas Treatment

Thermal oxidation is a process in which organic contaminants are destroyed in a combustor at temperatures of approximately 1,800°F (1,000°C). The primary advantage of thermal oxidation is that contaminants are chemically degraded into nontoxic compounds. This process is typically applied to streams with contaminant concentrations greater than 12,000 parts per million by

volume (ppmv). Vapor/liquid separators are used prior to thermal oxidation units to remove noncombustible components from the treatment stream.

Effectiveness—Thermal oxidation effectively removes VOCs, SVOCs, and fuel hydrocarbons from gaseous streams. However, it is typically targeted toward treatment of non-halogenated compounds and can be problematic when used on waste streams containing chlorinated materials such as those present at JPL (EPA, 1993b). This is mainly because hydrochloric acid (HCl) is generated, which is highly corrosive, and can damage various system components. Furthermore, since halogenated compounds are present, the system would be Resource Conservation and Recovery Act (RCRA) regulated as a hazardous waste incinerator, which would require extensive permitting.

Conclusion—All four of the constituents of interest at the JPL OU-2 site are chlorinated, and the presence of chlorine makes thermal oxidation inappropriate for the waste stream at this site due to the production of HCl. Based on low effectiveness, this treatment process is eliminated from further consideration in this FS.

4.3.3.2 Alternative 2b: Catalytic Oxidation (Halogenated) Off-Gas Treatment

Catalytic oxidation uses a catalyst to treat air streams containing halogenated organics, typically at concentrations less than 12,000 ppmv. During treatment, the air stream is preheated to approximately 840°F (450°C) and then passed through the catalyst bed where it is oxidized. The contaminants and oxygen are adsorbed onto the catalyst surface where they react to produce carbon dioxide, water, and hydrogen chloride or hydrogen fluoride gas (for the VOCs at this site). The exhaust typically requires scrubbing (usually with water) to remove the chloride and fluoride, prior to final discharge to the atmosphere.

Effectiveness—While catalytic oxidation can remove halogenated VOCs from an air stream, it may not be able to reach the fairly low levels that would be required by the SCAQMD and may require additional polishing of air stream prior to discharging to atmosphere (typically GAC). The major advantage of this process is that it permanently destroys the contaminants resulting in complete toxicity removal. Since the discharge from the catalytic oxidation system will contain halogenated acids (as halogenated VOCs are the primary constituents of concern), this method will require additional treatment options for addressing halogenated acids (typically scrubbing). Risks to the public and site workers during implementation are well controlled and are negligible if the system is operated correctly.

Implementability—This process has been used successfully in the past, and can be installed and operated reliably. While no permits would be required, the “substantive” requirements of a Permit to Construct/Operate from the South Coast Air Quality Management District (SCAQMD) would have to be met.

The constituents of interest at the JPL OU-2 site are halogenated, primarily with chlorine, but also with fluorine (Freon 113). Emissions from the oxidation unit will, therefore, contain

hydrogen chloride and hydrogen fluoride, and they would require scrubbing prior to discharge to the atmosphere. This would result in another waste stream (water). Also, since the halogenated volatiles do not have a very high calorific value, the catalytic unit will require heat energy (either natural gas or electricity). Some specialized training may be required for operating personnel. Oxidation units are available to treat a large range of flow rates.

Cost—This process option is rated as ‘Better’ by the EPA, indicating that a general cost range, based on past experience, is less than \$7 per pound of off-gas treated (EPA, 1993b). However, this cost does not reflect the additional costs that would be incurred for scrubbing and the significant amounts of energy (gas or electricity) that would be required. Hence, actual costs are expected to be much higher. Typical costs for a 500 cfm system are on the order of \$200,000 (capital), and \$5,000 per month for electricity, chemicals, and laboratory analyses.

Conclusion—Catalytic oxidation could be used to treat VOCs in the off-gas stream from the SVE system. However, additional treatment may be required to scrub hydrogen chloride and/or hydrogen fluoride from system emissions. Additional polishing of the exhaust may be needed to comply with SCAQMD requirements. Hence, this option is eliminated from further consideration in this FS.

4.3.3.3 Alternative 2c: Granular Activated Carbon Off-Gas Treatment

This off-gas treatment process uses GAC to capture contaminant molecules from the gas phase. Typically, the GAC is contained in a packed bed through which the off-gas flows. When the carbon becomes saturated with contaminants, it is regenerated in place or removed and regenerated at an off-site facility.

Contaminants treated by GAC include VOCs, SVOCs, fuel hydrocarbons, and pesticides. This process is most effective for contaminants with molecular weights between 50 and 200, boiling points between 75° and 300°F (24° and 150°C), and on air streams with a low moisture content. Carbon adsorption is typically used when contaminant concentrations are less than 1,000 ppmv and is capable of high removal efficiencies.

Effectiveness—GAC is effective in removing halogenated VOCs from a vapor stream. Constituents of interest at this site have molecular weights ranging from 97 (1,1-DCE) to 187 (Freon 113) and boiling points ranging from 98.6°F (1,1-DCE) to 188°F (TCE). Because removal rates with GAC are high, this process is frequently used to bring contaminated streams into compliance with regulations and will be able to reach the levels required by the SCAQMD. This has been confirmed during the pilot test by laboratory analyses of the treated vapors. One minor disadvantage of GAC is that the contaminants are not initially destroyed. The contaminants are removed from the carbon in a regeneration process during which they typically are destroyed.

Risks to the public, site workers, and the environment during implementation are low. GAC treatment is reliable and is not likely to result in unintentional releases of contaminants to the surroundings.

Implementability—GAC is a commonly used vapor treatment process for halogenated VOCs. Construction and operation are readily accomplished, and equipment is available from several vendors. Regeneration service is usually provided by the carbon vendor. Different GAC systems are available for treatment of a large range of flow rates, and only require limited special training. Hence, GAC systems are considered to be easy to implement.

Cost—This process option is rated as ‘Better’ by the EPA, indicating that a general cost range, based on past experience, is less than \$7 per pound of off-gas treated (EPA, 1993b). Typical costs for a 500 cfm system are on the order of \$60,000 (capital), and \$2,000 per month for electricity, chemicals, and laboratory analyses.

