INTERSTATE TECHNOLOGY AND REGULATORY COOPERATION WORK GROUP (ITRC)

IN SITU

BIOREMEDIATION WORK TEAM,
CLOSURE CRITERIA FOCUS GROUP

FY-97 REPORT

-FINAL-
March 3, 1998

Prepared by
Interstate Technology and Regulatory Cooperation
Work Group
In Situ Bioremediation Work Team
Closure Criteria Focus Group
ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at www.itrcweb.org.

DISCLAIMER

This document is designed to help regulators and others develop a consistent approach to their evaluation, regulatory approval, and deployment of specific technologies at specific sites. Although the information in this document is believed to be reliable and accurate, this document and all material set forth herein are provided without warranties of any kind, either express or implied, including but not limited to warranties of the accuracy or completeness of information contained in the document. The technical implications of any information or guidance contained in this document may vary widely based on the specific facts involved and should not be used as a substitute for consultation with professional and competent advisors. Although this document attempts to address what the authors believe to be all relevant points, it is not intended to be an exhaustive treatise on the subject. Interested readers should do their own research, and a list of references may be provided as a starting point. This document does not necessarily address all applicable health and safety risks and precautions with respect to particular materials, conditions, or procedures in specific applications of any technology. Consequently, ITRC recommends also consulting applicable standards, laws, regulations, suppliers of materials, and material safety data sheets for information concerning safety and health risks and precautions and compliance with then-applicable laws and regulations. The use of this document and the materials set forth herein is at the user’s own risk. ECOS, ERIS, and ITRC shall not be liable for any direct, indirect, incidental, special, consequential, or punitive damages arising out of the use of any information, apparatus, method, or process discussed in this document. This document may be revised or withdrawn at any time without prior notice.

ECOS, ERIS, and ITRC do not endorse the use of, nor do they attempt to determine the merits of, any specific technology or technology provider through publication of this guidance document or any other ITRC document. The type of work described in this document should be performed by trained professionals, and federal, state, and municipal laws should be consulted. ECOS, ERIS, and ITRC shall not be liable in the event of any conflict between this guidance document and such laws, regulations, and/or ordinances. Mention of trade names or commercial products does not constitute endorsement or recommendation of use by ECOS, ERIS, or ITRC.
INTERSTATE TECHNOLOGY AND REGULATORY
COOPERATION WORK GROUP (ITRC)

IN SITU

BIOREMEDIATION WORK TEAM, CLOSURE
CRITERIA FOCUS GROUP

FY-97 REPORT

-FINAL-
March 3, 1998

Prepared by
The Interstate Technology and Regulatory Cooperation
Work Group
In Situ Bioremediation Work Team
Closure Criteria Focus Group
ACKNOWLEDGMENTS

The members of the Interstate Technology Cooperation Work Group (ITRC), In Situ Bioremediation (ISB) Technical Work Team, Closure Criteria Focus Group wish to acknowledge the individuals, organizations and agencies that contributed to this document.

The In Situ Bioremediation Work Team effort, as part of the broader ITRC effort, is funded primarily by the United States Department of Energy, Office of Science and Technology (EM-50). Additional funding has been provided by the United States Department of Defense and the United States Environmental Protection Agency. Administrative support for state grants is provided by the Western Governors Association and the Southern States Energy Board. Without this generous financial help, the state representatives would not have met together to develop this or other ITRC products.

Recognition of their efforts and thanks go to those representatives from state and federal government entities, and members from industry, who formulated the core of this work group and contributed regulatory, technical and policy considerations during the construction of this document. They are: Paul Hadley (Team Leader), and Bal Lee California Environmental Protection Agency; Jeff Kelley (Focus Group Leader), Nebraska Department of Environmental Quality; and, Steve Hill, Coleman Energy and Environment.

The work team also wishes to recognize the efforts of individual state regulatory staff and other ITRC members who made the time in their already over-taxing schedules to provide technical, regulatory, and "reality check" review of the documents, and to respond to the work team survey.
EXECUTIVE SUMMARY

The Interstate Technology and Regulatory Cooperation Work Group (ITRC) was established in February, 1995 to encourage interaction among various regulatory and non-regulatory parties. This federal, state, industry, and stakeholder group aims to improve the deployment of innovative technologies or approaches for the environmental remediation of sites across the U.S. Participating state environmental agencies are using the network to verify the effectiveness of various technologies and methodologies in an attempt to reduce paperwork and expensive duplication of effort.

In FY-97, the ITRC established six technical task teams, including one charged with reviewing a number of technical and regulatory issues surrounding In situ Bioremediation technologies. The In situ Bioremediation Technical Task Group established smaller, more focused groups to study specific aspects of the field, including the Focus Group on Closure Criteria. This is the report of that Focus Group.

Three relatively common approaches to remediation of sites with volatile organic compounds (VOCs), soil vapor extraction, bioventing, and natural attenuation, were included in a survey to determine practices and trends in establishing closure criteria for such sites. Closure criteria essentially define the performance required for any remediation technology. Based on 24 responses to a survey (sent out in November 1996), these basic approaches were observed for establishing closure criteria: attaining soil cleanup criteria (either soil chemical analysis or soil gas), a technology limits, and risk assessment. In general, these three approaches are remarkably dissimilar in principle and practice, and only the risk assessment approach robustly addresses issues related to protection of public health and the environment. The soil cleanup criteria approach is typically conservative, even in meeting conservative remediation objectives (MCLs in ground water back calculated for soil cleanup values). The technology-based approach, often associated with soil vapor extraction (SVE) projects, does not quantify residual risk associated with a site. However, soil vapor extraction has been remarkably successful in removing tremendous amounts of VOCs from the subsurface and has been shown to meet extremely conservative cleanup requirements in many states.

The conclusions of the Focus Group may be summarized that:

- the wide range of contaminant specific closure criteria may be due to differences in current or future resource use, site specific considerations (soil type, lithology, etc.), or the method of calculating closure criteria or modeling contaminant fate and transport; and,
- a national consensus on the methodology used to establish closure criteria would bring some consistency to the field, which would prove particularly beneficial for SVE technologies.
TABLE OF CONTENTS

ACKNOWLEDGMENTS.......................................................................................... i

EXECUTIVE SUMMARY...................................................................................... iii

1.0 BACKGROUND.............................................................................................. 1

2.0 INTRODUCTION............................................................................................. 1
  2.1 Closure Criteria Group Objective .............................................................. 1
  2.2 Technologies Selected .............................................................................. 2
  2.3 Importance of Closure Criteria Development .......................................... 2

3.0 METHODOLOGY............................................................................................ 3
  3.1 Closure Criteria Methodologies ................................................................. 3
  3.2 Technology-Specific Implications of Survey Responses ......................... 5
  3.3 Closure Criteria Development Considerations ......................................... 7

4.0 CONCLUSIONS/FINDINGS............................................................................ 9
  4.1 Soil Vapor Extraction .............................................................................. 9
  4.2 Bioventing ............................................................................................... 9
  4.3 Natural Attenuation ................................................................................ 9
  4.4 Closure Criteria ...................................................................................... 9

5.0 RECOMMENDATIONS.................................................................................. 10

6.0 REFERENCES............................................................................................... 12

LIST OF FIGURES

FIGURE 3.1 Asymptote Example .................................................................. 4

FIGURE 3.2 Total # Sites/TechnologyReviewed and Completed for Sites .......... 6

FIGURE 4.1 Selected Contaminants and Closure Criteria for Surveyed Sites ..... 11
APPENDICES

APPENDIX A: Acronyms

APPENDIX B: ITRC Contacts, ITRC Fact Sheet, Product Information and User Survey

APPENDIX C: Spreadsheet Summary of Survey Responses

APPENDIX D: Soil Gas Data to Define the Presence of NAPL

APPENDIX E: Alternative Closure Criteria Based on SVE Limits
INTERSTATE TECHNOLOGY AND REGULATORY COOPERATION (ITRC)
WORK GROUP IN SITU BIOREMEDIATION (ISB) TECHNOLOGIES TASK
TEAM CLOSURE CRITERIA FOCUS GROUP REPORT

1.0 BACKGROUND

The Interstate Technology and Regulatory Cooperation (ITRC) Work Group, established in 1995, is a state-led partnership between state environmental regulatory agencies, federal agencies, tribal, public and industry stakeholders. The purpose of the ITRC is to improve environmental cleanup by encouraging the use of innovative environmental technologies, while reducing regulatory paperwork and overall costs. States are collaborating to develop and facilitate the use of standardized processes for the performance verification of new technologies. The In-situ Bioremediation Work Team (ISB) of the ITRC initiated a project to survey various states’ experiences and perceptions of regulatory and policy issues regarding a number of in-situ bioremediation methods.

2.0 INTRODUCTION

In FY-96, the ISB produced evaluations of, and consensus statements for, protocols dealing with the applications of bioventing and natural attenuation for the remediation of petroleum hydrocarbons. Those reviews identified that the perceived absence, uncertainty, or variability of closure criteria frequently impeded the use of certain technologies, including those being reviewed (i.e., soil vapor extraction, bioventing and natural attenuation).

There has been discussion for several years regarding when a treatment technology or facility may discontinue operations for the remediation of volatile organic compounds (VOCs), including petroleum hydrocarbons. Various jurisdictions have identified criteria for the closure (or designation of "No Further Action") of sites using soil vapor extraction (SVE), bioventing, and natural attenuation. Many states are re-thinking their approaches to site cleanup, and to petroleum sites in particular. These issues presented the ISB technical task team an opportunity to follow-up on perceived barriers by providing member and non-member states an analysis of closure criteria used at active and closed sites around the nation. By investigating current practices and trends among states in establishing closure criteria for technologies being deployed at petroleum and solvent contaminated sites, the common and unique elements among these projects can be examined and discussed. Collectively, in situ projects with established closure criteria offer a data set to evaluate these approaches and trends.

