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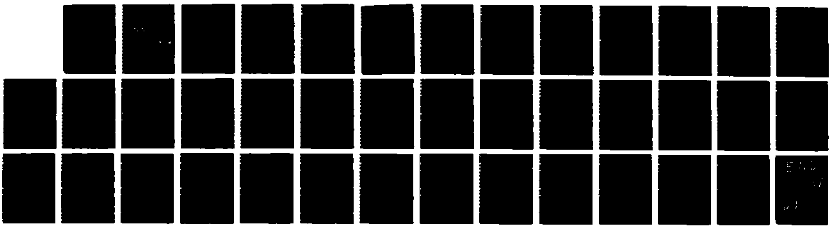

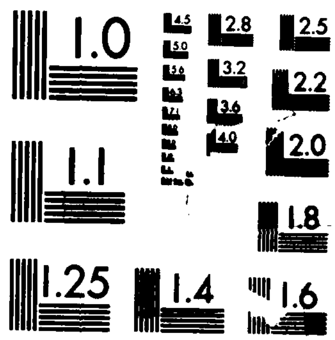

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REPORT NO. AMXTH-TE-CR-87123

Installation Restoration General Environmental Technology

Contract No. DAAK11-85-D-0007/0004

In Situ Volatilization (ISV) Remedial System Cost Analysis

TECHNICAL REPORT

August 1987

Distribution Unlimited; Approved for Public Release

Prepared for:
U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
Edgewood Area, Aberdeen Proving Ground, Maryland 21010

WESTON
MANAGERS DESIGNERS/CONSULTANTS
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1460B

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This report presents a cost analysis of In Situ Volatilization (ISV) to three hypothetical contaminated soil sites. The treatment costs per cubic yard of soil were developed.

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EXECUTIVE SUMMARY

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) has conducted studies of the technical feasibility for emerging soil and groundwater remedial treatment technologies. The In Situ Volatilization (ISV) technology has yielded extremely encouraging results for treatment of soils contaminated with volatile organic compounds, including many solvents. ISV is a treatment system applicable for soils in the vadose zone (above the water table) and treats the contamination in place without the need for excavating the soil. This is an attractive option when large volumes of soil or difficult excavation obstacles (buildings, utilities, and roadways) are encountered. Also, many other treatment technologies for excavated soils require extensive soil handling, screening, or crushing operations.

The costs for implementing a complete ISV remedial action are examined in this study. Three hypothetical contamination situations were developed to reflect a range of possible ISV applications at U.S. Army facilities. Situation 1 (Small Tank Leak) is a leak from an underground solvent storage tank. The contamination is in a small area, but extends to a depth of approximately 100 ft. Situation 2 (Tank Farm Leaks) is a soil contamination problem resulting from several leaks in a tank farm. The contaminated area has several "hot spots" which were targeted in the remedial action. Situation 3 (Disposal Area) is a lagoon area where degreasers and solvents have been disposed.

For each situation it has been assumed that the Remedial Investigation (RI) fully defined the extent and types of contaminants. From this point the necessary implementation steps, i.e., bench-scale testing, pilot testing and full-scale design, and regulatory approval permitting were outlined and the costs estimated. A conceptual plan of a full-scale system was developed to include typical construction practices for each situation. The equipment, materials, and start-up costs were included in the capital cost estimate. The operations and maintenance costs cover labor, emissions monitoring, maintenance, power, and activated carbon for the vapor control system. A length of system operation based on the extent of contamination at the site was assumed and the operation and maintenance costs were estimated accordingly.

In order to provide a cost which may be compared to other soil treatment technologies, the cost per cubic yard of soil was developed. The results are as follows:

- Situation 1: Small Tank Leak $250-340/cu yd
- Situation 2: Tank Farm Leak $ 55-65/cu yd
- Situation 3: Disposal Area $ 12-15/cu yd

This demonstrates the large variation in possible treatment costs due to system size. Comparison of these costs to other treatment options should include site-specific considerations such as depth of excavation, proximity of buildings or roadways and the presence of above- or below-ground utilities. In Situation 1 the depth of the contamination requires under-pinning the nearby building and excavating a large area to remove the full depth of contamination. This significantly increases the excavation costs.

Another consideration for cost comparison is the full treatment and disposal costs associated with excavated soils. The estimates outlined in this study include carbon regeneration off-site (Situations 1 and 2), or on-site regeneration with off-site treatment and disposal of the reclaimed solvent (Situation 3). Also, treatment of excavated soil may require special handling, screening, or crushing operations.

The final aspect of any technology comparison should include the extent of remediation required. At this time it is not possible to confidently quantify the ISV system performance because there are no specific soil contaminant standards to use for comparison. Also, there are no situations where an ISV system has been in operation long enough to determine the final level of cleanup obtained. Other technologies such as incineration may achieve a higher treatment effectiveness (99.9999 percent destruction efficiency) than can be attained by ISV. Therefore, the costs presented in this report are for implementing the ISV technology only. It is not certain that these are the costs for completely remediating the site.

1. INTRODUCTION

1.1 Background

Soil and groundwater contamination from past handling and disposal practices for chlorinated solvents, non-chlorinated solvents, and hydrocarbons has been identified as a major environmental concern throughout the country. Many U.S. Army facilities are dealing with contamination problems resulting from leaks or spills from buried storage tanks holding degreasing solvents or fuels. Also, past waste handling procedures have resulted in problems at lagoons, landfills, and other disposal areas at these facilities. Contaminant releases from underground tanks, sumps, and former disposal areas have mobilized contaminants into the surrounding soil and groundwater. Remedial responses to these situations should address both source control (i.e., soil remediation) and migration control (i.e., groundwater treatment). This remedial approach is consistent with current U.S. EPA Remedial Investigation/ Feasibility Study (RI/FS) methodology and requirements of the National Contingency Plan (NCP). The Superfund Amendments and Reauthorization Act of 1986 (SARA) stresses the need for permanent remedial actions at hazardous waste sites. Consequently, source control measures which remove and destroy contamination will receive more serious consideration.

While groundwater treatment is widely accepted and practiced as a cleanup strategy, soil decontamination and treatment techniques are still being developed as innovative technologies. The two primary accepted alternatives for mitigating volatile organic soil contamination involve either site isolation through capping, or excavation and removal of contaminated soil for disposal in a permitted off-site commercial landfill facility. Source capping prevents infiltration and further leachate generation, but does not provide a barrier between soil contamination and groundwater. Capping does not address treatment or removal of the contaminants and the long-term integrity of the cap may be a concern. Soil excavation and removal is costly, may threaten nearby structures, and involves larger volumes of soil. Land disposal of VOC-contaminated soils will become much more difficult and unacceptable as the Hazardous and Solid Waste Amendments of 1984 prohibitions for secure land disposal become effective.

The inability to remove or isolate soil contaminants often results in the potential for long-term groundwater impacts. Specific soil cleanup standards for volatile organic compounds (VOCs) have not been established by the U.S. EPA or most state environmental agencies. Instead, Applicable or Relevant and Appropriate Requirements (ARARs) such as recommended water quality criteria and primary drinking water standards have been used as guides for hazardous waste remedial actions.