Conclusion—GAC is a viable choice for treatment of the off-gas stream based on selection criteria discussed above and past operating experience. Despite its disadvantages, GAC units typically compare favorably with other off-gas treatment processes and will be retained for further evaluation.

4.3.3.4 Alternative 2d: VOC Adsorbing Resin Off-Gas Treatment

Adsorbing resin treatment systems are similar to GAC treatment systems except that resin systems rely on various synthetic resins to adsorb VOCs rather than activated carbon. In contrast to activated carbon, which will adsorb a wide variety of chemicals, synthetic resins are designed to selectively adsorb particular chemicals or families of chemicals.

Synthetic resins may be regenerated more than 1,000 times without loss of adsorptive capacity, and systems are typically constructed with on-site regenerative systems. This entails two sets of resin beds, one in the adsorption mode and one in the desorption mode. In the desorption process, the adsorbed chemicals are removed by heating and/or the application of a vacuum. The desorbed chemicals are then condensed from the purge stream and recovered.

Effectiveness—Synthetic resins are effective in removing targeted contaminants from the gas stream and would be appropriate for the constituents of interest at this site because they are all from the family of small, halogenated VOCs. One disadvantage of resins is that the contaminants are not destroyed and must be removed from the resin at a later time and further treatment is needed. Synthetic resins typically have a greater tolerance than GAC systems for off-gas streams with high moisture content.

Risks to the public, site workers, and the environment during implementation are low. Resin adsorption systems are not likely to result in unintentional releases of contaminants to the surroundings.

Implementability—Synthetic resin systems have not been widely used for off-gas treatment. Therefore, availability of equipment and materials may be more limited than for GAC. Regulatory acceptance of resin systems may also be more difficult to obtain than for GAC

systems because this is a relatively new application of resin adsorption. Resin systems can be applied for a large range of flow rates and may require some special training.

Cost—This process option is not rated by the EPA in the Technology Screening document (EPA, 1993b); however, synthetic resin systems with on-site regeneration generally have greater capital costs than typical GAC systems requiring off-site regeneration or disposal. Although this may be balanced by lower operating costs for the synthetic resin systems, these systems have not been widely used for off-gas treatment because of the significantly high capital cost. Typical costs for a 500 cfm system are on the order of \$100,000 (capital), and \$3,000 per month for electricity, chemicals, and laboratory analyses.

Conclusion—Synthetic resins are capable of treating halogenated VOCs in dilute air streams. The higher capital cost is a disadvantage compared to GAC (while resin system performance is about the same as for GAC), which, in turn, results in higher operating costs because of the higher costs for regeneration of resins. Because of the higher cost without significant benefit over GAC, synthetic resins will not be considered further in this FS.

4.3.4 Summary of Off-Gas Treatment Evaluation

Of the four off-gas treatment processes considered for the in situ SVE system at JPL OU-2, one has been retained for further consideration. Results of this evaluation are summarized below:

Off-Gas Treatment	Conclusion
Thermal Oxidation	Reject. Not appropriate for halogenated compounds.
Catalytic Oxidation	Reject. Applicable to constituents of interest at this site. Costs are expected to be on the high side. May require additional side stream treatment, as well as polishing.
GAC	Retain. Proven technology, and proven to be effective for VOC treatment. Applicable to constituents of interest at this site. Less costly compared to other appropriate technologies reviewed.
Synthetic Resin	Reject. Limited performance data. High capital cost with no appreciable benefit in performance over GAC.

Hence, GAC is the preferred treatment for the VOC-containing soil vapors.

4.4 RETAINED ALTERNATIVES

Two alternatives, one consisting of SVE as the presumptive remedy with four variations in terms of off-gas treatment, have been evaluated. The alternatives are developed in more detail in Section 5.0. A more detailed evaluation is then performed to select the preferred alternative for remediation at the JPL OU-2 site.

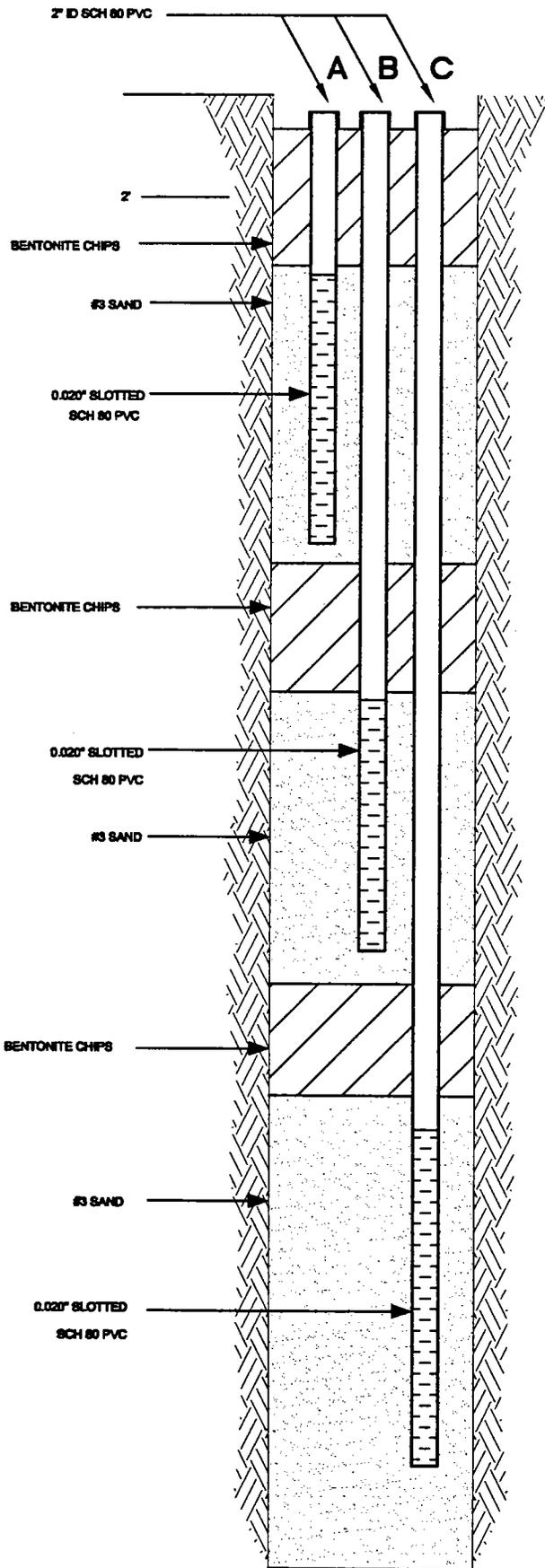
The alternatives retained for further consideration are listed in the following table.