2.1 Closure Criteria Focus Group Objective

The objective of the Closure Criteria Focus Group was to evaluate current and changing practices among states for establishing and achieving closure criteria for bioventing, soil vapor extraction and natural attenuation for petroleum hydrocarbons and chlorinated solvents. These, particularly in situ technologies, face common obstacles in remediating soils and ground water.
2.2 Technologies Selected

Three approaches used to remediate sites contaminated with volatile organic compounds (VOCs), which are included in this report, include soil vapor extraction, bioventing and natural attenuation. We have considered all three approaches as technologies, although each could also be described as a technique rather than a technology.

2.2.1 Soil Vapor Extraction (SVE)

Soil vapor extraction is an in situ technology for the removal of volatile organic compounds (VOCs) from the unsaturated zone through the use of vapor extraction wells installed in the contaminated zone. As air is removed from the soil, ambient air is injected or drawn into the subsurface at locations around the contaminated site. When ambient air passes through the soil, contaminants are volatilized and removed. Depending on contaminant concentrations and regulatory requirements, the recovered vapors may require treatment before release to the environment.

2.2.2 Bioventing

Bioventing is the use of induced low volume air movement through unsaturated soils, with or without nutrient addition, to reduce soil contamination through biodegradation. The progress of biodegradation is monitored using respiration tests that measure the consumption of oxygen attributable to biological activity that destroys organic compounds.

2.2.3 Natural Attenuation (NA)

The natural attenuation processes that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or ground water. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biochemical stabilization, transformation, or destruction of contaminants. (USEPA OSWER Directive 9200.4-17)

2.3 Importance of Closure Criteria Development

Closure criteria can be considered at various points in the site cleanup process. The rationale used for establishing various closure criteria, the ability of technologies to achieve those criteria, and methods used to develop closure criteria are obviously important to demonstrating necessity and adequacy of remediation and the importance to the achieveability of site remediation. Closure criteria define the performance requirements for technologies or technical approaches employed at a given site. The relationship between technology performance, benefits due to cleanup, and the cleanup time frame and cost of cleanup are all dependent on establishment of closure criteria. Closure criteria can be similar, or identical to those criteria that caused a site to be investigated e.g. MCLs. Closure criteria can also differ from these same criteria by applying institutional controls and other factors.
3.0 METHODOLOGY

A survey was conducted by distributing a questionnaire to state Points of Contact (POCs) of the ITRC work group; and EPA, DOD and industry representatives of the ITRC work group. State POCs were asked to disseminate the survey throughout their agencies to obtain a broad response. The questionnaire asked agencies and industry to identify sites where closure criteria had been established and/or achieved using SVE, bioventing or natural attenuation. The questionnaire also asked for the rational agencies used for development of site specific closure criteria. The surveys were distributed in November, 1996 and in May, 1997 twenty four responses had been received. A spreadsheet tabulating the responses to the questionnaire is included in Appendix C.

3.1 Closure Criteria Methodologies

According to the 24 responses received through the survey, closure criteria are based on various factors including contaminant concentrations in soils, ground water and soil gas; risk; system performance limitations or recovery rate asymptote; site use (existing or projected); threat to ground water; cost and time. Six parameters are reportedly used to establish closure criteria: soil gas concentration, soil contaminant concentration, defined asymptote or technology limits, time, risk reduction, and mass removal rate/cost basis. Each are discussed below:

1a. Soil gas based (mg/kg) without attenuation: Calculate vapor concentration in soil with contaminated ground water at MCL concentrations in equilibrium with the vadose zone:

\[
\text{Concentration (vapor)} = [\text{Concentration (water)}] \cdot [\text{Henry's Law Constant (dimensionless H-contaminant specific)}]
\]

*(Bentley, H. W. and Walter, G. R., 1997, See Appendix D for this report)*

1b. Soil gas based plus attenuation:

Soil gas concentration calculated from 1a above, plus incorporation of an attenuation factor based on modeling or other method.

2a. Soil based concentration (mg/kg) without attenuation: *(EPA Guidance 9355.4-23 and 9355.4-17A)*

Calculate soil concentration in equilibrium with ground water, at MCL concentrations using:

\[
C \text{ (soil)} = [C \text{ (water)}] \cdot [Kd] = [\text{MCL, ug/l}] \cdot [Kd] \\
\text{where } Kd = (K_{oc}) \text{ (foc)}
\]

Kd: soil-water partition coefficient (L/kg)

foc: fraction organic carbon in soil (g/g)

K_{oc}: soil organic carbon/water partition coefficient (L/kg)

2b. Soil based concentration plus attenuation: Soil concentration calculated from 2a above, plus incorporation of an attenuation factor based on modeling or other method.
3. Defined Asymptote: (SVE technology/site condition limits) Conditions reach a line considered a limit to a curve in the sense that the perpendicular distance from a moving point on the curve to the line approaches zero (or other values) as the point moves an infinite distance from the origin, however the point never quite reaches zero (or the designated value). Figure 3.1 shows a typical asymptotic curve. SVE systems typically demonstrate a sharp decrease in initial concentration values. As time progresses mass removal rates and extracted vapor decrease approaching the asymptotic conditions.

![Figure 3.1 Example of an Asymptotic Curve](image)

This is an alternative closure criteria for the case where the cleanup level based on MCLs, either soil based or soil gas based, cannot be attained, (i.e., the cleanup standard falls below the concentration asymptote). In the past, states have required multiple (2 - 3 or more) restarts after initial stabilization to an asymptotic concentration to assure contaminant levels do not rebound to unacceptable levels. A US EPA guidance document, "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, a Guide for Corrective Action Plan Reviewers (USEPA 510-B-95-007, page II-29)," recommends maintaining the pulsed-mode operation for six months after the concentration asymptote has been initially reached.

As an example, within the sites surveyed, site #8 (see Appendix C) contains silty sand in the vadose zone. The calculated cleanup level of PCE based on MCLs ranged from 5 to 52 ppb in soil depending on the depth of the vadose zone soil. Some of these closure criteria are beyond the performance limit of SVE technology under these conditions. To accommodate these limits, alternative closure criteria being proposed at the site are:

- as the initial concentration asymptote is reached, pulsed-mode (on/off type) operation will commence and continue for at least one year, and/or,
- confirmation sampling at the termination of SVE operation; and/or
- assess the risk based on residual PCE concentrations in the vadose zone.

The California Department of Toxics Substance Control has established draft guidelines for use when establishing and measuring alternative closure criteria (see Appendix D, Alternative Closure Criteria Based on SVE Technology Limits).

4. Time basis: This is typically used as a precautionary measure to insure that rebound does not return to an unacceptable value (after remediation initially reaches an acceptable value) due to continued volatilization of contaminant from the unsaturated zone or shallow
unconfined aquifers. This includes continuous operation or pulsed operation as in the example above and in sites 9, 15, 16, 17, and 19 (Appendix C).

5. Risk Reduction Based Closure Criteria: Closure criteria are based on risk calculations (including risk to ground water), existing statutes, regulations and state guidance documents. Specific risk based closure criteria are typically based on risk assessment on a real or hypothetical (projected land use) receptor. Site # 6 used a local risk evaluation to establish soil gas concentration values for 2-butanone, ethylbenzene, xylene and PCE. Site # 8 established a soil gas risk based level for PCE as the target, with the stipulation that if this could not be achieved, due to variable lithology with depth, the performance limits of the SVE are to be applied at the site (and when asymptotic conditions are achieved [see # 3 above]) as the closure criteria. Site # 23 included a 10 - 6 risk level for naphthalene plus 4.5 years of quarterly monitoring and 1.5 years of semi-annual confirmation monitoring to close the site.

6. Mass removal rate/cost basis: Three sites in Appendix C (Site # 1, 3, 12) used mass removal as a technology performance target. Each, however, included soil or soil gas concentrations as the cleanup criteria.

Site # 1 used mass removal and cost as a basis for choosing SVE over pump and treat, however the ground water still required pump and treat after the vadose zone was satisfactorily treated with SVE.

Site # 3 included a minimum removal rate to be the technology performance criteria. The minimum removal rate was established as 10% of the initial removal rate (lbs./day) and the closure criteria was established as maximum soil concentrations calculated from ground water MCLs.

At site # 12, SVE was used only until its economic benefit approached zero (i.e. cost could not justify amount of product being removed). Natural attenuation will be proposed to complete remediation to the state’s ground water standards for each contaminant. The rationale for the use of natural attenuation requires the demonstrated absence of any imminent impact to receptors.

3.2 Technology-Specific Implications of Survey Responses

3.2.1 Soil Vapor Extraction

SVE technology performance limitations do not appear to be a restriction to its use, however consideration of site-specific system design and site conditions (such as low permeability soils) is critical to the optimal performance of the system. Of the Sites using only SVE as a remediation technology, 6 of the 7 have been closed (see Figure 3.2). Those using SVE with sparging and bioventing have closed 3 of 4 and 1 of 3 respectively. In the initial stages of SVE operation, soil gas concentrations reduce rapidly and rate of contaminant recovery decreases with time. When the system is shut down, concentrations may rebound as contaminants in the soil matrix or pore water and underlying ground water volatilize into the soil/sediment pore space.
Most sites in this survey, where rebound was tested, indicated that it was not observed to any measurable extent. Most SVE sites attained closure goals within six to eighteen months. The exceptions are sites with significant interbedded clay lenses (i.e. Sites # 8 and #18). To accommodate site specific conditions, the systems are generally pulsed over a period of weeks or months to detect contaminant concentration rebound. Based on responses to the survey, costs for SVE averaged $500,000 for a 1000 SCFM system. Characterization and pilot studies, prior to the operation of a full scale SVE system, commonly took about five times the period necessary for the installed system to reach closure goals.