In Situ Volatilization (ISV) is an emerging technology for soil treatment. It is primarily applicable to treatment of VOC-contaminated soils. The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) was involved in the early developmental stages of this technology. The ISV system removes VOCs from the soil by mechanically drawing air through the soil pore spaces. VOCs volatilize into the air as the air moves through the soil. The VOC laden air is then collected and discharged or treated, depending on the amount and types of contaminants present.

This is accomplished by installing an array of vents in the contaminated portion of the unsaturated (vadose) zone. The vents are manifolded to air blowers (vacuum pumps), creating a negative pressure in the system and drawing air from the soil. Each vent is valved and can be adjusted to the desired flow rate. Using these valves an ISV system has the flexibility to withdraw air from the most contaminated areas, maximizing the mass removal rate, or operating at a lower mass emission rate as required by the emissions treatment system.

VOCs are released from the soil matrix into the air being drawn through the vents and through the vacuum pump. The VOCs in the air are discharged from the pump. Depending upon concentration, vapor phase carbon treatment of the air stream is a common treatment technology, particularly for chlorinated solvent contaminants. A general schematic of the ISV process is shown in Figure 1.

The ISV technology was demonstrated in a pilot study conducted by WESTON for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) in 1984 and 1985 at Site D of the Twin Cities Army Ammunition Plant (TCAAP), in New Brighton, Minnesota. The process is presently being applied to two full-scale remedial operations (Sites D and G) at TCAAP. Site D is a former leaching pit disposal area and Site G is an inactive landfill. Both sites contain soils contaminated with trichloroethylene, trichloroethane, and small quantities of other chlorinated VOCs. In addition to the TCAAP application at disposal sites, the ISV technology has proven to be effective at other sites in remediating soil contamination resulting from storage tank leaks. Spills occurring during the transfer of solvents to or from tanks, and leaks from one or more storage tanks, result in areas of soil contamination which are generally much smaller in areal extent compared to that encountered at the TCAAP disposal areas. The ISV technology is particularly useful when buildings are in close proximity to the contamination and could be structurally compromised by excavation activities, or when the contamination extends to depths which render excavation impractical.

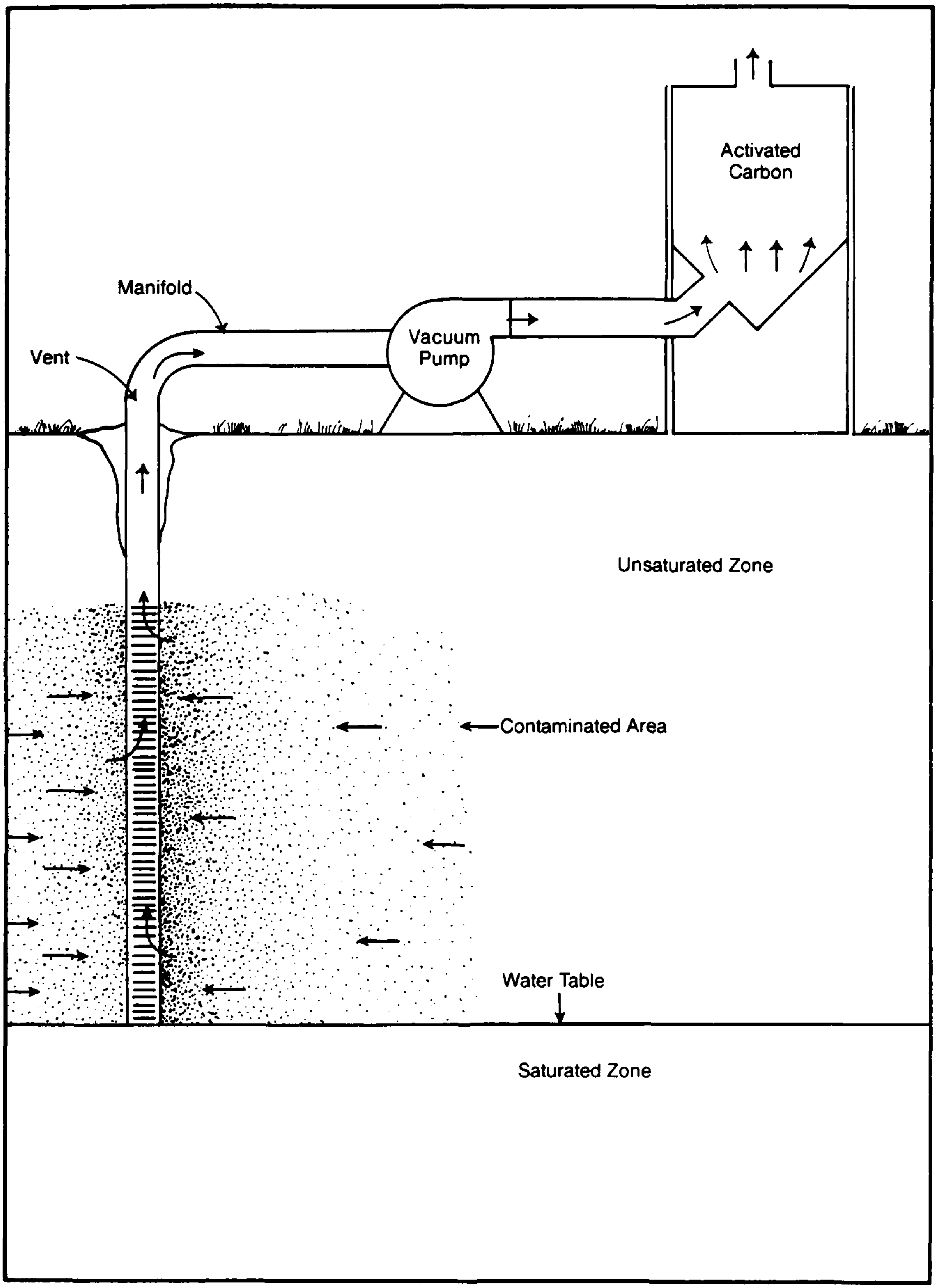

Figure 1. In situ volatilization pilot system schematic.

Two parameters which must be assessed when determining the viability of ISV technology for a particular site are air permeability and contaminant compound volatility. The soil must have a permeability great enough to allow for air movement through the soils. Sandy soils are ideal for ISV applications, although air flow has been observed in silty clay soils when high vacuum pressures were applied. The contaminant must have a vapor pressure which allows it to transfer from the soil to the vapor phase and travel with the air out of the soil matrix. Compounds which have been successfully removed from soils include: trichlorethylene, dichloroethylene, tetrachloroethylene, chloroform, methylethylketone, toluene, tetrahydrofuran, gasoline, and xylene. As mentioned earlier, specific soil cleanup standards have not been determined. As a result it has been impossible at this time to determine the cleanup performance of the ISV. At present ISV effectiveness has been evaluated on the basis of the total amount of contaminant removed from the soil. Although the early results of ISV applications are extremely promising, the exact range of soil and contaminant types where ISV has been determined applicable and its effectiveness are not well defined. It can be assumed that other compounds with properties similar to those listed above would be amenable to this type of treatment.