RETAINED ALTERNATIVES	
Alternative	Description
Alternative 1	No Action
Alternative 2c	In Situ SVE/GAC Off-Gas Treatment

In reviewing these alternatives against the statutory preferences identified in CERCLA and listed in Section 4.1, it can be seen that:

- Alternative 2c involves treatment that permanently and significantly reduces the volume of contaminants in soil. This is preferred over alternatives that prevent exposure only, of which there are none at this site.
- Alternatives that do not include off-site transport and disposal of hazardous substances or contaminated materials are preferred over those that do. None of the alternatives at JPL OU-2 include off-site transport of untreated materials.
- Remedial actions included in Alternative 2c incorporate permanent solutions and innovative treatment technologies (i.e., in situ SVE), which are preferred over other approaches.

Therefore, the alternatives being carried forward for further consideration at this site are in compliance with the CERCLA preferences.



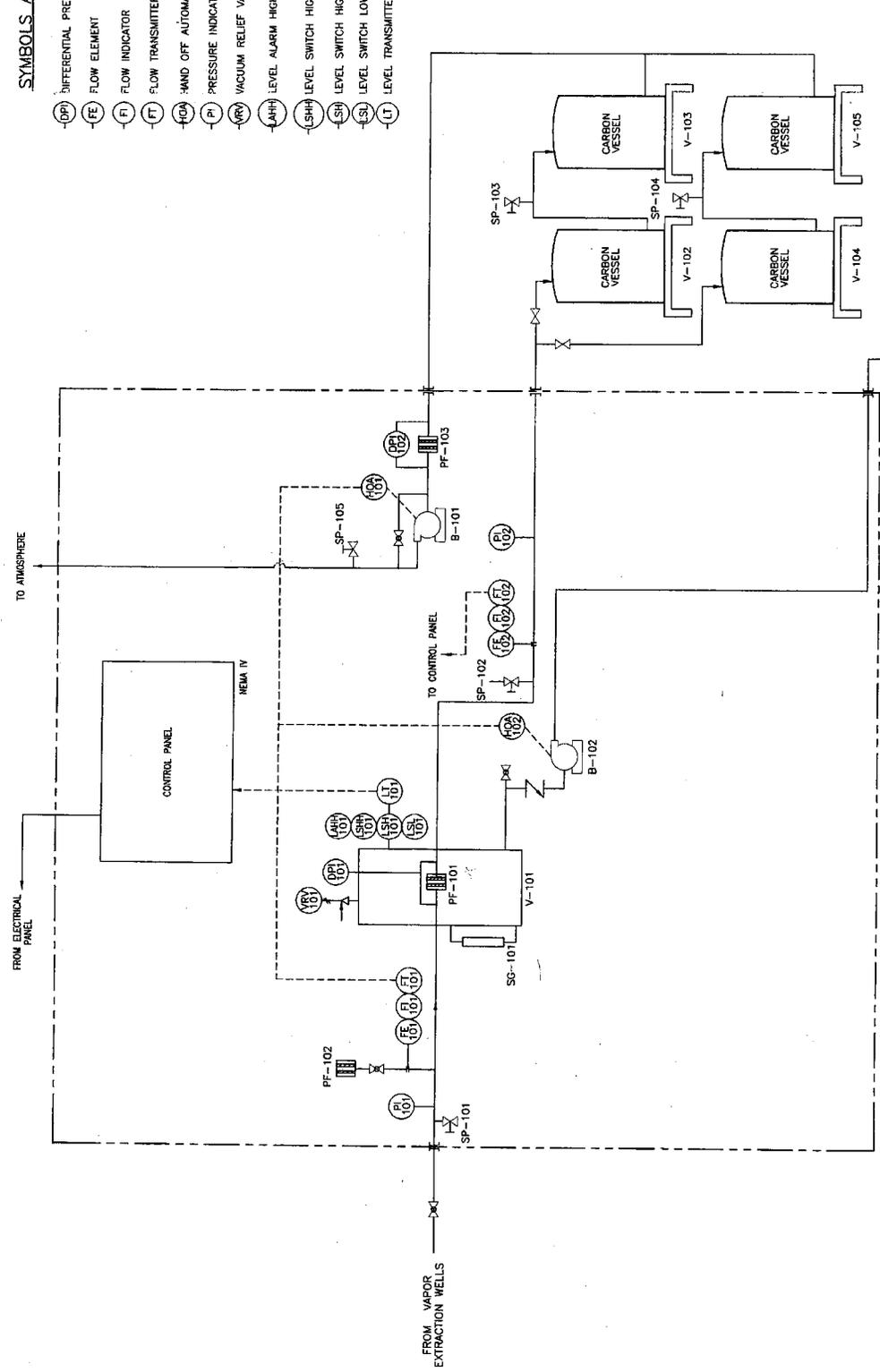
SCREEN A: 44' TO 84' BGS
 SCREEN B: 94' TO 134' BGS
 SCREEN C: 145' TO 185' BGS

I:\1572-JFL\DWG\FSG-00\FIG4-2.DWG
 PLOT/UPDATE: MAY 11 2000 10:06:33

FIGURE 4-2
**VAPOR EXTRACTION WELL
 VE-1**
 Jet Propulsion Laboratory
 Pasadena, California
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 CORPORATION