3.2.2 SVE / Bioventing

SVE and bioventing actions are typically installed to prevent or reduce migration of contaminants into the aquifer. MCLs for groundwater, or calculated soil or soil gas requirements, are typically used as the cleanup standards in ground water and vadose zone. In the survey, bioventing is restricted to BTEX contaminated areas and SVE for solvent and BTEX contaminants (see Sites #4, #13 and #18). Of the three sites using SVE and bioventing, site # 4 has been closed successfully over a two year operational period (Figure 3.2 & Appendix C). Site 13 closure is based on an asymptotic recovery rate followed by confirmation sampling for contaminant specific closure criteria and Site # 18 requires cleanup to soil gas concentrations calculated using Henry’s Constant from MCLs (See Appendix D).

![Graph showing Total # of Sites/Technology Reviewed and Completed Sites](image)

3.2.3 Bioventing

Three sites use bioventing for remediation of TPH (Sites #s 18, 19, and 20) Sites 19 and 20 contain only BTEX contaminants and use either oxygen utilization rates or contaminant reduction as the performance measures. Bioventing for Site # 18 is only applied to a diesel contaminated area and defines the closure criteria in the vadose zone using equilibrium between the soil gas and ground water using Henry’s Constant (see # 1a above). Site # 19 has defined closure criteria as, a measurable decrease in the oxygen utilization rate plus one year of continuous operation. Site # 20 is still in the pilot phase, therefore closure criteria have not been established, however, During the 200 day pilot test BTEX was reduced by 90%. As can be seen in Figure 3.2 the two
operational bioventing sites have not been closed. Site #19 has operated since 1993 and is expected to operate through 1997 and submit a closure plan to the state. Site 18 began operation in 1996 and predicts 5 - 10 years of operation.

3.2.4 Natural Attenuation

Four aquifer remediation sites using natural attenuation are include in the survey (Sites 21 And 22 contain solvents; Sites 23 and 24 contain BTEX. Site #23 has been closed using 10-6 risk factor and deed restrictions as the closure criteria. Site # 24 established MCLs for BTEX components and naphthalene as the closure criteria. Both include dense monitoring configurations and post closure monitoring. The solvent sites (#21 and #22) established MCLs as the closure criteria, however extensive modeling and dense operational and post closure monitoring are required.

3.3 Closure Criteria Development Considerations

Cleanup goals, monitoring parameters and confirmation sampling requirements are finalized through negotiation with state (primarily) and federal agencies. Some states have established soil or soil gas closure criteria or provide the regulatory methodology or guidance to arrive at closure criteria. Closure criteria can be designed to accommodate multiple functions of the remediation project. For instance Site # 8 recognizes the asymptote, based on the limitation of the technology (SVE) at that particular site. However because the subsurface lithology is quite variable and controls the contaminant concentration, SVE can be terminated at the asymptote followed by one additional year of pulsed-mode operation, or when confirmation soil/sediment sampling results are below established PCE soil gas risk-based concentration levels.

Using soil gas concentrations, as closure criteria, provides a challenge to obtain representative samples and contaminant concentrations in gas. Contaminant concentration in gas is a function of the subsurface and can deceptively indicate that closure criteria have been met quickly only to find that continued contaminant volatilization from the pore fluid and matrix particle rebound gas concentrations in extraction wells. Restarts (pulsing) for weeks and months are required to document the absence of rebounding contaminant concentrations. Most sites surveyed indicated that rebounding soil gas concentrations were not a significant problem, however, the subsurface lithology (clay content) dictates the extent of diffusion/volatilization of the gas.

Closure confirmation, at the sites included in this survey, is typically based on MCLs or the soil or soil gas equivalent calculated in equilibrium with the ground water contaminant concentration (See 1a & b and 2a & b in the Survey Results section of this report). Typically if soil gas or soil contaminant concentrations are used as the closure criteria for SVE or bioventing, air sparging, pump & treat or natural attenuation are used to treat the remaining ground water contamination. Combinations of SVE and bioventing (if petroleum contamination) in the unsaturated zone; and natural attenuation, air sparging and pump & treat in the saturated zone can effectively address the contaminated system.

Verification that soil based closure criteria has been achieved is a difficult task. It is difficult to obtain reliable recoveries of VOCs from soil samples. Significant soil gas concentrations in the
pore spaces of soils may be lost during sample collection, preparation and analysis. These analyses may yield lower apparent levels of VOCs as a result.

Regardless of the method used to establish closure criteria, it is critical to the success of the remediation project to define closure criteria early in the process and optimally before technology selection. This allows the owner/consultant the opportunity to model the effects of the various treatment techniques/technologies according to closure criteria, time and cost.

3.3.1 Technology Treatment Trains With In situ Bioremediation Technology

Technology combinations were more the norm than the exception in the sites surveyed. SVE and/or bioventing were typically used in combination with pump & treat, air sparging and natural attenuation. At one site, however, (site # 9) the owner persistently pulsed a SVE system, to clean a shallow aquifer, even though the closure criteria is based on soil contaminant concentrations. The closure criteria at this site were effectively achieved in two years of operation (1992 - 1994). Soil contaminant concentrations were reduced from an initial value of 26,000 mg/kg PCE to less than 0.5 mg/kg.

Treatment systems have been designed to operate sequentially or concurrently. For instance at Site #8 1 and 2 SVE was used to treat solvents in the unsaturated zone followed by pump & treat in the saturated zone. At Site # 15 a SVE system and air sparging system have been installed and run concurrently. Closure criteria on both are based on ground water MCLs and were achieved in two years.

3.3.2 Additional Considerations

At a uniform concentration of 1.0 mg/kg (1.0 ppm) of trichloroethylene (TCE), a site with one acre in surface area and a thickness of 10 feet would hold about 4.3 gallons of TCE. At a concentration of 1.0 ug/kg (1.0 ppb) this same volume of soil would contain about 0.5 fluid ounces of TCE. In light of the heterogeneous nature of soil contamination, it is entirely probable that post-closure sampling of a site will produce measurements of TCE in soil above closure criteria and will be reported in data sets otherwise containing nondetects. Since closure criteria are most often based on the highest reported concentration, the lower the closure criteria the less likely that there is no place on a site that does not exceed the criterion. At the same time, exceedences of the closure criteria in individual samples, or few samples, does not by itself indicate a significant mass of contamination and therefore a significant problem remaining at the site.

Clearly at the 1.0 ppb range, and even at the 1.0 ppm range, it is likely that the mass remaining at the closure criteria (0.5 fluid ounces and 4.3 gallons) is not distributed uniformly throughout the entire volume of the example site (435,600 cubic feet of material). To show comparatively that no sample at this site exceeds such low closure criteria would require an extraordinary number of soil samples and analyses; so many that the cost would be prohibitive.
pore spaces of soils may be lost during sample collection, preparation and analysis. These analyses may yield lower apparent levels of VOCs as a result.

Regardless of the method used to establish closure criteria, it is critical to the success of the remediation project to define closure criteria early in the process and optimally before technology selection. This allows the owner/consultant the opportunity to model the effects of the various treatment techniques/technologies according to closure criteria, time and cost.

3.3.1 Technology Treatment Trains With In situ Bioremediation Technology

Technology combinations were more the norm than the exception in the sites surveyed. SVE and/or bioventing were typically used in combination with pump & treat, air sparging and natural attenuation. At one site, however, (site # 9) the owner persistently pulsed a SVE system, to clean a shallow aquifer, even though the closure criteria is based on soil contaminant concentrations. The closure criteria at this site were effectively achieved in two years of operation (1992 - 1994). Soil contaminant concentrations were reduced from an initial value of 26,000 mg/kg PCE to less than 0.5 mg/kg.

Treatment systems have been designed to operate sequentially or concurrently. For instance at Site #8 1 and 2 SVE was used to treat solvents in the unsaturated zone followed by pump & treat in the saturated zone. At Site # 15 a SVE system and air sparging system have been installed and run concurrently. Closure criteria on both are based on ground water MCLs and were achieved in two years.

3.3.2 Additional Considerations

At a uniform concentration of 1.0 mg/kg (1.0 ppm) of trichloroethylene (TCE), a site with one acre in surface area and a thickness of 10 feet would hold about 4.3 gallons of TCE. At a concentration of 1.0 ug/kg (1.0 ppb) this same volume of soil would contain about 0.5 fluid ounces of TCE. In light of the heterogeneous nature of soil contamination, it is entirely probable that post-closure sampling of a site will produce measurements of TCE in soil above closure criteria and will be reported in data sets otherwise containing nondetects. Since closure criteria are most often based on the highest reported concentration, the lower the closure criteria the less likely that there is no place on a site that does not exceed the criterion. At the same time, exceedences of the closure criteria in individual samples, or few samples, does not by itself indicate a significant mass of contamination and therefore a significant problem remaining at the site.

Clearly at the 1.0 ppb range, and even at the 1.0 ppm range, it is likely that the mass remaining at the closure criteria (0.5 fluid ounces and 4.3 gallons) is not distributed uniformly throughout the entire volume of the example site (435,600 cubic feet of material). To show comparatively that no sample at this site exceeds such low closure criteria would require an extraordinary number of soil samples and analyses; so many that the cost would be prohibitive.
The closure criteria reported in the study gave no specific consideration to the mass of the residual contamination at a site. Since residual human or environmental risks are proportional to residual mass, this consideration might merit further development in future work.