1.2 Objectives

The objective of this study is to perform a cost analysis for applying the ISV technology to VOC-contaminated soils. This allows a comparison of ISV to other soil remedial technologies on a cost basis. Three hypothetical applications have been developed by WESTON. These applications reflect a range of situations where ISV may be applied. For each situation a conceptual plan for an ISV system was developed to the point where material quantities and equipment sizes could be estimated along with capital, operation and maintenance costs. Finally, the treatment cost per cubic yard of contaminated soil has been developed as a basis for comparison with other soil remediation techniques. However, it must be noted that this analysis does not provide a basis for comparing treatment effectiveness for the various removal technologies.

1.3 Implementation

In order to maximize an ISV system's effectiveness and performance and to minimize costs, the system should be designed to address the specific site characteristics. The soil type, soil profile, moisture content, contaminant type, contaminant concentration, and distribution of contaminants in the soil all impact the system design. Prior to designing and installing a a full-scale ISV remedial system, two steps should be taken to determine the applicability and to estimate the effectiveness of the ISV at a specific site. The first step is to conduct a laboratory bench-scale experiment to determine if air can be moved through the soil, resulting in sufficient VOC volatilization. Test air is forced through a soil sample held in a special aeration chamber. The predetermined air flow rate is applied and the off-gas effluent is monitored to detect the total VOCs volatilized from the soils. Pre- and post-test soil samples are analyzed to determine the extent of VOC removal. This test gives an indication of soil permeability and the extent of contaminant volatility.

Once it has been established via bench-scale testing that air flow and contaminant volatilization can be achieved, the second site-specific test may be performed. This consists of an on-site pilot test to establish design criteria for the full-scale system. The subsurface vacuum pressure is monitored to determine the radius of influence for each vent. The optimal air flow rate per vent is determined for use in the total system flow rate design. Finally, estimates of the system emissions are developed for use in the design of the vapor control system. The pilot test may vary in complexity depending on the site. The information developed in these tests allows the design of the full-scale ISV system to incorporate necessary operating conditions for the specific site characteristics. This results in a more efficient and cost effective system.

The air permitting requirements for implementation of the ISV technology are site-specific and difficult to predict due to the complexity and variability in the application of air pollution control regulations by the states. For example, in ozone nonattainment areas, Lowest Achievable Emission Rate (LAER) requirements may be applied. For attainment areas, Prevention of Significant Deterioration (PSD) requirements, including implementation of the Best Available Control Technology (BACT), may be applied. This entails a facility description including the facility boundaries, details of all other emissions sources on the facility, and evaluation of contemporaneous emission increases at the site for the last five years. The U.S. EPA and various state agencies are in the process of developing Air Toxics regulations for specified organics. If contaminants are listed as air toxics, they will be subject to more stringent controls under these regulations.

The air permit would only apply to the system emissions. It is possible that the ISV remedial system would also be permitted. Many of the sites where the ISV technology is applicable may be regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, Superfund), or the Resource Conservation and Recovery Act (RCRA). In the case where a facility has, or is applying for a RCRA Part B Permit, application of the ISV technology to a contaminated area would require a permit modification under a RCRA Corrective Action Plan. In any case, a remedial action will most likely require the notification and consent of Federal and state regulatory agencies.

2. APPLICATIONS

The three hypothetical situations were developed to present a range of ISV applications that have been demonstrated to date, based on WESTON's experience. The conditions and parameters specified for the applications describe typical field situations. Assumptions were also made to make the sites comparable with respect to application of the ISV technology. The assumptions common to all situations are:

- Sandy soils; the soils are relatively homogeneous (i.e., layers of high- or low-permeability soils are not present to any significant degree).
- There are no underground structures or utilities.
- There are no aboveground obstacles (i.e., powerlines or pipelines).
- The contaminant-laden air stream is nonexplosive.
- Electrical, water supply, and sewer utilities are available at the site.

These conditions are not absolutely necessary for ISV implementatation. Variations from these conditions may require ISV system modifications to address specific site characteristics. The system costs and removal efficiencies will be affected by these modifications. For each site it is necessary to evaluate soil contamination, site features, site design, and the ISV remedial system, in order to address the specific conditions at the site.

2.1 Situation 1: Small Tank Leak

2.1.1 System Description

In Situation 1 soil contamination has resulted from a leaking storage tank. The contaminants have traveled vertically down to the water table, located 100-feet below ground-surface (bgs), with very little horizontal spread. Soil borings and samples have defined the area of contamination to be approximately ten feet by fifteen feet. The contamination extends to a depth of 100 feet, i.e., to the water table. The contaminants xylene and toluene were found in the soil in concentrations ranging from ND-200 ppm.

The storage tank was an underground tank along the outer wall of a production building. It was determined that excavation to a depth of 100 feet would not only compromise the building foundation, but was not feasible due to sandy soil. The primary objective of the ISV remedial system was to maximize the removal of xylene and toluene from the soils in a short period of time.

The results of bench-scale testing indicated rapid volatilization of the contaminants and relatively high permeability. On the basis of these results and the small size of the contaminated area, the pilot test was omitted and a full-scale system was designed.

The full-scale system consists of two vents, an above-ground pipe manifold, an extraction blower, and a vapor control system. A plan view of the system layout is given in Figure 2. The pipe manifold uses PVC pipe to connect each vent to the PVC header pipe. Each of the pipes has a valve to regulate the air flow from the vent. The extraction blower functions as a vacuum pump. The pump has an air flow rate capacity of 280 cfm at a maximum vacuum pressure of 10 inches of Hg. The pump discharges to a vapor control system. The vapor control system for this application is an activated carbon unit.

The vents are constructed of PVC well screen. Figure 3 is a typical vent construction diagram. After placing the well screen and riser in the open bore hole the annular space is backfilled with gravel pack. A bentonite grout plug is placed at the ground surface to prevent short-circuiting of ambient air along the outside of the riser pipe. The vents are screened to provide air flow through the full depth of the unsaturated zone.