SYMBOLS AND IDENTIFICATION LETTERS

- ◇ DIFFERENTIAL PRESSURE INDICATOR
- ◇ INTERLOCK LOGIC
- ◇ FE FLOW ELEMENT
- ◇ F FLOW INDICATOR
- ◇ FT FLOW TRANSMITTER
- ◇ HOA HAND OFF AUTOMATIC
- ◇ PI PRESSURE INDICATOR
- ◇ VRV VACUUM RELIEF VALVE
- ◇ LAHH LEVEL ALARM HIGH HIGH
- ◇ LSHH LEVEL SWITCH HIGH HIGH
- ◇ LSH LEVEL SWITCH HIGH
- ◇ LSL LEVEL SWITCH LOW
- ◇ LT LEVEL TRANSMITTER
- ◇ DP DIFFERENTIAL PRESSURE INDICATOR
- ◇ BALL VALVE
- ◇ SAMPLE PORT
- ◇ RELIEF VALVE
- ◇ FLOW LINES (LIQUID/VAPOR)
- ◇ SIGNAL LINE
- ◇ PARTICULATE FILTER
- ◇ SG SIGHT GLASS
- ◇ CHECK VALVE



CONTROLS

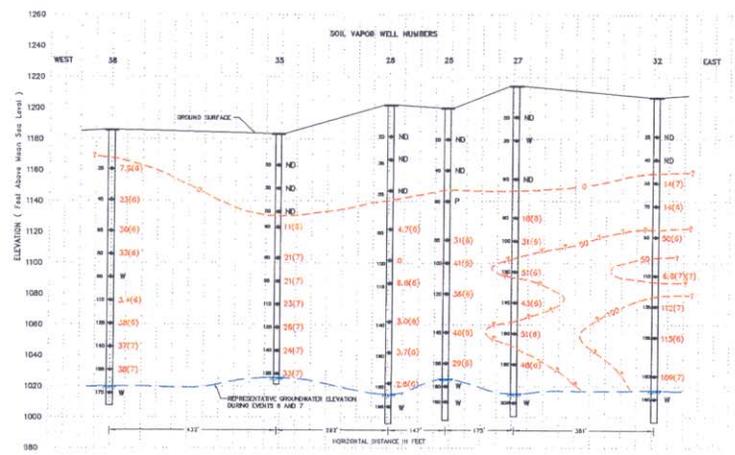
1. SHUT DOWN B-101 FOR ALARM HIGHS IN V-101 AND V-106. PROVIDE TWO INDICATING LIGHTS FOR EACH ALARM IN CONTROL PANEL.
2. RECORD FLOWS FROM FT-101, AND 102 ON RECORDER IN CONTROL PANEL.
3. ALL MOTOR STARTERS FOR B-101 AND B-102 SHALL BE INSTALLED IN CONTROL PANEL AND EQUIPPED WITH HOA SWITCHES.
4. LSH-101 TURNS ON PUMP B-102.
5. LSHH-101 SHOULD SHUT DOWN B-101 UNTIL RESOLVED.
6. LSHH-102 SHOULD SHUT DOWN B-101 UNTIL RESOLVED.

INSTRUMENTATION

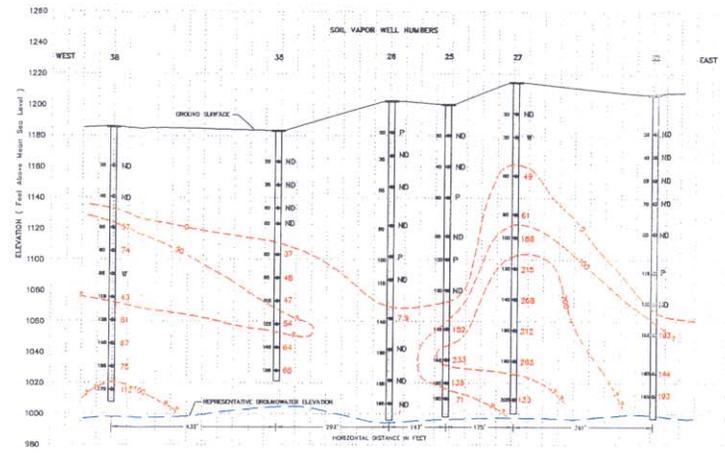
NAME	DESCRIPTION	RANGE
DP-101	MAGNETIC, PRESSURE INDICATOR	0-10 H ₂ O
DP-102	MAGNETIC, PRESSURE INDICATOR	0-10 H ₂ O
FE, FI, FT-101	PITOT TUBE, INDICATOR, TRANSMITTER	0-600 scfm
FE, FI, FT-102	PITOT TUBE, INDICATOR, TRANSMITTER	0-600 scfm
PI-101	MAGNETIC, VACUUM INDICATOR	0-150 H ₂ O
PI-102	MAGNETIC, VACUUM INDICATOR	0-150 H ₂ O
VRV-101	VACUUM RELIEF	10 Hg

FIGURE 4-3
**PIPING AND INSTRUMENTATION
 DIAGRAM-PILOT TEST**
 Jet Propulsion Laboratory
 Pasadena, California
**FOSTER WHEELER ENVIRONMENTAL
 CORPORATION**