4.0 CONCLUSIONS/FINDINGS

4.1 Soil Vapor Extraction

Contaminant recoveries from SVE generally far exceed pre-system start estimates of contaminants in place in the unsaturated soils.

   a. SVE attainment of closure criteria is successful in the majority of survey responses.
   b. Asymptotic conditions are not a concern for technology limits for most sites that reported reaching closure criteria. However, sites with very stringent closure criteria i.e. California (see figure 4.1) may find asymptotic concentrations higher than the closure criteria. In this case, alternative closure criteria based on SVE’s technology limit could be considered (See Appendix E).

4.2 Bioventing

Bioventing sites included in the survey, and those achieving closure to date, are few. It should be noted that many pilot bioventing sites reported being started with no established closure criteria prior to system startup. This increases the uncertainty that the chosen technology is capable of achieving an acceptable endpoint. This results in projects continuing until budgeted funds are exhausted or a “cease operations” is issued by regulators.

4.3 Natural Attenuation:

Natural attenuation sites are in the early stages of achieving compliance with existing MCLs as the closure criteria. One site is closed, however deed restrictions were imposed as a precautionary measure to final release. Sites in the survey typically continue to require significant operational and post closure monitoring data to validate fate and transport modeling of contaminant movement.

4.4 Closure Criteria:

There is a wide range of contaminant specific closure criteria among the survey responses (orders of magnitude). This may be due to differences in current or future resource use, site specific considerations (soil type, lithology, etc.), or the method of calculating closure criteria or modeling contaminant fate and transport (Figure 3).
5.0 RECOMMENDATIONS:

There is a tremendous need for a detailed evaluation of the various methods used to establish closure criteria. Such analyses would benefit all in situ technologies, especially soil vapor extraction, which is commonly deployed in many states. It is our recommendation that such an analysis expands on this current work and could identify an approach, which promotes broad consensus in a consistent methodology to establish closure criteria at contaminated sites.
Selected Contaminants & Closure Criteria for Survey Sites
Figure 4.1

- Benzene
- Perchloroethene
- Trichloroethylene
6.0 REFERENCES

USEPA OSWER Directive 9200.4-17, November 18, 1997, *Draft Interim Final OSWER Monitored Natural Attenuation Policy*


USEPA 40/R-95/128, 1995, *Organic Leachate Model*

USEPA 9355.4-23, April 1, 1996, *Soil Screening Guide: Users Guide*

USEPA 9355.4-17A, May 1, 1996, *EPA Soil Screening Guide: Technical Background Document*

APPENDIX A

Acronyms
ACRONYMS

AFCEE: Air Force Center for Environmental Excellence
ARARs: Applicable Relevant and Appropriate Requirements
Cal-EPA: California Environmental Protection Agency
DTSC: Cal-EPA, Department of Toxic Substances Control
EPA: United States Environmental Protection Agency
FID: Flourescent Ion Detector
ISB: In situ Bioremediation Technical Task Group of the ITRC
ITRC: Interstate Technology and Regulatory Cooperation Work Group
NA: Natural Attenuation
MCL: Maximum Concentration Limits
PCE: Perchloroethylene
SCFM: Standard Cubic Feet per Minute
SVE: Soil Vapor Extraction
VOCs: Volatile Organic Compounds
APPENDIX B

ITRC Work Team Contacts
ITRC Fact Sheet
Product Information
User Survey
ITRC CONTACTS

Paul Hadley
Cal-EPA, Dept. Toxic Substances Control
P.O. Box 806
301 Capitol Mall, 1st Floor
Sacramento, CA 95814
P 916-324-3823
F 916-327-4494

Bal Lee
Cal-EPA, Dept. Toxic Substances Control
P.O. Box 806
301 Capitol Mall, 1st Floor
Sacramento, CA 95814
P 916-324-3823
F 916-327-4494

Jeff Kelley
Nebraska Dept. of Environmental Quality
1200 N Street, Suite 400
The Atrium Building
Lincoln, NE 68509-8922
P 402-471-3388
F 402-471-2909
deqstaff@doc.state.ne.us

Steve Hill
Coleman Research Corporation
2995 N Cole Road, Ste 260
Boise, ID 83704
P 208-375-9029
F 208-375-5506
steve_hill@mail.crc.com
WHAT IS THE ITRC?

The Interstate Technology and Regulatory Cooperation Work Group (ITRC) is a state-led, national coalition with the mission of focusing on creating tools and strategies to reduce interstate barriers to the deployment of innovative hazardous waste management and remediation technologies. Originating in 1995 from a previous initiative by the Western Governors Association, the ITRC has expanded to include the environmental agencies of more than 25 states, three federal partners, public and industry stakeholders, and two state associations -- the Western Governors Association and the Southern States Energy Board.

WHAT PROBLEM IS THE ITRC TRYING TO ADDRESS?

As environmental regulations have increased over the past two decades, they have created a maze of federal, state and local requirements which often vary from state to state and region to region. Correspondingly, many regulators are unable to accept performance data collected in another state, because the data do not address the needs of their state. This lack of consistency from state to state is further amplified because often neither the technology developer nor the state regulator consider other sites in designing the test plan(s) for the collection of performance data.

WHAT SOLUTION IS PROPOSED BY THE ITRC?

One solution proposed by the ITRC is that state environmental regulatory agencies should accept performance data gathered under another state’s oversight as if the testing had been done in their own state. To accomplish this, the ITRC develops consensus among state regulators, with input from industry and public stakeholders, on the type of technical regulatory information that should be addressed when using a specified technology. This information is captured in guidance documents which are intended to help regulatory staff in an expeditious review of the use of a specified technology. Thus, these guidance documents foster greater consistency in technical requirements among states and result in reduced fragmentation of markets.

Additionally, these guidance documents help technology developers and vendors collect performance data that can be used to support regulatory approval at other sites. By looking ahead to the typical technical requirements that will be imposed by a regulatory agency, they can collect and evaluate information that will facilitate and smooth the regulatory approval process for multi-state deployment.
WHAT HAS BEEN DONE TO DATE?

To date, the ITRC has developed (either final or near final) 24 guidance documents intended to help regulatory staff and technology vendors in the deployment of innovative technologies. In general, ITRC guidance documents are defined as providing a regulatory perspective on the informational needs (background and/or regulatory requirements) of state environmental agencies to approve the use of a specified technology.

More specifically, these guidance documents are categorized into three areas:

1. *Technical/Regulatory Guidelines*: Previously called “protocols”, these guidance documents reflect a consensus of state technical/regulatory concerns that should be considered when approving the use of a specified technology or in demonstrating a technology. Documents of this nature are formally circulated to the state environmental program managers to seek their concurrence to use the proposed guidance.

2. *Technology Overviews*: These documents may come in the form of status reports on emerging technologies or state input into guidance documents and deployment activities being developed by other organizations.

3. *Case Studies*: Reports include benchmarking of state practices in areas relating to the verification, testing and/or approval of emerging technologies, as well as, documenting state approaches to implementation of various programs and policies.

Within these categories, thirteen technical/regulatory guidelines documents, seven technology overview documents and four case studies have been completed. (A complete list of these products is available.)

HOW CAN YOU BENEFIT FROM USING THE ITRC GUIDANCE DOCUMENTS?

The use of these tools offers a consistent approach to the review and approval of specified technologies to clean up a specific site. This saves the state time in reviewing applications, training costs, and helps lessen the uncertainty associated with innovative technologies. Likewise, these tools offer industry a consistent and predictable process for the regulatory review and approval of these technologies. Similarly, technology developers also have a guide to the collection of performance data that will likely be requested by regulators when their technology is commercialized. Finally, as more states incorporate guidance from ITRC documents into their formal guidance to site managers, technologies which are successfully used by these states can gain even more expeditious review and approval for multi-site deployment across the nation.

WHERE CAN I GET MORE INFORMATION?

From the Internet: http://www.westgov.org/itrc
Please fax your order form to:  
Chris McKinnon, Western Governors Association  
fax: (303) 534-7309

Please send the indicated documents to the mailing address shown below.

Name:  
Mailing Address:  
City, State, ZIP  
Phone Number:  

More information on the ITRC can be found on the WGA web site at: http://www.westgov.org/itrc. Documents and associated concurrence information will soon be available at this site. All documents have been peer reviewed by members of individual ITRC Work Teams. Those designated as Technical/Regulatory Guidelines also have undergone/will undergo full ITRC multi-state review through the ITRC concurrence process.