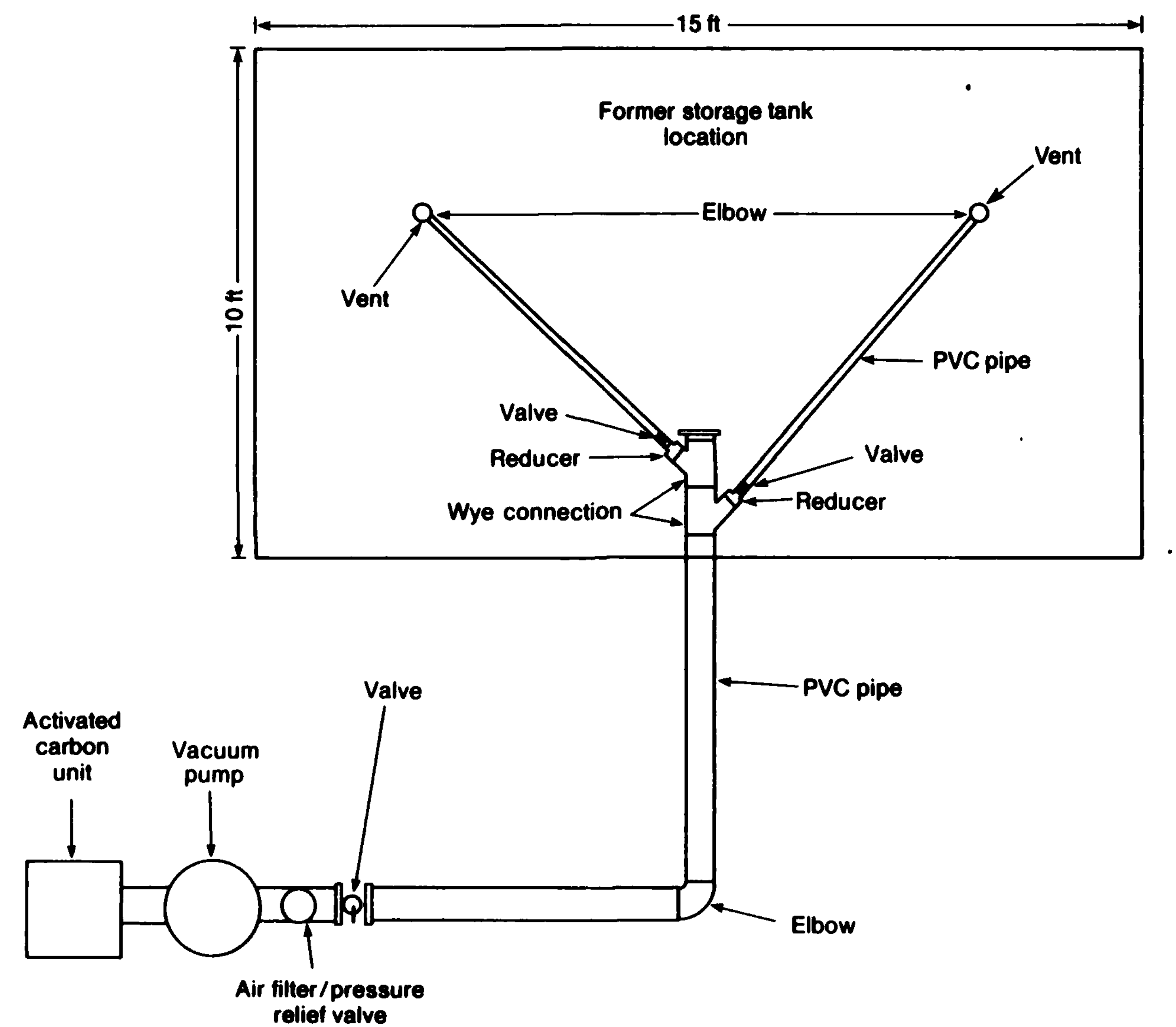

Figure 2. ISV system layout - Situation 1 plan view.

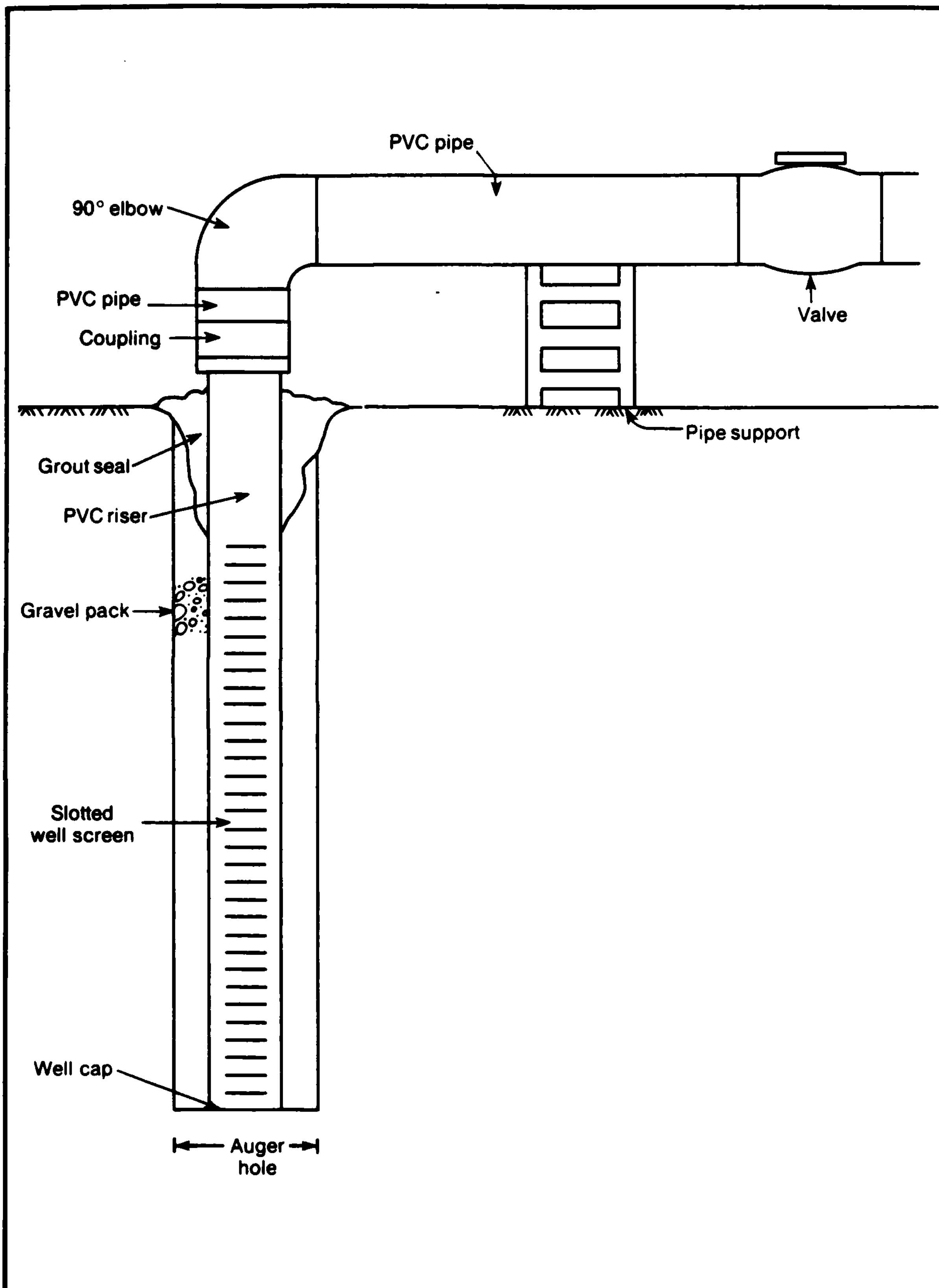

Figure 3. Typical vent construction - Situation 1

2.1.2 Cost Estimate

An estimated cost breakdown for treating this site using the ISV technology is presented in Table 1. This cost estimate includes the costs for a single bench-scale test, full-scale design, and permit application/regulatory approval costs, in addition to estimated capital costs and operating/maintenance costs. Detailed cost backup information is supplied in Appendix A.