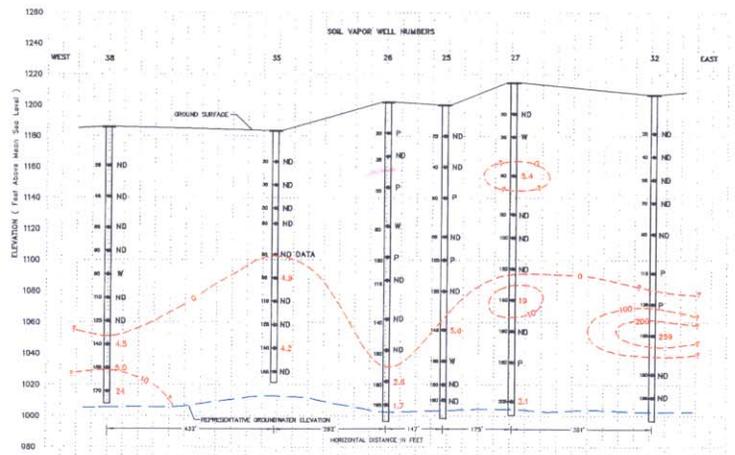
3DC



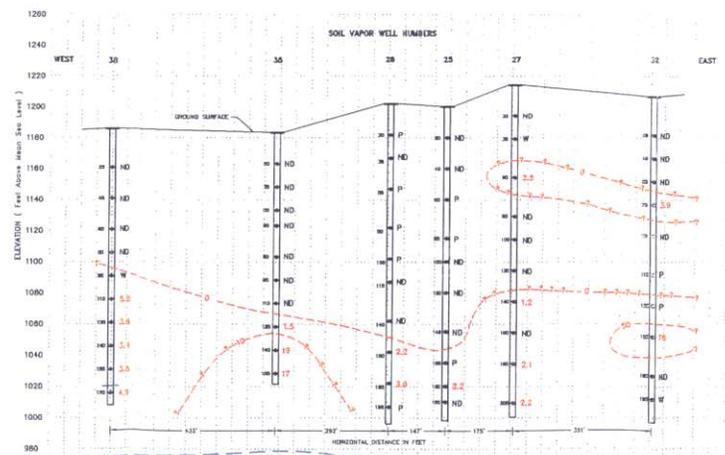
MAY-JUNE 1998



OCTOBER 1998



MARCH 1999



OCTOBER 1999

Explanation

- 25 → Soil Vapor Sample Point and Depth
- 31 Concentrations of Freon 113 ($\mu\text{g/L-Vapor}$)
- (6) Indicates Results from Event 6, May 1998
- (7) Indicates Results from Event 7, June 1998
- ND Non-Detect @ Laboratory Detection Limit of 1.0 $\mu\text{g/L-Vapor}$
- P Sample Port Plugged; No Sample Collected
- W Sample Port Waterlogged; No Sample Collected
- ? Indicates points where spatial control is lacking

Note:

Location of cross-section is shown on Figure 4-1.

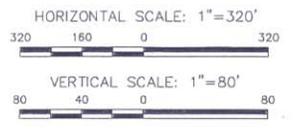


FIGURE 4-6

REPRESENTATIVE HORIZONTAL AND VERTICAL DISTRIBUTION OF FREON 113

Jet Propulsion Laboratory
Pasadena, California



FOSTER WHEELER ENVIRONMENTAL CORPORATION

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5.0 DETAILED ANALYSIS OF ALTERNATIVES

The remedial alternatives developed in Section 4.0 and retained for the detailed analysis are evaluated in this section. The detailed evaluation of each remedial alternative includes the following:

- Refinement of the remedial alternative using quantitative data, where available.
- Detailed evaluation of the remedial alternatives emphasizing the criteria outlined in EPA guidance [EPA, 1988 (guidance for RI/FS)].
- Evaluation of the remedial alternatives with respect to the statutory preferences in CERCLA Section 121(b), as amended.

This stage is the most detailed in the evaluation process, and for this reason, the alternatives are defined more quantitatively.

5.1 EVALUATION OF ALTERNATIVES

The following criteria from EPA's RI/FS guidance document (EPA, 1988) are used as the basis for the detailed analysis:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs
- Long-term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume
- Short-term Effectiveness
- Implementability
- Cost
- State Acceptance
- Community Acceptance

Factors considered for each of the evaluation criteria are summarized in Table 5-1.

Of the nine evaluation criteria, only the first seven will be fully evaluated. State and community acceptance will be evaluated during State review of the draft FS, the public comment period, and the post-RI/FS meeting/public comment period. Also, as discussed in Section 1.0, this analysis is required when the presumptive remedy format is used.

The remedial alternatives retained in Section 4.0 for the detailed evaluation are as follows:

Alternative 1: No Action

Alternative 2c: In Situ SVE/Off-Gas Treatment with GAC

5.1.1 Alternative 1: No Action

The No Action alternative is included to provide a baseline for comparison with the other alternatives. No remedial activities are planned under this alternative except those that occur naturally. A soil-vapor monitoring program (currently in place) is used to track contaminant concentrations and areal extent in the soil vapor over time.

The monitoring program will consist of collection and analyses of soil-vapor samples from the soil vapor monitoring wells (see Figure 4-1) on a quarterly basis for 5 years. If VOC levels continue to decrease and/or remain stable, the frequency may be reduced to semi-annual or annual before the end of the 5-year period. At the end of the 5-year period, sampling will either be switched to annual or dropped entirely depending on data from the first 5 years. Agency approvals will be obtained for all monitoring strategies.

Overall Protection of Human Health and the Environment

Alternative 1 is protective of human health in terms of exposure to contaminants via direct contact with soils, based on results of the human health risk assessment (Foster Wheeler, 1999b).

Mitigation of potential human health risks associated with exposure to groundwater is being considered in the OU-1/OU-3 FS. Furthermore, it is noted that groundwater extracted by the local purveyors for domestic consumption is currently being treated to meet strict regulatory requirements. Risks associated with the groundwater in the OU-1/OU-3 risk assessment were based on exposure to untreated water, which in reality, never occurs. This has been confirmed by the Agency for Toxic Substances and Disease Registry (ATSDR), which issued a report in 1998 stating that, in effect, there were no human health risks associated with groundwater at the site. It is acknowledged, however, that Alternative 1 is not protective of groundwater because of migration of VOCs from vadose zone soils to groundwater.

Compliance with ARARs

ARARs established for the JPL OU-2 site are presented and discussed in Section 2. As expected, this alternative does not meet chemical-specific ARARs since the constituents of interest are left in place and groundwater beneath the site is not protected. This alternative does meet location-specific ARARs since it does not involve construction activities. It also meets action specific ARARs. In particular, soil vapor monitoring will be used in accordance with RWQCB guidelines.

Long-Term Effectiveness and Permanence

This alternative is not effective over the long-term because the soil contamination continues to migrate into the groundwater. However, human health is protected in the long-term with regard to surface soils based on results of the OU-2 Human Health Risk Assessment.

Reduction of Toxicity, Mobility, and Volume

No remedial treatment is planned with this alternative; therefore, there is no reduction in toxicity, mobility, and volume of contamination in JPL OU-2 soils. While there will be some natural attenuation that reduces the overall toxicity, mobility, and volume of constituents of interest, its impact is not expected to be significant.