<table>
<thead>
<tr>
<th>Doc. #</th>
<th>Product Category</th>
<th>TITLE</th>
<th>PRODUCT DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc. #</td>
<td>Product Category</td>
<td>TITLE</td>
<td>PRODUCT DESCRIPTION</td>
</tr>
<tr>
<td>-------</td>
<td>------------------</td>
<td>-------</td>
<td>---------------------</td>
</tr>
<tr>
<td>ISB-3</td>
<td>Technical/Regulatory Guidelines</td>
<td>Natural Attenuation of Chlorinated Solvents in Groundwater - Principles and Practices</td>
<td>FINAL scheduled to be sent out for Concurrence /available July 1998. Description of practices to be used to recognize and evaluate the presence of natural attenuation of chlorinated solvent contamination.</td>
</tr>
</tbody>
</table>

**Metals in Soils**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc. #</td>
<td>Product Category</td>
<td>TITLE</td>
<td>PRODUCT DESCRIPTION</td>
</tr>
<tr>
<td>-------</td>
<td>------------------</td>
<td>-------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Pol-1</td>
<td>Case Studies</td>
<td>Case Studies of Selected States Voluntary Clean-Up/Brownfields Programs</td>
<td>FINAL Information Document. In-depth case studies of selected states’ voluntary clean-up/brownfields programs and recommendations for possible enhancements.</td>
</tr>
<tr>
<td>TD-2</td>
<td>Technical/Regulatory Guidelines</td>
<td>Technical Requirements for On-Site Thermal Desorption of Solid Media Contaminated with Hazardous Chlorinated Organics</td>
<td>FINAL scheduled to be sent out for Concurrence/available Feb 1998. Minimum technical requirements for use of thermal desorption on solid media contaminated with hazardous chlorinated organics.</td>
</tr>
<tr>
<td>TD-3</td>
<td>Technical/Regulatory Guidelines</td>
<td>Technical Requirements for On-Site Thermal Desorption of Solid Media and Low Level Mixed Waste Contaminated with Mercury and/or Hazardous Chlorinated Organics</td>
<td>FINAL scheduled to be sent out for Concurrence/planned for late 1998. Minimum technical requirements for use of thermal desorption for special categories of mixed waste.</td>
</tr>
</tbody>
</table>
APPENDIX C

Spreadsheet Summary of Survey Responses
<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>LOCATION</th>
<th>TECHNOLOGY</th>
<th>CONTAMINANTS</th>
<th>STATUS</th>
<th>CLEANUP LEVEL</th>
<th>RATIONALE</th>
<th>NOTES, COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Well M-3 Site</td>
<td>Hastings, Nebraska</td>
<td>SVE, solvents</td>
<td>Complete</td>
<td>Reach extraction rate of 0.001 lbs/hr</td>
<td>Represents cost per pound equivalent of SVE operation versus pump and treat costs to recover the same amount of contaminant</td>
<td>Cleanup criteria reached in 9 months, followed by a 2 month shutdown period (no rebound). Site now in pump and treat phase with ground water contaminant levels near MCL. Initial CC4 concentration was 1,234 ppmw. At end of action CC4 was 0.93 µg/l at OAC inlet. Total costs: $448,000.</td>
<td></td>
</tr>
<tr>
<td>2. Colorado Avenue Site</td>
<td>Hastings, Nebraska</td>
<td>SVE, solvents</td>
<td>Operational</td>
<td>Two tiers: both must be reached; Soil: Organic Leachate Model (Fed. Reg. 7/22/96) Soil Gas: concentration of VOCs in air in equilibrium with ground water at MCLs using Henry's Law (Cv = Cw[H]^k)</td>
<td>System startup in July 1996, includes horizontal SVE pilot, will be followed by pump and treat of TCE-4 plume &quot;hot spots&quot; with air sparging pilot. Initial TCE concentrations were 6,000 mg/m3; PCE was 225 mg/m3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Fairchild Site</td>
<td>San</td>
<td>SVE, solvents</td>
<td>Closed, attained closure criteria</td>
<td>Operate until total removal rate less than 10 lbs/day and removal rate from individual wells to less than 1% for 10 consecutive days</td>
<td>Removal rate decline and asymptote defined</td>
<td>Achieved cleanup goal of 10 lbs per day in 8 months. After 16 months of operation, the removal rate declined to less than 4 lbs/day. Total recovered: 18,000 pounds. Rebound was tested at 2, 4 and 8 week intervals (no rebound observed). The original ROD specified a cleanup goal of 1 mg/kg for each contaminant, but an amendment was issued. Soil sampling after 7 months of operation showed only 3 samples that had reached the original 1 mg/kg goal. Initial TCA 3,530 mg/kg, xylene 141 mg/kg.</td>
<td></td>
</tr>
<tr>
<td>SITE NAME</td>
<td>TECHNOLOGY</td>
<td>LOCATION</td>
<td>CONTAMINATE</td>
<td>STATUS</td>
<td>CLEANUP LEVEL</td>
<td>RATIONALE</td>
<td>NOTES, COMMENTS</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>----------</td>
<td>-------------</td>
<td>--------</td>
<td>---------------</td>
<td>-----------</td>
<td>----------------</td>
</tr>
<tr>
<td>4. Hill AFB Site</td>
<td>SVE then Biovent, TPH</td>
<td>914, Ogden UT</td>
<td>Closed, attained closure criteria</td>
<td>Soil TPH maximum 65 mg/kg with: Benzene &lt;0.2 Toluene &lt; 100 Xylenes &lt;1000 Ethylbenzene &lt;70</td>
<td>Utah Dept. of Health Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites</td>
<td>Over two year operational period reduced TPH concentrations in soil to an average of 6 mg/kg. Recovered 211,000 pounds of contaminants at a removal rate of 20 to 400 lbs/day. Total Costs costs were $598,000. TPH max. 10,400 mg/kg.</td>
<td></td>
</tr>
<tr>
<td>5. Luke AFB North Fire Training Area, Arizona</td>
<td>SVE, TPH/STEX</td>
<td>Completed, attained closure criteria</td>
<td>TPH 100 mg/kg Benzene 0.13 Ethylbenzene 68 Toluene 200 Xylenes 44 Total BTEX 412</td>
<td>Arizona Action Levels</td>
<td>Achieved cleanup goals in 30 weeks of operation. Removed 12,000 pounds of contaminants with a removal rate of 40 lbs/day at completion. 66% reduction of benzene. Total costs were $507,000. Initial TPH max. 1,380 mg/kg; Benzene 16; Toluene 183; Ethylbenzene 84; and xylenes 336 mg/kg.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Sacramento Army Depot Tank 2 OU, Sacramento</td>
<td>SVE, Chlorinated and Non-Chlorinated Aliphatics</td>
<td>Completed, attained closure criteria</td>
<td>ROD: 2-Butanone 1.2 ppm Ethylbenzene 0 Xylenes 23 PCE 0.2 ppm</td>
<td>Risk calculations based on a public health evaluation corresponding to risk reductions of 92-99% depending on the contaminant</td>
<td>Achieved cleanup goals in six months of operation (contaminants actually reduced to non-detect at 0.01 mg/kg). Site soils were low permeability. System recovered 2300 pounds of contaminants. Total costs were $556,000. Initial max. contaminants: 2-Butanone 150 mg/kg; Ethylbenzene 2,103; PCE 980; and xylenes 11,000 mg/kg.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## In Situ Bioremediation
### Closure Criteria Focus Group
#### Survey Results Summary

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Technology</th>
<th>Status</th>
<th>Cleanup Level</th>
<th>Rationale</th>
<th>Notes/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. SMS Instruments, Deer Park, NY</td>
<td>SVE, Chlorinated and Non-Chlorinated Aliphatics and Semi-volatile compounds</td>
<td>Completed, attained closure criteria</td>
<td>T-1, 2-DCE 0.5 mg/kg, 2-Butanone 0.5, 2-Hexanone 0.7, PCE 1.5, Toluene 1.5, TCE 1.0, Xylenes 1.2, Ethylbenzene 5.0, Chlorobenzene 1.0, 1,4-DCB 1.0, 1,3-DCB 1.5, 1,2-DCB 1.0, Naphthalene 1.0, 1,2,4-TCB 2.3, 2-Methylphenanthrene 2.0 mg/kg, Phenol 0.33, 2-Methylphenol 2.6, Bis(2-ethylhexyl)phthalate 4.5</td>
<td>Developed by the New York State Dept. of Environmental Conservation. No more than 20% of soil samples at closure could exceed individual contaminant cleanup levels, and for individual samples contaminant levels could not exceed twice the soils cleanup levels.</td>
<td>Cleanup achieved in 400 days at a cost of $450,000. Initial max. concentrations: volatiles 1,200 mg/kg; semi-volatiles 1,800 mg/kg.</td>
</tr>
<tr>
<td>8. California Central Valley</td>
<td>SVE, PCE</td>
<td>Closure criteria developed</td>
<td>Assymptote defined as mass removal and VOC concentration rates do not vary by more than 2% over four consecutive weekly monitoring events. Cycling is required, with a minimum of one year operation required. PCE soil gas risk-based level 0.4 to 3.9 ppnm depending on lithology and depths. PCE soil levels are 5 to 60 ppb depending on lithology and depth. If risk-based level is not achievable the performance limit of the SVE unit will be used.</td>
<td>California Regional Water Quality Control Board (LA Region) &quot;Interim Guidance for Remediation of VOC Impacted Sites&quot;.</td>
<td>Pilot tests conducted, in design stage. Initial PCE level in soil gas was 1,000 ppnm.</td>
</tr>
<tr>
<td>SITE NAME</td>
<td>TECHNOLOGY</td>
<td>CONTAMINANTS</td>
<td>STATUS</td>
<td>CLEANUP LEVEL</td>
<td>RATIONALE</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>--------------</td>
<td>--------</td>
<td>---------------</td>
<td>-----------</td>
</tr>
<tr>
<td>9. West Boise PCE Contamination Site, Idaho</td>
<td>SVE, PCE</td>
<td>Complete, attained closure criteria</td>
<td>PCE 0.5 mg/kg</td>
<td>Based on the elimination of leachable material to ground water. System removed essentially all vadose zone contamination so cleanup levels in soil did not become an issue.</td>
<td>System reached cleanup goals in two years (1992-1994). System is now pushed to aid in removal of VOCs from shallow water table. Closure requirements called for 10 soil borings to be analyzed. Initial PCE levels were 29,000 mg/kg.</td>
</tr>
<tr>
<td>10. Verona Well Field, Battle Creek, MI</td>
<td>SVE, Chlorinated and Non-Chlorinated Aliphatics</td>
<td>Complete, attained closure criteria</td>
<td>Benzene 0.02 mg/kg, Carbon tetrachloride 0.01, 1,1-DCA 0.02, 1,1-DCE 0.01, cis-1,2-DCE 0.02, trans-1,2-DCE 2.0, Ethylbenzene 1.4, Methylene chloride 0.1, TCE 0.014, Toluene 16, 1,1,1-TCA 4, TCE 0.06, Xylenes 6 mg/kg</td>
<td>1991 NOD levels established to coincide with cleanup levels for two nearby OUs. State of Michigan law (Act 307) also established cleanup goals that correspond to 10E-6 risk.</td>
<td>Operational four years. A total of 45,000 lbs of VOCs were removed. EPA's first application of SVE at a Superfund site cost was $1,645,000.</td>
</tr>
<tr>
<td>11. ACME Printing, Kansas City, Kansas</td>
<td>SVE, hydrocarbons and solvents</td>
<td>Closure criteria developed, remedial action started.</td>
<td>System is interim SVE is temporarily shut down having reached asymptotic levels. Awaiting installation of air sparging system to treat the ground water.</td>
<td>Planned for reaching technology limit (asymptotic), then staged to air sparge.</td>
<td>System startup in 1991. Long term monitoring will be required after system shut down. Alternate cleanup levels have been established to delineate area of active air sparging. Institutional controls will be part of the final remedy. Quarterly monitoring is required. Initial and current levels: Initial (mg/m^3): Benzene 63.66, Toluene 274.98, Ethylbenzene 6.14, Xylenes 51.38. n-Hexane 72.97, n-Heptane 80.83, n-Octane 32.71, Iso-Octane 17.51, Acetone.</td>
</tr>
</tbody>
</table>
## In Situ Bioremediation
### Closure Criteria Focus Group
#### Survey Results Summary