In developing the implementation costs several assumptions were made. The bench-scale test cost assumes that one soil sample was tested. A pilot test was not carried out for this situation due to the small areal extent of the contamination. To be positive the vacuum pump provided a sufficient vacuum to draw air at a depth of 100-foot bgs, and to impact the entire area of contamination, the vacuum pressure rating for the pump was specified at 10 inches of Hg. This is a higher vacuum pressure than previously used with this soil type in prior applications. The full-scale design effort assumed there were no major design obstacles. The permitting costs vary widely, depending on the type of facility and the location.

The capital costs include the drilling and installation costs for the vents, manifold, and pump, and the preparation of the bases for the pump and activated carbon units. Since shipping costs are dependent on location, they are not included in the estimate. The start-up costs are based on a two-week shakedown period. Travel costs and expenses are not included. The costs for the vapor control system are based on using specially-fabricated activated carbon units. These units contain 2,000 pounds of carbon, and act as both a shipping container and adsorber vessel. This vessel is returned to the supplier for regeneration. The estimated cost for the vapor control carbon units includes equipment leasing and regeneration of the carbon.

The operation and maintenance costs are based on a four-month operation. A four-month operation was assumed based on the relatively small size of the contaminated area, high volatility of the contaminants, and the sandy soils. The system runs 24-hours a day, with periodic checks by an operator. Emissions monitoring is carried out weekly once the start-up work has been completed.

Table 1

Situation 1: Small Tank Leak
Cost Estimate for ISV Remedial System

Implementation	Estimated Costs
Bench-Scale Test	$ 12,000
Design	8,000
Permitting/Approval	10,000-50,000
	$ 30,000-70,000
Capital	
Vents	$ 7,000
Manifold	4,000
Vacuum Pump	8,000
Vapor Control System	11,000
Start-Up	14,000
	$ 44,000
Operation and Maintenance (4 Month Operation)	
Labor and Supervision	$ 17,000
Maintenance	1,000
Power	1,000
Emissions Monitoring	6,000
Vapor Control	8,000
	$ 33,000
SUBTOTAL	$107,000-147,000
Contingency 15%	$ 16,000- 22,000
TOTAL	$123,000-169,000
Cost per cubic yard of soil treated (500 cubic yards)	$ 250 - 340

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The total volume of soil treated is 500 cubic yards. This results in an estimated ISV treatment cost of $250 to $340 per cubic yard of contaminated soil. Included in this are the implementa- tion, capital, and operations costs.

2.2 Situation 2: Tank Farm Leaks

2.2.1 System Description

In Situation 2 soil contamination has resulted from several leaking underground storage tanks located in a tank farm over a number of years. The water table at this site is at a depth of 50 feet. Soil borings and samples have defined the area of contamination to be an approximately 50 feet by 80 feet. The contamination extends to the water table (50-foot bgs). The contaminants are xylene, trichloroethylene, perchloroethylene, and methylethylketone.

The storage tanks were underground tanks in a tank farm supplying a production facility. Extensive excavation of soils in this area would be costly and interfere with operations at the facility. The primary objective of the ISV remedial system operation is to maximize the removal of contaminants in as short of a time as possible.

The results of the bench-scale test indicate rapid volatilization of the contaminants. The pilot study was conducted to determine site-specific design basis for the full-scale system. Vents were also placed in areas of highest contamination.

The full-scale system consists of fourteen vents, an above-ground pipe manifold, an extraction blower, and activated carbon units. A plan view of the system layout is given in Figure 4. The pipe manifold uses PVC pipe to connect the vents to the PVC header. Ball valves are placed at the junction of each vent pipe and at the header. The vacuum pump has an air flow rate of 2,000 cfm, at a maximum vacuum pressure of 5 inches of Hg. The vacuum pump discharges to an activated carbon vapor control system.

The vents are constructed of PVC well screen. Figure 3 is a typical vent construction diagram. The vents are of the same construction as those specified in Situation 1, with gravel pack and a bentonite grout plug. The fourteen vents extend to a depth of 50 feet. The placement of the screened section is designed to maximize air flow throughout the entire unsaturated area.

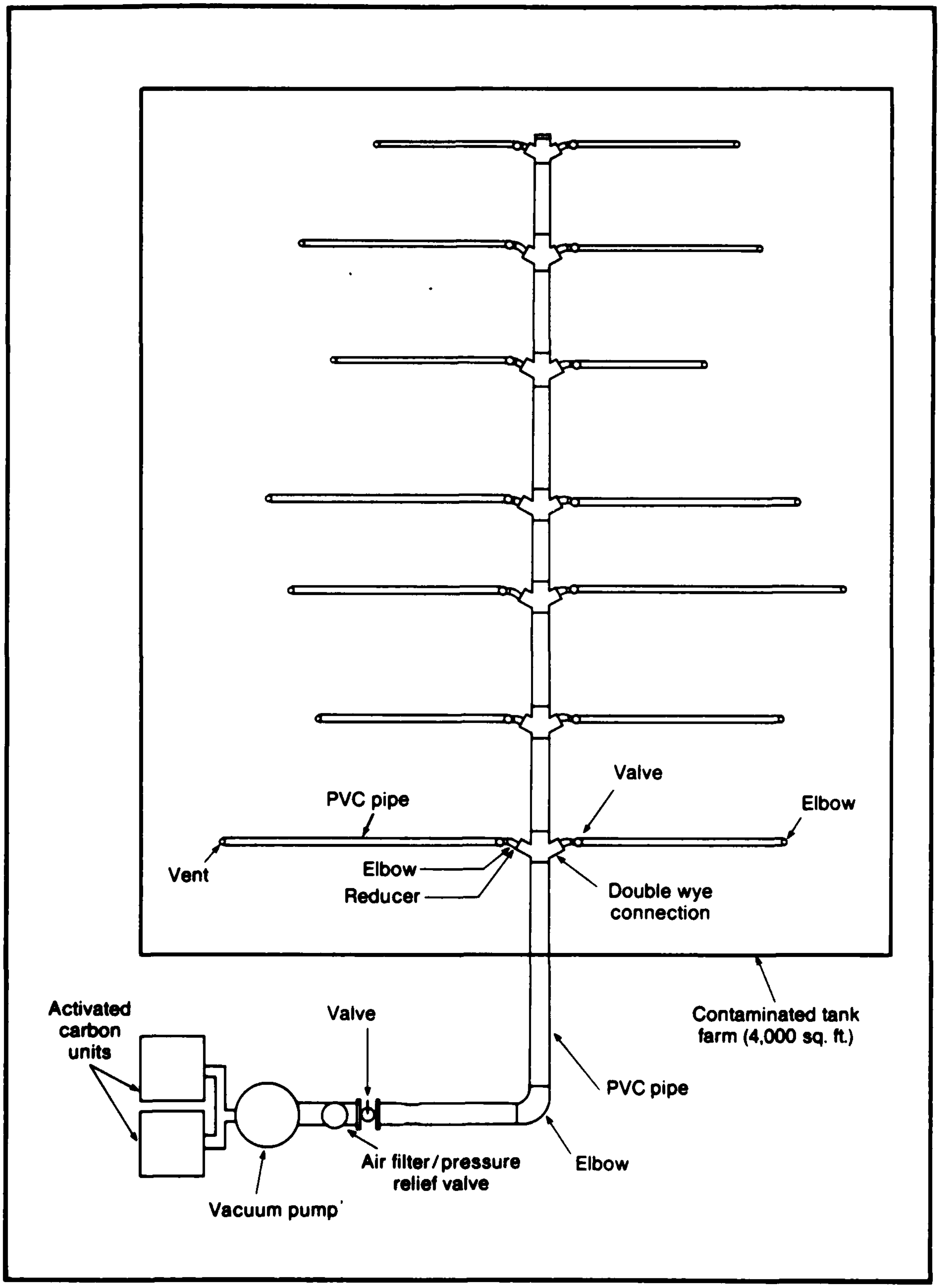

Figure 4. ISV system layout - Situation 2 plan view.