Short-Term Effectiveness

Because this alternative is the No Action alternative, no activities are planned. Hence, there are no short-term risks to the community resulting from implementation activities.

Implementability

This alternative is easily implemented since there are no activities associated with Alternative 1.

Cost

The only costs associated with this alternative are those relating to the soil monitoring program. Costs were estimated based on quarterly sampling events for the first 5 years, followed by 25 annual events. Based on these parameters, the approximate cost estimate for Alternative 1 is \$1,477,000. Cost calculations are provided in Appendix B. It should be noted that the durations for the quarterly and annual sampling (5 and 25 years) are conservative, and they may be reduced significantly depending on the data obtained.

5.1.2 Alternative 2c: In Situ SVE/GAC Off-Gas Treatment

Alternative 2c uses in situ SVE to treat VOCs in soils in OU-2. For the purpose of this FS, it is assumed that up to 5 new vapor extraction wells, and up to 5 new extraction and treatment systems will be required. It should be noted that while 5 wells have been assumed for the purpose of this FS, the actual number of wells for the full-scale system will be determined during the remedial design phase. The full-scale system will be designed to be protective of groundwater and comply with RWQCB (1996) requirements.

The new wells will be screened similar to the existing well, and will have up to three discrete screens. The depth and extent of the screens will depend on the well's location, and will take into account the variations in water level at the site. At least one screen may extend to depths that are below the "high" water table. Such screens would be operated only when water table is lower than the bottom of the screen, thereby effecting VOC removal from soils that are below water table during wet periods.

The actual number of wells will depend on the results of the SVE pilot test, and the extent of VOC contamination. The systems would be operated until sufficient VOC mass reduction is effected, as evidenced by conformance with specific criteria, which will be determined and agreed upon during the remedial design phase.

Also, it is recognized that there is some uncertainty regarding VOC levels to the west of soil vapor well No. 36. Given the RORI of 400 feet, VOCs to the west of soil vapor well No. 36, if any, will be captured by an appropriately placed extraction well.

Alternative 2c includes the same soil vapor monitoring program as described for Alternative 1. Results from the soil-vapor analyses will be used to determine the extent of remediation, if operations should be adjusted, or if a new approach must be taken for the remainder of the remediation. Adjustments include shutting down wells or selected screens within specific wells to enhance remediation.

Overall Protection Of Human Health and the Environment

Alternative 2c is protective of human health from the standpoint that the VOCs in the vadose-zone soils do not pose a threat to human health because there are no direct exposure pathways. The groundwater beneath the site is protected through remediation of the vadose zone, which limits future migration of VOCs to the water table. Treatment of the off-gas stream further protects the environment by removing VOCs before the off-gas stream is released into the atmosphere.

Compliance with ARARs

Alternative 2c is in compliance with all identified chemical-specific, action-specific, and site-specific ARARs as discussed below.

Alternative 2c is in compliance with the chemical-specific ARARs identified in Section 2.0. The MCLs for groundwater are indirectly applicable since SVE will be implemented in a manner that meets the stated RAO of protecting groundwater. The PRGs and SSLs (which are TBCs, see Table 2.1) were used in the risk assessment during the RI (see Section 1.3.9.1). The RWQCB's approach to investigation and clean-up of soil (a TBC) addresses all of the remaining RWQCB ARARs (i.e., this approach is designed to take these ARARs into account).

Location-specific ARARs will be taken into account during the remedial design phase (see Table 2-1). Specifically, as noted in Table 2-1, wastes will be managed in accordance with the Federal Facilities Compliance Act (soil cuttings, decontamination solutions, etc.). System facilities will be situated outside the 100-year flood plain of the Arroyo Creek. Potential locations will be surveyed for historic, archeologic, architectural, and cultural resources during design.

All of the chemical-specific ARARs pertaining to discharge of air will be addressed by the GAC treatment system. Dust generated during well installation (and piping installation, if below grade) will be controlled. The spent carbon and wastewater (entrained moisture in extracted vapor) will

be profiled and appropriately disposed. The RWQCB's standards for SVE operation and soil-vapor sampling will be followed.

Long-Term Effectiveness

Alternative 2c is effective in the long-term. The SVE process permanently removes VOCs from the vadose zone. The VOC-laden air is processed through the vapor-phase GAC, which in turn permanently removes the VOCs from the extracted soil vapor. The VOCs are subsequently removed from the carbon, either through thermal regeneration in which the VOCs are destroyed, or through chemical regeneration in which the VOCs are transferred to the regenerating solution. Because contaminants are permanently removed from the soil, existing and future risks to groundwater are reduced. Once remediation is completed (based on RWQCB requirements), residual VOCs would not be expected to further impact groundwater, and, thus, long-term reliability is achieved.

Reduction of Toxicity, Mobility, and Volume

This alternative permanently and irreversibly removes VOCs from the vadose zone, thus, reducing the volume and mobility of contamination in the soil. Based on pilot study results, the amount of mass removal is expected to be significant. As discussed in Appendix A, the pilot test, which was conducted on an extraction well located in the center of the VOC plume, has already resulted in removal of 1,050 pounds. This removal has caused VOCs in soil-vapor monitoring wells to reduce significantly. Reductions of over 80 percent were observed in sampling tips 400 feet away from the extraction well. The amount of reduction decreased with distance from the well (see Appendix A). Thus, this alternative will reduce the volume of VOCs in the subsurface. In addition, shutdown of the system will be based on RWQCB criteria (RWQCB, 1996) which is designed to ensure that impact to groundwater is minimal.

The mobility of VOCs will be reduced within the zone of influence of the extraction well(s), since these VOCs would move towards the extraction well, and eventually be captured by the well. While there is no direct reduction in toxicity as a result of this alternative, the decrease in VOC-vapor volume results in reduction of the amount of toxic material.

Thus, Alternative 2c meets this criterion.

Short-Term Effectiveness

In situ SVE presents very few risks to on-site workers or the community with the exception of possible dust generation during well installation.