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Technology</th>
<th>Contaminants</th>
<th>Status</th>
<th>Cleanup Level</th>
<th>Rationale</th>
<th>Notes, Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. State of New Jersey</td>
<td>SVE, Natural Attenuation, BTEX</td>
<td>Closure Criteria SOP</td>
<td>Economic limit for SVE, then ground water standards for NA</td>
<td>Responsible party determines that the cost of operation does not justify the amount of product removed. Submits proposal to NJ DEP for natural attenuation to reach ground water goals if there is no imminent receptor impact.</td>
<td>Draft rules to be adopted 1/97. Natural attenuation requirements include: characterize site to show evidence of NA; a minimum of 12 quarters of monitoring data; four monitoring wells; and use of the Mann-Whitney U-Test to show NA occurring. 25 year planning horizon.</td>
<td></td>
</tr>
<tr>
<td>13. State of South Dakota</td>
<td>SVE, Bioventing BTEX compounds</td>
<td>Closure Criteria SOP</td>
<td>Soils: Benzene 0.2 ppm, Toluene 15.0 ppm, Ethylbenzene 10.0 ppm, Xylenes 300.0 ppm, Naphthalene 26 ppm</td>
<td>RBCA-generated from Groundwater Services software: &quot;Tier 1/Tier 2 RBCA Spreadsheet System and ASTM.&quot;</td>
<td>When an asymptotic level or 95% reduction of initial effluent concentration is reached, soil samples may be collected and analyzed and compared to the closure criteria to consider the site for closure by SODENR.</td>
<td></td>
</tr>
<tr>
<td>14. Cascade Corp, Troutdale Oregon</td>
<td>SVE, Solvents with sparging</td>
<td>Closure Criteria developed, remedial action ongoing</td>
<td>TCE soil gas 5 ppm, ground water TCE MCL of 5 ppb.</td>
<td>Restore vadose zone so no longer a source for contaminating ground water. 5 ppm in soil gas represents equilibrium concentrations between soil and ground water.</td>
<td>29 monitoring wells, ground water at 10 feet. Offsite migration threatening municipal and private wells. RCD 12/96. Start summer 1997. Estimate 7 years to completion for operation. Must maintain 5 ppm during one year monitoring after shutdown. Costs: $800,000 capital and $3.1 million O&amp;M.</td>
<td></td>
</tr>
<tr>
<td>SITE NAME</td>
<td>TECHNOLOGY</td>
<td>STATUS</td>
<td>CLEANUP LEVEL</td>
<td>RATIONALE</td>
<td>NOTES, COMMENTS</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------------</td>
<td>--------------------------------------------------</td>
<td>---------------------------------</td>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
BTEX: 886 ppb ND (IL 0.2) MTBE: 15 ND  
Five air sparging vertical wells total 70 ft. 10 monitoring wells. Plume 270 ft long, 210 ft wide and 25 ft deep. Reach ND 3.5 months after start. Confirmation samples will be required for closure. System will be run for one more quarter. Quarterly sampling required. Costs: Investigation and design $30K, Installation and startup $150K, monthly operation, maintenance and monitoring costs $60K. |
| 16. Petro & Pantry Grantville, Kansas | SVE with air sparging Petroleum hydrocarbons | Closure Criteria developed, remedial action ongoing | Ground Water:                   | MCL's based on Kansas Action Levels Reached cleanup levels in six months. Original plume 360 feet in diameter. | System operational since 4/98. Ground water has been nondetect for one quarter but the SVE system concentrations are still at 100 ppm. Will run for one quarter, shut down for a quarter, then restart. Will require more sampling before closure. Current quarterly monitoring. Costs including two years of O&M are estimated to be approx. $240,000. Levels: Initial Current (12/98)  
Benzene 6000 ppb ND  
MTBE 337  
Naphthalene 655 ND  
12 SVE wells, 4 air sparging wells and 12 monitoring wells. |
## In Situ Bioremediation
### Closure Criteria Focus Group
#### Survey Results Summary

<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>LOCATION</th>
<th>TECHNOLOGY</th>
<th>CONTAMINANTS</th>
<th>STATUS</th>
<th>CLEANUP LEVEL</th>
<th>RATIONALE</th>
<th>NOTES, COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Kansas Soldier's Home</td>
<td>Fort Dodge, Kansas</td>
<td>SVE, BTEX with P&amp;T system</td>
<td>Benzene: 5 ppb, Toluene: 1000, Ethylbenzene: 680, Total Xylenes: 440, Naphthalene: 143</td>
<td>Closure Criteria developed, site to be closed after confirmation sampling</td>
<td>Ground water: MCL's based on Kansas Action Levels. Original plume 500 ft. in diameter.</td>
<td>System consists of 22 monitoring wells, 5 SVE wells, and 6 ground water extraction wells. Operated from 10/93 to 11/95 then shut in with non detect in vadose and saturated zones. Date: BTEX ppb 10/93 38580 4/96 5.96 7/95 8.15 10/95 ND</td>
<td>Monthly monitoring required during operation. Recently restarted SVE with 10 ppmv then ND after 1.5 hours. Will take confirmation boring samples to officially close. Costs: $200,000</td>
</tr>
<tr>
<td>18. Davis Transmitter</td>
<td>Davis, California</td>
<td>SVE, Biovent Diesel, solvents</td>
<td>Closure Criteria developed, action started.</td>
<td>Interim ROD 2/96: PCE 500 ppbv, other VOCs reduced to level where no longer acting as a continuing source to groundwater.</td>
<td>Equilibrium established between groundwater at MCL for PCE (5 ppb). Cleanup goal is MCL times Henry's Constant</td>
<td>SVE system for chlorinated area; biovent for diesel area; groundwater pump and treat Chemical Initial Current Groundwater: PCE 2000 ppb 200 ppb TCE 2000 ppb DCE 200 ppb 120 ppb Soil gas: PCE 40,000 ppbv 100 TCE 2,400 100 DCE 1,000 25 System start in June 1995, estimate 5-10 year duration.</td>
<td></td>
</tr>
</tbody>
</table>
### In Situ Bioremediation

#### Closure Criteria Focus Group

#### Survey Results Summary

<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>TECHNOLOGY</th>
<th>CONTAMINANTS</th>
<th>STATUS</th>
<th>CLEANUP LEVEL</th>
<th>RATIONALE</th>
<th>NOTES, COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Building 406, Offutt AFB, Omaha, NE</td>
<td>Bioventing</td>
<td>BTEX</td>
<td>Action started, closure criteria developed</td>
<td>By respiration tests: want to see oxygen utilization rates decrease. By soil gas: BTEX nondetect. Closure plan to be submitted to NDEQ.</td>
<td>Decrease in oxygen utilization rates will indicate cleanup is complete. Will confirm with soil gas and respiration tests.</td>
<td>System start October 1993. Respiration tests and soil gas conducted annually. Will run system for one more year and submit closure plan to NDEQ. One blower: current 16 CPM Four vent wells, 3 vapor monitoring wells. Soil gas: Chemical 10/93 11/96 TVH: 26,000 ppmv 860 Benzene: 370 0.004 Degradation Rate: Start: 1,000-23,000 mg/kg/yr 11/96: 99-300 mg/kg/yr Oxygen utilization rate: Start: 0.4-10.2 %/hour 11/96: 0.04-1.4 %/hour Oxygen (percent): Start: 0-20 11/96: 0-10.2</td>
</tr>
<tr>
<td>20. Tyndall AFB, Florida</td>
<td>Bioventing, petroleum hydrocarbons</td>
<td>Pilot study</td>
<td></td>
<td></td>
<td></td>
<td>200 day pilot study: initial TRPH max. In two test plots was 6,100 and 7,700 mg/lqg. Average reduction was 2,000 mg/kg TRPH (40%) with BTEX reduced by 90%</td>
</tr>
<tr>
<td>21. Confidential Mississippi</td>
<td>Natural Attenuation, Solvents</td>
<td>Operational</td>
<td>Vinyl Chloride 2 mg/l (MCL)</td>
<td>Maximum contaminant level for vinyl chloride</td>
<td>11 monitoring wells. Cleanup standard will be reached by 2004 based on computer simulation (MODFLOW MT30)</td>
<td></td>
</tr>
</tbody>
</table>
In Situ Bioremediation  
Closure Criteria Focus Group  
Survey Results Summary