2.2.2 Cost Estimate

The estimated cost for treating this site using the ISV technology is presented in Table 2. This cost estimate includes bench-scale testing, pilot testing, full-scale design, and permitting costs, in addition to estimated capital costs and operating/maintenance costs. Detailed cost backup information is supplied in Appendix A.

Under implementation costs the bench-scale test assumed that three soil samples were tested. The full-scale design effort includes the modifications necessary to address the site-specific information obtained in the pilot study. As in Situation 1, the permitting/approval costs vary widely with the facility type and location.

The drilling and installation costs for the vents, manifold, pump, and carbon units are included in the capital cost estimates. Shipping costs, which are location dependent, are not included. The startup costs are based on a two-week period and do not include travel. As in Situation 1, the vapor control system utilizes the activated carbon units. The estimated costs for these units include equipment leasing and carbon regeneration.

The operation and maintenance costs are based on a 9 month operating period. The system runs 24-hours a day, with periodic checks by an operator. Emissions monitoring is carried out weekly after the system startup.

The total volume of soil treated is approximately 7,000 cubic yards (i.e., an area 50 feet by 80 feet and 50 feet deep). This results in an estimated ISV treatment cost of $55 to $65 per cubic yard of contaminated soil, and includes implementation, capital, and operating/maintenance costs.

2.3 Situation 3: Disposal Area

2.3.1 System Description

In Situation 3 soil contamination has resulted from the disposal of degreasers and solvents into lagoons. The contaminants were detected in high concentrations (greater than 5,000 ppm) on-site. The majority of contamination is found at depths from 0 to 30 feet. Contaminant concentrations decrease below 30 feet, though low levels of contamination are found continuously to a depth of 50 feet. This corresponds with the water table. The contaminants present are trichloroethylene, dichloroethylene, trichloroethane, and perchloroethylene.

Table 2

Situation 2: Tank Farm Leaks
Cost Estimate For ISV Remedial System

Implementation	Estimated Costs
Bench-Scale Test	$ 27,000
Pilot test/Design	107,000
Permitting/Approval	10,000- 50,000
	$144,000-184,000
Capital	
Vents	$ 27,000
Manifold	10,000
Vacuum Pump	22,000
Vapor Control System	11,000
Start-Up	18,000
	$ 88,000
Operation and Maintenance	
Labor and Supervision	$ 38,000
Maintenance	4,000
Power	$ 3,000
Emissions Monitoring	13,000
Vapor Control	62,000
	$ 120,000
SUBTOTAL	$352,000-392,000
Contingency 15%	$ 53,000- 59,000
TOTAL	$405,000-451,000
Cost per cubic yard of soil treated (7,000 cubic yards)	$ 55 - 65

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The disposal area is located on a production facility and covers an area of one to two acres. Excavation of this site would require the removal of approximately 80,000 cubic yards of material. The contaminants and soils at this site are suited to ISV application. Remedial objectives at the site are long-term in nature compared to the previous two situations.

The bench-scale test results indicate a rapid volatilization of the contaminants and relatively high permeabilities. A pilot study was conducted to collect information to design the full-scale remedial system.

The full-scale remedial system consists of fifty (50) vents, a manifold, vacuum pumps, and activated carbon vapor control units. A plan view of the system layout is given in Figure 5. The pipe manifold consists of polyethylene pipes from the vents to the lateral polyethylene pipe, which connects to the header pipe. Each vent is valved before the connection to the lateral. The vacuum pumps are housed in a small garage-type building which also contains the electric meters and starters. The air is pumped to an activated carbon vapor control system.

The vents are constructed in the same manner as in Situations 1 and 2. Figure 3 is a typical vent construction diagram. The well screen and riser are both PVC pipe. The placement of the screened section is designed to maximize the air flow throughout the contaminated unsaturated zone. The vapor control system utilizes an on-site steam regeneration system. This is necessary due to the high carbon utilization rate, particularly during the initial stages of the operation. The on-site steam regeneration system requires on-site utilities (water, electricity, and propane). The length of system operation was estimated to be two years since there are high levels of contamination over a large area.

2.3.2 Cost Estimate

An estimated cost breakdown for treating this site using the ISV technology is presented in Table 3. This cost estimate includes bench-scale tests on three soil samples, a pilot test, full-scale design, and permitting costs, in addition to estimated capital costs and operation/maintenance costs. Detailed cost backup information is supplied in Appendix A.