Equipment and operations for in situ SVE systems are readily available. The proposed SVE system will be designed such that the wells and the associated piping is under vacuum at all times (the extracted vapor will be "pulled" through carbon vessels by the extraction blower). The portions of the piping that are under pressure will only contain treated vapor. The treatment of the vapors with GAC will remove the majority of the VOCs, thereby minimizing VOC emissions to the atmosphere.

Thus, Alternative 2c meets this criterion.

Implementability

In situ SVE is one of the most commonly used remedial processes for treatment of VOC contamination in soil. Required equipment is readily available from many sources and does not require specialized knowledge for installation. Installing and operating vapor extraction wells requires fewer engineering controls than other technologies such as excavation and incineration, and no difficulties are foreseeable with regard to obtaining approvals from the various agencies.

GAC is the most widely used off-gas treatment for SVE systems. Treatment units are readily available and installation and operation are not difficult. Because the waste (spent carbon) is routinely transported and treated off-site, there are no anticipated issues regarding on-site waste storage and/or disposal services.

Soil vapor sampling is a proven technology, has been successfully tested at JPL, and is readily implemented particularly since numerous soil vapor sampling tips are already in place.

Thus, Alternative 2c meets this criterion.

Cost

Costs associated with this alternative include extraction-well installation, vacuum blowers, well-head GAC units, and the soil monitoring program.

Capital costs include installation of five new extraction wells that would be similar in construction to the existing pilot test extraction well (averaging 200 feet deep and each having three discrete screened intervals). Each well will be equipped with a 500-cfm blower and up to four GAC vessels containing 2,000 pounds of carbon each. Operating and maintenance costs cover power consumption for the blowers and carbon replacement/regeneration for the GAC units. The major pieces of equipment are expected to last for the duration of the treatment period without replacement.

Site engineering and planning are included as 15 percent of the construction cost and a 25 percent contingency is included. A present worth value for this alternative was determined using a 5 percent discount rate and assuming that the SVE system will operate for 5 years. The soil vapor monitoring component is assumed to be the same as for Alternative 1 (i.e., 5 years of quarterly monitoring followed by 25 years of annual monitoring). It should be noted that these durations (for both system operation and monitoring) are conservative and may be reduced depending on the ongoing soil vapor monitoring results.

Based on these parameters, the cost estimate for Alternative 2c is approximately \$3,816,600. Cost calculations are presented in Appendix B.

5.2 COMPARATIVE ANALYSIS

Contained in this section is a comparative analysis of the alternatives with respect to each of the seven evaluation criteria. The comparative analysis provides the basis for identifying a preferred alternative for the JPL OU-2 site. A summary of the comparative analysis is presented in Table 5-2.

5.2.1 Overall Protection of Human Health and the Environment

This evaluation criterion involves assessing the degree to which each alternative provides adequate protection of human health and the environment. For this FS, both alternatives are considered protective of human health with regard to exposure to contaminants via direct exposure to soil. This is because the risk assessment indicated that the VOCs in surface soil do not pose a risk to humans. The focus is, therefore, a comparison of how well the alternatives protect the environment, specifically the groundwater. The VOCs in soils have migrated to the water table and are currently impacting groundwater quality. Protection of the environment is taken to be the inhibition of further groundwater contamination.

Alternative 1, the No Action alternative, relies on natural attenuation to reduce VOC concentrations in the vadose zone. This provides negligible protection of the environment. Alternative 2c uses in situ SVE to remove VOCs from the contaminant plume in soil. This is substantially more protection than is offered by Alternative 1.

5.2.2 Compliance with ARARs

This evaluation criterion is used to evaluate how well each alternative conforms to federal and state ARARs or whether there is adequate justification for invoking waivers to specific ARARs. The ARARs for these remedial alternatives are described in Section 2.

Alternative 1 does not comply with ARARs since there is no VOC removal. Alternative 2c meets all ARARs as discussed in Section 5.1.2.

5.2.3 Long-Term Effectiveness and Permanence

Long-term effectiveness relates to the amount of risk remaining at the site after the remedial action objectives are met. At this site, risk will be reduced if continued migration of contaminants to groundwater is prevented, which is the only concern at this site for OU-2. Alternative 1 does not prevent migration of contaminants into groundwater and offers negligible long-term effectiveness and permanence. Alternative 2c is effective in the long-term because it permanently removes VOCs from the vadose zone.

Both alternatives include longer-term soil vapor sampling for, possibly, up to 30 years. The sampling program poses minimal risks to the community, the environment, or to workers involved in handling environmental samples.

5.2.4 Reduction in Toxicity, Mobility, and Volume

This criterion is a measure of the reduction in toxicity, mobility, and volume of the constituents of interest at a site and also the extent to which the reduction is irreversible. Alternative 1 does not include any treatment, so there is no reduction in toxicity, mobility, or volume except for minor reductions provided by natural attenuation.

Alternatives 2c provides significant reduction in volume by permanently and irreversibly removing VOCs from the vadose zone. This reduces the mobility of the contaminants and the volume of contamination in the soil.

5.2.5 Short-Term Effectiveness

Short-term effectiveness is a measure of the impacts to workers, the community, and the environment during the construction and operating life of the remedial action. Because Alternative 1 does not include either construction or operation of a treatment system, there are no effects on the community, workers, or the environment. For these reasons, Alternative 1 has very few impacts in the short term.

Alternative 2c relies on in situ SVE for treatment, and requires installation of up to five new soil vapor extraction wells. Short-term impacts to workers and the community are limited to possible dust releases during well installation, which would have a negligible impact. SVE system operation would also result in negligible impacts since the system is in situ. The only waste streams generated include spent GAC and entrained water (entrained moisture, which is separated using a knockout tank). VOCs in the off-gas stream are permanently removed from the stream, and emissions will comply with air emission standards. Therefore, Alternative 2c results in only slightly higher short-term risks than the No Action alternative.

5.2.6 Implementability

Implementability is a measure of how easily a remedial action can be installed and operated. At the JPL OU-2 site, Alternative 1 is the easiest alternative to implement because no construction activities are performed.