<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>TECHNOLOGY</th>
<th>STATUS</th>
<th>CLEANUP LEVEL</th>
<th>RATIONALE</th>
<th>NOTES/COMMENTS</th>
</tr>
</thead>
</table>
| 22. Koch Industries, Wichita  
   Kansas                  | Natural attenuation, solvents  
   Closure criteria developed, remedial action started | Established 1/5/09  
   Plume will be allowed to naturally attenuate within site boundary.  
   MCLs are preserved as final closure goals.  
   Compliance wells (29) downgradient to be monitored quarterly.  
   If detects >MCL, re-evaluate. If >4X MCL, contingency actions to contain and reduce contamination will be implemented.  
   TCE MCL 5 ppb  
   1,1,1-TCA 200 ppb  
   Benzene 5 ppb | Maximum initial levels include acetone 170 ppm  
   TCE and degradation products 31 ppm,  
   1,1,1-TCA and degradation products 34 ppm and benzene 4 ppm. The closure criteria rationale is based on the site investigation, risk evaluation, groundwater flow and modeling which suggests that, with the carbon sources available, the migration of contaminants had reached or was nearing equilibrium.  
   There are no direct or immediate health threats. | 14 compliance wells installed in April 1999, and will be sampled quarterly indefinitely. Seven additional wells in the plume will be monitored semi-annually to document changes in contaminant location and concentration. For closure, sampling must document that no contamination is detected at or above the MCL in four consecutive, equally spaced sampling episodes over a period no less than two years. |
| 23. DDT Maintenance  
   Detroit, Oregon         | BTEX, Natural Attenuation  
   Closure Criteria reached, site closed | Initial:  
   Benzene 5 ppb  
   Naphthalene 28 ppb  
   Final:  
   Benzene 3.9 ppb  
   Naphthalene 150 ppb  
   Vapor phase Benzene 23 ppb  
   Outside air Benzene 12,000 ppb | Initial: MCL's for ground water  
   Final: 10-6 risk plus institutional controls and deed restrictions (site specific with no ground water targets | Eleven monitoring wells.  
   Initial benzene 3,000 ppb and naphthalene 1,000 ppb in ground water.  
   Current levels 250 ppb and 20 ppb respectively. Monitoring demonstrated plume reduction, and Oregon DEQ reduced closure criteria to the outside air standard of 12,000 ppb. Naphthalene closure level of 150 ppb represents 10-6 risk level.  
   Required quarterly sampling for 4.5 years, then semi-annual for last 1.5 years. |
<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>LOCATION</th>
<th>TECHNOLOGY</th>
<th>CONTAMINATES</th>
<th>STATUS</th>
<th>CLEANUP LEVEL</th>
<th>RATIONALE</th>
<th>NOTES, COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>24. Steve's Standard Great Bend, Kansas</td>
<td>Natural Attenuation (enhanced), BTEX</td>
<td>Closure criteria developed, action started</td>
<td>Ground Water: Benene: 5 ppb Toluene: 1000 Ethylbenzene: 680 Total Xylenes: 440 Naphthalene: 143</td>
<td>MCL's based on Kansas Action Levels. Original plume 375 by 500 ft.</td>
<td>injected oxygen releasing compound (ORC-2325 lbs) in 115 Geoprobe borings in July and August 1998. 20 piezometers were also installed. Total BTEX in most contaminated monitoring well measured 13,230 ppb at start. During first quarterly sampling in 11/98 BTEX had decreased to 1,084 ppb. It is estimated that it will take three to four years to closure. Ground water must be below MCL's for at least four quarters. Total costs are estimated to be $95,000.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D

Soil Gas Data to Define the Presence of NAPL
The Use of Soil Gas Data to Obtain Soil VOC Concentrations

and

To Identify the Presence of NAPL

by

Harold W. Bentley
Hydro Geo Chem, Inc.
6905 E. Ocean Blvd
Long Beach, California 90803

Gary R. Walter
Hydro Geo Chem, Inc.
1430 N. 6th Avenue
Tuscon, Arizona 85705
The Use of Soil Gas Data to Obtain Soil VOC Concentrations

and

To Identify the Presence of NAPL

1. Conversion of Soil Gas Concentrations to Soil Concentrations

The concentration of a VOC in soil gas can be converted to its total concentration in the soil by considering the equilibrium laws governing the partitioning of the VOC between the gas, liquid, and solid phases. The reasoning and methodology are as follows:

Unless a separate liquid phase of VOC, i.e. a NAPL, is present, the soil gas concentration is controlled by the distribution of the VOC between the soil, water and the soil organic matter. If the moisture content in the soil is greater than 5%, normally the case, the vapor phase contaminant concentration will be controlled by its gas water distribution coefficient, the Henry’s Law coefficient (H). The Henry’s Law coefficient can be written in its dimensionless form, H_0. The dimensionless Henry’s Law coefficient relates the concentration of a compound in the vapor phase to its concentration in the aqueous phase.

\[ H_0 = \frac{C_g}{C_w} = \frac{H}{RT} - \frac{P_v}{S} \]  \hspace{1cm} (1)

Where:

- \( H \) is the Henry’s Law Coefficient
- \( R \) is the ideal gas constant
- \( T \) is degrees Kelvin
- \( P_v \) is the VOC’s vapor density (the vapor pressure of the pure liquid expressed as mass/unit volume)
- \( S \) is the water solubility

The aqueous-phase concentration will in turn be controlled by the distribution of contaminants between water and the solid soil matrix. This distribution is governed by \( K_D \), the water-solid distribution coefficient. Rarely is the direct distribution of contaminants between the gas and solids important.

If the water-solid distribution is controlled by adsorption onto organic carbon, which occurs above organic carbon concentrations of approximately 0.001 (fraction), (Chiu and Shoup, 1985) the water-solid distribution coefficient is:

\[ K_D = \frac{C_s}{C_w} - \frac{((K_{OC})(%OC)/100)}{100} \]  \hspace{1cm} (2)

Where:

- \( C_s \) is the concentration in the solid (mass VOC/mass solids)
- \( C_w \) is the concentration in the water (mass VOC/volume water)
- \( K_{OC} \) is the water-organic carbon distribution coefficient

(D - 2)
\( F_{oc} \) is the fraction, by weight, of organic carbon in the soil.

The total soil VOC concentration \((M/L^3)\) is the sum of the mass/unit volume in each of the three phases.

\[
C_t = C_e P_b + C_w \theta_w + C_g (\theta_r - \theta_w)
\]

(3)

Where \(C_g\) is the concentration in the gas (M/V air), \(C_t\) is the total concentration in the soil (M/V (bulk volume soil)), \(P_b\) is the bulk dry soil density (M/V solid), \(\theta_r\) is the total porosity, and \(\theta_w\) is the water filled porosity.

The ratio of a VOC's total concentration in the soil gas to its concentration in the soil is given by substituting (1) and (2) and (3) and dividing the bulk density \((p_b)\) to convert soil concentration units from mass/volume to mass/mass:

\[
C_t/C_g = (K_{oc}/H_0) \left( \theta_r/H_0 P_b \right) (\theta_r - \theta_w)/P_b
\]

(4)

Where \(C_t\) is the total concentration in the soil (M/V).

Table 1 represents an example of the results of using (4) to relate soil gas and soil concentrations. For each of the compounds listed, a soil gas concentration of 100ug/L was converted to the equivalent soil VOC concentration in ug/kg. The soil parameters utilized in the calculation were \(f_{oc}\) (fraction) = 0.005; total porosity (fraction) = 0.40; volumetric moisture content (fraction) = 0.2; and dry soil bulk density (gm/cm \(^3\)) = 2.00.