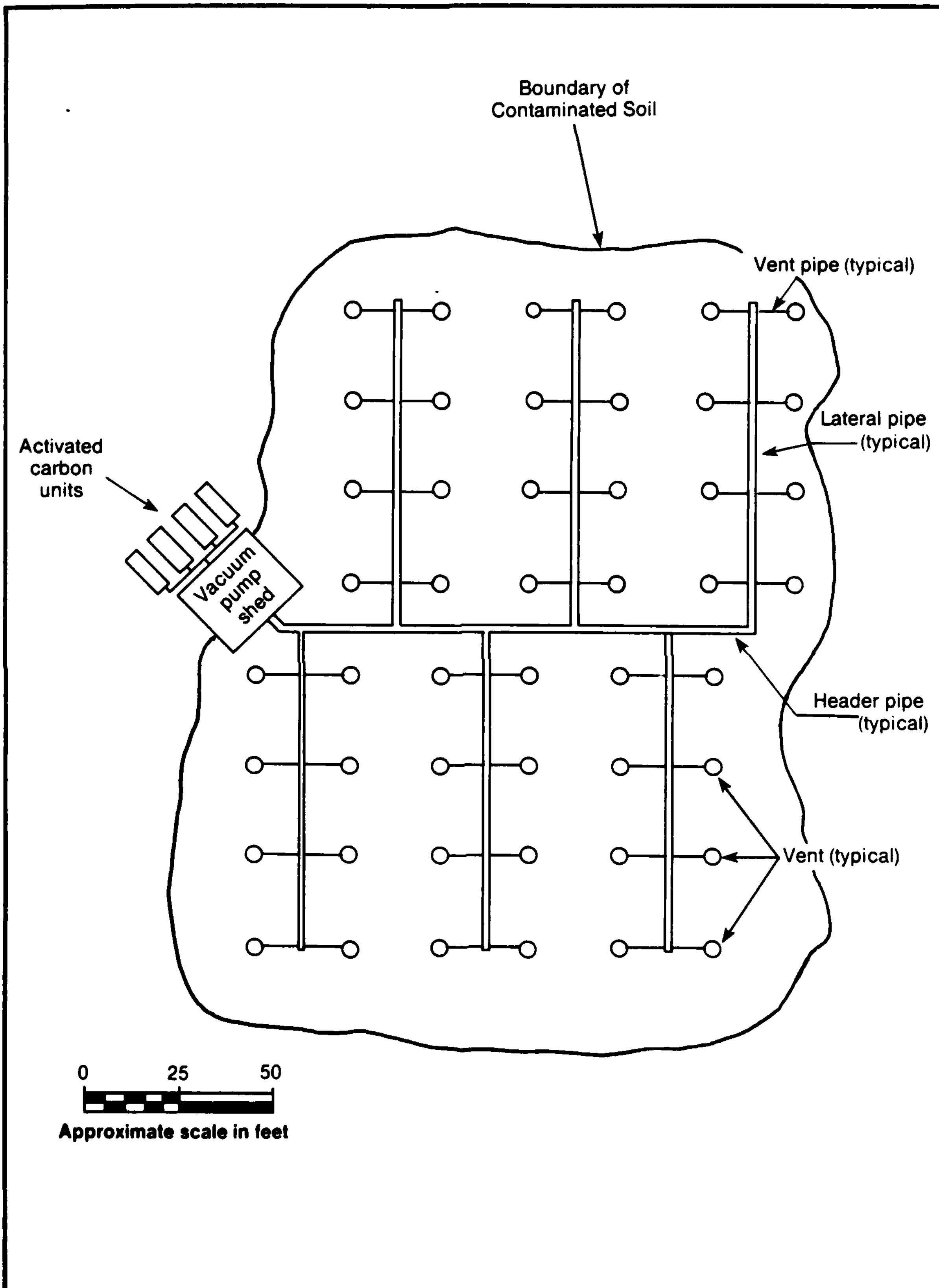

Figure 5 ISV system layout - Situation 3 plan view.

Table 3

Situation 3: Disposal Area
Cost Estimate For ISV Remedial System

Implementation	Estimated Costs
Bench-Scale Test	$ 27,000
Pilot Test/Design	113,000
Permitting/Approval	25,000- 75,000
	$165,000-215,000
Capital	
Vents	$ 100,000
Manifold	30,000
Vacuum Pump	24,000
Vapor Control System	270,000
Start-Up	23,000
	$ 447,000
Operation and Maintenance (2-year Operation)	
Labor and Supervision	$ 100,000
Maintenance	54,000
Power	42,000
Emissions Monitoring	38,000
Vapor Control	54,000
	$ 288,000
SUBTOTAL (Two-Year Operation)	$900,000-950,000
Contingency 15%	$135,000-143,000
TOTAL	$1,035,000-1,093,000
Cost per cubic yard of soil treated (based on a 1-acre area 50 ft deep, approximately 80,700 cu yd and two-year operation)	$12.00 - 15.00

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Under implementation, costs for bench-scale and pilot testing are essentially the same as those given in Situation 2. Three soil samples are tested for contaminant volatility. The full-scale design effort includes the modifications necessary to address the site-specific conditions. The permitting costs vary widely, and are higher than those for either Situation 1 or 2. It is assumed that remediation of a former disposal area would require more complicated permitting than the other situations.

The drilling and installation costs for the vents, manifold and pump are included in the capital cost estimates. Shipping costs, which are location dependent, are not included. The startup costs are based on a 2-week period using a 3-man team and do not include travel and expenses.

The vapor control unit is an activated carbon/steam regeneration unit. This system was developed as the most cost-effective method for treating this air stream in the "Novel Technology Evaluation for Volatile Organic Compounds Emissions Control" report number AMXTH-TE-CR 86099, prepared for USATHAMA, January, 1987. As explained in this report, either catalytic oxidation or incineration may be viable alternatives to activated carbon treatment. For both of these options a quench and wet scrubber system must be included in the vapor control system to neutralize the hydrochloric acid generated when chlorinated solvents are burned.

The operation and maintenance costs are the estimated annual costs. The total operation period is estimated at two years. The system is in operation 24-hours a day with periodic checks by an operator. Emissions monitoring is carried out weekly after the system startup.

The total volume of soil treated is approximately 80,700 cubic yards (i.e., 1 acre area 50 ft deep). This results in an estimated ISV treatment cost of $12 to $15 per cubic yard of contaminated soil treated, and includes implementation, capital, and operating/maintenance costs.

3. SUMMARY

The economies of scale are demonstrated in this analysis. The cost per cubic yard of soil treated is presented in Table 4.

Table 4

Treatment Cost Estimates

	Volume (cu yd)	Cost (cu yd)
Situation 1: Small Tank Leak	500	$250-340
Situation 2: Tank Farm Leaks	7,000	55- 65
Situation 3: Disposal Area	80,700	12- 15

Comparing these cost estimates with cost estimates for other remedial technologies should incorporate such site-specific characteristic as depth of contamination, proximity to buildings, and presence of utilities both above and below ground. For example, in Situation 1 the tank leak is small in areal extent, but deep and near a production building, and requires the removal of a large amount of soil surrounding the spill area to allow excavation to the full depth of contamination. This will significantly increase the excavation costs per cubic yard of contaminated soil removed. Another consideration is the cost of treatment and final disposal of the contaminated soil. The estimates presented here include the costs for regenerating the activated carbon, either at a regeneration facility (Situations 1 and 2), or on-site with disposal of the recovered solvent.

Finally, since the overall efficiency of the ISV system and the final containment soil concentrations are unknown, these may not be the only costs of complete remediation at a site.

APPENDIX A

COST ESTIMATE
CALCULATION TABLES

Cost Breakdown
Situation 1

Implementation	Estimated Cost
• Bench-Scale Test	
- Labor: 120 hrs at $75/hr	$ 9,000
- Expenses: Soil Analyses	1,500
Equipment	700
Supplies	100
	$ 12,000
• Pilot Test/Design	
- Pilot test not carried out for Situation 1	
- Full-scale Design	
Labor: Design 80 hrs at $75/hr	$ 6,000
Drafting 24 hrs at $40/hr	1,000
Report	500
	$ 8,000
• Permitting/Approval	$10,000-50,000
TOTAL (rounded off)	$30,000-70,000

Cost Breakdown
Situation 1
(continued)

Capital		Estimated Cost
• Vents (with screened sections at different depths to assure air flow through entire unsaturated zones)		
Vent 1: Drilling		$ 500
Materials		1,775
	Subtotal	$ 2,300
Vent 2: Drilling		$ 900
Materials		3,650
	Subtotal	$ 4,600
• Manifold		
- Valves:	4 at $187.50 each	$ 800
- Lateral Piping:	90 ft at $10.85/LF	1,000
- Manifold Piping:	50 ft at $17.10/LF	800
- Fittings:	11 at $127.30 each	1,400
		$ 4,000
• Vacuum Pump: $4,000 x 2 Installation Factor		$ 8,000
• Vapor Control System		
- Heat Exchange Unit:		$ 1,000
- Activated Carbon:		9,800
		$ 11,000
• Start-Up		
- Air Sample Analysis: 20 at $225 each		$ 4,500
- Labor: 160 hrs at $50/hr		8,000
- Equipment Rental		600
- Safety Equipment (Level D)		500
	Subtotal	$ 14,000
	TOTAL	$ 44,000