Implementation of the in situ SVE systems for Alternative 2c is relatively straightforward in that this is the most commonly used process for treating VOC contamination in soil. Required equipment is readily available from many sources and does not require specialized knowledge for installation.

5.2.7 Cost

Cost considerations include capital costs and O&M costs as well as the cost of the soil vapor monitoring program.

Alternative 1 is the least expensive alternative since no activities are planned under this alternative except soil-vapor monitoring. The estimated total cost for Alternative 1 is approximately \$1,477,000.

The estimated total cost for Alternative 2c is approximately \$3,816,600. This includes installation of the five new vapor extraction wells, five new vapor extraction and treatment systems, operation and maintenance of the existing and new systems for a 5-year period, quarterly soil-vapor monitoring for first 5 years, and annual soil-vapor monitoring for 25 years.

5.3 PREFERRED ALTERNATIVE

Alternative 1, No Action, is not appropriate for the site because no protection of groundwater is provided, and, therefore, the RAO for the site will not be met. Based on the preceding analysis of alternatives, Alternative 2c, In Situ SVE/GAC Off-Gas Treatment, is chosen as the preferred alternative for the JPL OU-2 site.

TABLES

TABLE 5-1

FACTORS FOR DETAILED EVALUATION OF ALTERNATIVES

Overall Protection	How alternative provides human health and environmental protection.
Compliance with ARARs	Compliance with chemical-specific ARARs. Compliance with location-specific ARARs. Compliance with action-specific ARARs. Compliance with other criteria, advisories, and guidance.
Long-Term Effectiveness and Permanence	Reduction of existing risks. Magnitude of future risks. Long-term reliability. Prevention of future exposure to residuals.
Reduction of Toxicity, Mobility, and Volume Through Treatment	Amount of hazardous materials destroyed or treated. Degree of expected reductions in toxicity, mobility, and volume. Degree to which treatment is irreversible. Type and quantities of residuals remaining after treatment.
Short-Term Effectiveness	Time until protection is achieved. Short-term reliability of technology. Protection of community during remedial actions.
Implementability	Ability to operate and construct the technology. Ability to phase into operable units. Ease of undertaking additional remedial actions, if necessary. Ability to monitor effectiveness of remedy. Ability to obtain approvals from other agencies. Coordination with other agencies. Availability of treatment, storage, and disposal services and capacity. Availability of necessary equipment and specialists.
Cost	Construction costs. Operating costs for implementing remedial action. Other capital and short-term costs until remedial action is complete. Costs of operation and maintenance for as long as necessary. Costs of 5-year reviews (if required).
State Acceptance ⁽¹⁾	Features of the alternative the state supports. Features of the alternative about which the state has reservations. Features of the alternative the state strongly opposes.
Community Acceptance ⁽¹⁾	Features of the alternative the community supports. Features of the alternative about which the community has reservations. Features of the alternative the community strongly opposes.

Notes:

(1): Not evaluated in feasibility study because of limited available information. State and community acceptance will be fully addressed in the record of decision (ROD).

TABLE 5-2

DETAILED SCREENING OF ALTERNATIVES

	Alternative 1	Alternative 2c	Comments
Description	<ul style="list-style-type: none"> No Action Soil-Vapor Monitoring 	<ul style="list-style-type: none"> <i>In Situ</i> SVE GAC Off-Gas Treatment Soil-Vapor Monitoring 	
Overall Protection	<ul style="list-style-type: none"> Not protective of environment. 	<ul style="list-style-type: none"> Protective of environment. 	<ul style="list-style-type: none"> Protection of human health not needed because no human receptors at this site. Alternative 2c indirectly provides protection by reducing VOCs in the subsurface soils, which in turn reduces the potential for further impact to groundwater.
Compliance with ARARs	<ul style="list-style-type: none"> Does not comply with ARARs 	<ul style="list-style-type: none"> Complies with ARARs 	<ul style="list-style-type: none"> Compliance for Alternative 2c is either direct, or through design of full-scale SVE systems.
Long-Term Effectiveness	<ul style="list-style-type: none"> Not effective in long-term. Constituents of interest remain at site and will be released to groundwater. 	<ul style="list-style-type: none"> Very effective in long-term. Constituents of interest permanently removed from vadose zone. 	
Reduction of Toxicity, Mobility, or Volume	<ul style="list-style-type: none"> No reduction in toxicity, mobility, or volume of constituents of interest. 	<ul style="list-style-type: none"> Nearly complete reduction in volume of constituents of interest through SVE. GAC removes, but does not destroy constituents of interest. 	<ul style="list-style-type: none"> COPCs are transferred to VPGAC for Alternative 2c, but are subsequently removed during regeneration.
Short-Term Effectiveness	<ul style="list-style-type: none"> Extremely high short-term effectiveness. No risks to workers, community, or environment. 	<ul style="list-style-type: none"> High short-term effectiveness. Few risks to workers, community, or environment. 	<ul style="list-style-type: none"> Alternative 1 has highest short-term effectiveness. Alternative 2c highly effective in short-term.
Implementability	<ul style="list-style-type: none"> Very easily implemented. No activities required. 	<ul style="list-style-type: none"> Easily implemented. SVE is well-known treatment system. GAC also well-known, easily implemented. 	<ul style="list-style-type: none"> Alternative 1 is most easily implemented. Alternative 2c is easily implemented due to wide acceptance of GAC for off-gas treatment.
Cost	<ul style="list-style-type: none"> Approximate cost: \$1,477,000 	<ul style="list-style-type: none"> Approximate cost: \$3,816,600 	<ul style="list-style-type: none"> Alternative 1 is least expensive. Alternative 2c is most expensive.
Conclusion	<ul style="list-style-type: none"> Does not pass first two criteria (threshold criteria). 	<ul style="list-style-type: none"> Preferred alternative. 	<ul style="list-style-type: none"> Meets RAOs, complies with ARARs in a cost-effective manner.

Notes:

- ARAR – Applicable or relevant and appropriate requirement
COPC – Constituent of potential concern
GAC – Granular activated carbon
RAO – Remedial action objective
SVE – Soil vapor extraction
VOC – Volatile organic compound
VPGAC – Vapor-phase granulated activated carbon

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