<table>
<thead>
<tr>
<th>Compound</th>
<th>(K_{oc}) (ml/g)</th>
<th>Henry's Coefficient (H)</th>
<th>(H_0^*) (H/RT)</th>
<th>(K_D) (mg/L)</th>
<th>Sgas-Soil Conversion Factor</th>
<th>Soil Gas Conc. (ug/L)</th>
<th>Soil Conc. (ug/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCL4</td>
<td>110</td>
<td>2.41E-2</td>
<td>1.0</td>
<td>0.55</td>
<td>0.75</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>Chloroform</td>
<td>31</td>
<td>2.87E-2</td>
<td>0/119</td>
<td>0.155</td>
<td>2.24</td>
<td>100</td>
<td>224</td>
</tr>
<tr>
<td>1,1 DCA</td>
<td>30</td>
<td>4.31E-3</td>
<td>0.179</td>
<td>0.15</td>
<td>1.50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>1,2 DCA</td>
<td>14</td>
<td>9.78E-3</td>
<td>0.047</td>
<td>0.07</td>
<td>10.2</td>
<td>100</td>
<td>1020</td>
</tr>
<tr>
<td>1,1 DCE</td>
<td>65</td>
<td>3.40E-2</td>
<td>1041</td>
<td>0.325</td>
<td>0.401</td>
<td>100</td>
<td>40.1</td>
</tr>
<tr>
<td>cis 1,2</td>
<td>49</td>
<td>7.58E-3</td>
<td>0.315</td>
<td>0.245</td>
<td>1.2</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>DCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trans 1,2</td>
<td>59</td>
<td>6.56E-3</td>
<td>0.273</td>
<td>0.295</td>
<td>1055</td>
<td>100</td>
<td>155</td>
</tr>
<tr>
<td>DCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,1,1 TCA</td>
<td>155</td>
<td>1.70E-2</td>
<td>0.707</td>
<td>0.775</td>
<td>1.33</td>
<td>100</td>
<td>134</td>
</tr>
<tr>
<td>TCE</td>
<td>126</td>
<td>9.10E-3</td>
<td>0.379</td>
<td>0.63</td>
<td>2.03</td>
<td>100</td>
<td>203</td>
</tr>
<tr>
<td>PCE</td>
<td>364</td>
<td>2.59E-2</td>
<td>1.08</td>
<td>1.82</td>
<td>1.88</td>
<td>100</td>
<td>188</td>
</tr>
</tbody>
</table>

(D - 3)
| Vinyl Chloride | 57   | 8.19E-2 | 3.41  | 0.285 | 0.212 | 100  | 21.2 |
| Benzene       | 83   | 5.59E-3 | 0.233 | 0.415 | 2.31  | 100  | 232  |
| Ethyl Benzene | 1100 | 6.43E-3 | 0.267 | 5.5   | 19.4  | 100  | 1940 |
| Toluene       | 300  | 6.37E-3 | 0.265 | 1.5   | 5.86  | 100  | 586  |
| Xylene        | 240  | 7.04E-3 | 0.293 | 1.2   | 4.53  | 100  | 453  |

*Roy & Griffin, 1989 – 1,1,1 TCA - *Montgomery & Welkom, 1990 – all others

It can be shown by sensitivity analysis of (4) that for all but the most water-soluble compounds, the ratio of soil gas to total soil concentration is most sensitive to Kd, next to Ke, and that the other parameters have relatively little effect. Thus, for all but the most quantitative applications, the soil parameters important in calculating the conversion of soil gas concentration to total soil concentration is total organic carbon. Reasonable estimates of moisture content, porosity, and bulk density, the additional soil parameters, would be sufficient for most purposes.

2. Predicting the Presence of NAPL from Soil Gas Concentrations

Equation 4 is valid in most soil gas applications, but can under predict a total soil concentration in cases where a separate non-aqueous liquid phase is present. The total VOC concentration is then a function of the VOC concentration in the NAPL, and the amount of NAPL in the soil. In such a case, although Equation 4 continues to account for the VOCs partitions into soil, water, and soil gas, it does not account for the VOCs dissolved in the NAPL. Where NAPL is present, the prediction of soil VOC soil concentrations from soil gas concentrations is not possible because vapor pressure of a VOC in the NAPL is a function of its concentration in the NAPL and the amount of NAPL is generally unknown.

When a VOC concentration in the NAPL is high, its distribution between the NAPL and the gas phase can be estimated by Rault’s Law.

\[
C_{v(i)} = (P_s)(X_i) 
\]

(5)

Where \( P_s \) is the vapor density (pure-compound vapor pressure0 of the VOC and \( X_i \) is the mole fraction of the \( i \)th VOC

The sum of the mole fractions of compounds making up a NAPL (or any liquid0 is equal to 1.

\[
\sum_{i=1}^{n} X_i = 1.0
\]

(6)

Where \( n \) is the number of compounds in the NAPL.

Assuming the NAPL is composed of VOCs, that is, each of the dissolved compounds has a
reasonable vapor pressure, the substitution of (5) into (6) yields.

\[ \sum_{i=1}^{N} \frac{(C_g) (i)}{(P_s) (i)} = 1 \]  
(7)

Thus, in a soil NAPL zone where NAPL is composed of VOCs, the sum of the quotients of soil gas concentrations divided by their respective pure-compound vapor pressure should approach 1. However, a lower than the theoretical value of 1.0 for the summation in (7) should be used to indicate the presence of a NAPL in unsaturated soils. In water saturated soils, because of attenuation by advective and diffusive processes, only 1% of the saturated solubility of a ground water contaminant is the criterion used to determine the presence of NAPL in ground water (Feenstra and others, 1991). Soil gas is less likely to be attenuated by advective processes, and the diffusive transport of a gas borne compound is much more effective than that of a compound dissolved in water, both processes leading to a larger zone of detection for soil gas sources. Thus a larger criterion than the 1% of the theoretical value is appropriate. We suggest, based on observations at a number of soil gas sites that 10% of the theoretical value be used to determine that a NAPL as present at a soil gas sampling location. The appropriate criterion, therefore, is:

\[ \sum_{i=1}^{n} \frac{C_g (i)}{p_s (i)} \geq 0.1 \]  
(8)

As an example of the use of this criterion, suppose that the soil gas data obtained at a point location are:

- PCE = 2,500 ug/l
- TCE = 4,200 ug/l
- Cis 1,2-DCE = 10,000ug/l

The calculations utilizing Equation 8 are summarized in Table 2.

<table>
<thead>
<tr>
<th>Soil Gas Analyte</th>
<th>Vapor Pressure (mm @ 20°C)</th>
<th>Molecular Weight (g)</th>
<th>Conversion Factor [ug/(mm<em>î</em>g)]</th>
<th>Vapor Density $p_s$ (ug/l)</th>
<th>Observed Concentration $C_g$ (ug/l)</th>
<th>$C_g/p_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCE</td>
<td>14</td>
<td>165.8</td>
<td>54.7</td>
<td>127,000</td>
<td>2,500</td>
<td>0.02</td>
</tr>
<tr>
<td>TCE</td>
<td>19</td>
<td>131.4</td>
<td>54.7</td>
<td>137,000</td>
<td>4,200</td>
<td>0.03</td>
</tr>
<tr>
<td>1,2 CIS DCE</td>
<td>180</td>
<td>97</td>
<td>54.7</td>
<td>955,000</td>
<td>10,000</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Sum of $C_g/p_s$ 0.06

(D - 5)
According to this calculation, the soil gas concentrations divided by their respective pure-solvent vapor pressure sum to less than 0.1. Thus the NAPL is not present where this soil gas probe was located, and the concentrations of PCE, TCE, and 1,2 cis-DCE at this location can be calculated by the methods summarized in Table 1.

References:


APPENDIX E

Alternative Closure Criteria
Based on Technology Limits
Alternative Closure Criteria Based on SVE Technology Limit

As an alternative closure criteria for a site, where closure criteria (typically MCL-based) cannot be achieved before reaching concentration asymptote, the following pulsed mode operation between 6 to 12 months has been implemented by California Department of Toxic Substance Control.

1. Define the Asymptote: The concentration of extracted VOC typically decreases rather quickly within several weeks (up to a few months) to a concentration asymptote. The asymptote should be defined where the VOC concentration, in combined extracted vapor, does not vary by more than 5 - 10% during four consecutive weekly monitoring events. Typically a FID is used for monitoring.

2. Optimize Recovery: When the VOC concentration (and mass removal rate) near the asymptote, SVE operation should be optimized by:
   1. Increasing the flow from the extraction wells, with the higher VOC concentrations, by shutting down the wells with low VOC concentrations, or
   2. Adjusting blower/total extraction rates to maximize the rate of contaminant removal.

The optimization efforts should start from the beginning of full scale operation, however, it will become particularly important near the asymptote because the optimization will extend the time to reach the asymptote. This optimization effort should be documented in the closure/post closure report.

3. Pulse-Mode Operation: Pulsed mode operation should begin once the asymptote is reached (see A above). The process is described below:
   1. The SVE unit is temporarily shut down.
   2. The criterion for assessing rebound should be based on undisturbed soil gas (as opposed to diluted soil gas concentrations at the blower inlet) concentrations obtained from SVE extraction and monitoring well on a weekly basis. Undisturbed/undiluted soil gas samples will represent equilibrium condition and also will tell us how close we are to the closure criteria.
   3. Document VOC rebound as the mean value of the soil gas concentration from extraction and monitoring wells within the radius of influence.
   4. When VOC concentrations reach 200% of the stabilized asymptote the SVE unit should be restarted and extraction should continue until the extracted gas restabilizes at the initial asymptotic concentration. (e.g. if the initial asymptotic concentration was 20 ppmv, the SVE unit should be restarted when the mean of the undisturbed equilibrium soil gas concentration reaches 40 ppmv.) This will avoid unnecessary restarts.
   5. Continue this cycle for 6 - 12 months.
4. Confirmation Sampling: After a period of pulsed-mode operation, site closure should proceed as follows:

1. Soil and gas confirmation sampling will be conducted at the end of the SVE operation to assess residual VOC concentrations. If closure criteria is based on soil VOC concentrations, soil gas screening data can be used to minimize the number of samples to be collected.

2. The closure/post closure report should be prepared and include, at a minimum:
   - Documentation of the optimization efforts described above,
   - confirmation sampling results,
   - estimated total VOC mass in the vadose zone before SVE treatment compared to the total estimated mass of VOC removed during SVE operation, and
   - through the SVE operation (with the pulsed-mode) period the plots of:
     a. ....... VOC concentration vs. Time, and
     b. ....... Cumulative extracted VOC mass vs. Time

3. Assess the residual contaminant impact to groundwater and;
   - Install post closure monitoring, or
   - estimate residual contaminant concentration risk, or
   - apply deed restrictions where appropriate.