Cost Breakdown
Situation 1
(continued)

Operation/Maintenance (4 months operation)	Estimated Cost
• Labor and Supervision	
- 1 Operator at $40,000/Manyear	$ 13,500
- Supervision at 25% of Labor	3,500
• Maintenance	
- 6% of Capital	1,000
• Power	
- 10 hp at 0.75 kw/hp at $0.04/kwh	1,000
• Air Monitoring	2,000
- 20 samples at $100/sample	2,000
- Technical labor: 8 hrs x 16 x $30/hr	4,000
• Activated Carbon	
- 2 units at $3,900/unit	8,000
TOTAL	$ 33,000

Cost Breakdown
Situation 2

Implementation	Estimated Cost
• Bench-Scale Test (3 Soil Samples)	
- Labor: 280 hrs at $75/hr	$ 21,000
- Expenses: Soil Analyses	4,500
- Equipment:	1,700
- Supplies:	100
	$ 27,000
• Pilot Test/Design	
- Labor:	
Engineer 830 hrs at $75/hr	$ 62,300
Technician 200 hrs at $30/hr	6,000
Draftsman 30 hrs at $40/hr	1,200
Report	500
- Materials	
1 Vent at $1,900/Vent	$ 1,900
Manifold PVC Pipe	800
Valves	200
Fittings	50
Vacuum Pump	8,000
Vapor Control Activated Carbon Units	8,800
Equipment	6,400
Laboratory Analyses: 50 at $225/ sample	11,300
	$107,000
• Permitting/Approval	$10,000-50,000
TOTAL	$144,000-184,000

Cost Breakdown
Situation 2
(continued)

Capital	Estimated Cost
• Vents: Each Vent includes:	
50 ft Deep Auger Hole at $10/ft	$ 500
Materials (well screen, riser pipe, gravel pack, and grout)	1,400
	$ 1,900
14 Vents at $1,900/Vent	$ 27,000
• Manifold	
- Valves: 16 at $95.63 each	$ 1,500
- Manifold Piping: 200 ft at $17.10/LF	3,400
- Lateral Piping: 150 ft at $10.85/LF	1,700
- Fittings: 43 at $79/each	3,400
	$ 10,000
• Vacuum Pump:	
- 2 pumps 1,000 cfm each, 5 in. Hg	$ 22,000
• Activated Carbon Vapor Control Unit	9,800
- 2 units, acceptance test and prepare base	
- Heat Exchanger	1,000
	$ 11,000
• Start-Up	
- Air Sampling Analysis, 30 at $225/each	$ 6,750
- Labor: 200 hrs at $50/hr	10,000
- Equipment Rental:	600
- Safety Equipment (Level D):	500
	$ 18,000
TOTAL	$ 88,000

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Cost Breakdown
Situation 2
(continued)

Operation/Maintenance (9 months operation)	Estimated Cost
• Labor and Supervision	
- 1 Operator at $40,000/Manyear	$ 30,000
• Supervision at 25% of Labor	8,000
• Maintenance	
- 6% of Capital	4,000
• Power	
- 15 hp at 0.75 kw/hp at $0.04/kwh - 24 hrs, 270 days	3,000
• Air Monitoring	
- 41 Samples at $100/sample	4,100
- Technician Labor: 8 nrs x 36 x $30/hr	8,600
• Activated Carbon	
- 16 Units at $3,900/unit	62,000
TOTAL	$120,000

Cost Breakdown
Situation 3

Implementation	Estimated Cost
• Bench-Scale Test (3 soil samples)	
- Labor: 280 hrs at $75/hr	$ 21,000
- Expenses: Soil Analyses	
Equipment	4,500
Supplies	1,800
	$ 27,000
• Pilot Test/Design	
- Labor:	
Engineer: 890 hrs at $75/hr	$ 66,800
Technician: 200 hrs at $30/hr	6,000
Drafting: 40 hrs at $40/hr	1,600
Report	1,000
- Materials:	
1 Vent at $1,900/Vent	1,900
Manifold PVC Pipe	800
Valves	200
Fittings	50
- Vacuum Pump: 200 cfm, 5 in. Hg	8,000
- Vapor Control Activated Carbon Units	8,800
- Equipment	6,400
- Laboratory Analyses: 50 at $225/sample	11,300
	$113,000
• Permitting/Approval	$25,000-75,000
TOTAL	$165,000-215,000

Cost Breakdown
Situation 3
(continued)

Capital	Estimated Cost
• Vents: Each Vent includes:	
50 ft Deep Auger Hole at $10/ft	$ 500
Materials (well screen, riser pipe, gravel pack, and grout)	1,500
	$ 2,000
- 50 Vents at $2,000/Vent	$100,000
• Manifold:	
- Valves: 51 at $98 each	$ 5,000
- Manifold Piping: 670 ft at $7.80/LF	5,200
- Lateral Piping: 720 ft at $2.08/LF	1,500
- Fittings: 230 at $80/each	18,300
	$ 30,000
• Vacuum Pump	
- 4 Pumps (1,300 scfm and 2.5 in. Hg each)	
- 4 Pumps x $3,000 x 2 Installation Factor	$ 24,000
• Activated Carbon Vapor Control Unit (on-site regeneration unit with ancillary equipment)	
- $85,000 Base Unit x 2.5 Installation Factor, Air Preheater at $500 Installed	$213,000
- Portable Steam Generator (1,530 lb/hr at 9 psi)	17,000
- Stack Test (Assumes cost for standard stack test)	15,000
- Ancillary Equipment	
(Water Supply Tank with Chiller)	7,000
(FRP Solvent Receiver Tank)	8,800
(6,000 gal FRP Water Receiver Tank)	8,800
	$270,000
• Start-Up	
- Air Sampling Analyses, 30 at $225 each	$ 6,750
- Labor, 300 hrs at $50/week	15,000
- Equipment Rental	600
- Safety Equipment (Level D)	500
	$ 23,000
TOTAL	$447,000

Cost Breakdown
Situation 3
(continued)

Operation/Maintenance	Annual Cost
• Labor and Supervision:	
- 1 Operator at $40,000/manyear	$ 40,000
- Supervisor 25% of Operator	10,000
• Maintenance	
- 6% of Capital	26,800
• Power (Vacuum Pump)	
- 80 hp at 0.75 kw/hp at $0.04/kwh x 24 hr x 365 days	21,000
• Air Monitoring	
- 62 Samples at $100/sample	6,200
- Technician Labor 8 hrs/wk x 52 wk x $30/hr	12,500
• Vapor Control System	
- Propane (2,700 gal at $1.25/gal)	3,400
- Power (15 hp at 0.75 kw at $0.04/kwh x 24 hr x 365 days)	4,000
- Disposal of Condensed Water Treatment (22,632 gals at $0.25/gal)	5,700
- Disposal of Recovered Solvent Treatment (32,200 lbs at $0.42/lb)	13,500
TOTAL	$144,000

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