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A/M AREA VADOSE ZONE MONITORING PLAN (U)

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LIST OF ACRONYMS AND ABBREVIATIONS

ACL	Alternate Contaminant Level
A/M Area	Administration and Metallurgical fabrications area
AMH	A/M Area Horizontal Well
B&K	Bruel & Kjaer Photoacoustic Infrared Sensor
Bgs	below ground surface
cc	cubic centimeter
cm	centimeters
CPT	Cone Penetrometer Test
CVOC	Chlorinated Volatile Organic Compound
CY	Calendar Year
DAF	Dilution and Attenuation Factor
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	U.S. Department of Energy
DUS	Dynamic Underground Stripping
DWS	Drinking Water Standard
EPA	U.S. Environmental Protection Agency
ft	feet
g	gram
gal	gallon
GC	Gas Chromatograph
GW	Groundwater
HAS	Hollow Stem Auger
hr	hour
IDW	Investigation Derived Waste
in.	inch
kg	kilogram
km	kilometer
l	liter
lb	pound
LDL	Landfill Lower Disposal Limit
LFR	Low-Frequency Resistive

LIST OF ACRONYMS AND ABBREVIATIONS continued

m	meters
MCL	Maximum Contaminant or Concentration Level
MHT	M-Area Groundwater Monitoring Well for an AMH
MHV	M-Area Vadose Zone Monitoring Well for an AMH
mi	miles
MSB	M-Area Groundwater Monitoring Well
MVC	A/M Area Vadose Zone Monitoring Well
MVE	A/M Area Vapor Extraction Well
PCE	Perchloroethylene; tetrachloroethylene
ppb	parts per billion
ppm	parts per million
ppbv	parts per billion in vapor volume or mole basis (ηl/l, ηmole/mole)
ppmv	parts per million vapor volume or mole basis (μl/l, μmole/mole)
ppbw	parts per billion weight basis (ηg/g)
ppmw	parts per million weight basis (μg/g)
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RF	Radio-Frequency
ROI	Radius of Influence
SCDHEC	South Carolina Department of Health and Environmental Control
scfm	standard cubic feet per minute
SPSH	Six Phase Soil Heating
SRL	Savannah River Laboratory
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SVE	Soil Vapor Extraction
SVEU	Soil Vapor Extraction Unit
TCA	1,1,1-Trichloroethane
TCE	Trichloroethylene
TCLP	Toxicity Characteristic Leach Procedure
VOC	Volatile Organic Compound

LIST OF ACRONYMS AND ABBREVIATIONS continued

VZMP	Vadose Zone Monitoring Plan
WSRC	Westinghouse Savannah River Company
yrs	years
ZOI	Zone of Influence

Executive Summary

Characterization and monitoring data from implementation and the first two and one half years of vadose zone remediation operations indicate that this activity has substantially improved the performance of the A/M Area Groundwater Corrective Action Program[1]. During this period, vadose zone remediation removed approximately 225,000 lbs (100,000 Kg) of chlorinated solvents (CVOCs) from the subsurface. Further, vadose zone remediation system operation increased the overall CVOC removal rate of the A/M Area Groundwater Corrective Action by 300% to 500% during this period versus the groundwater pump and treat system alone.

Various support activities have been performed to support operation and documentation of performance of the vadose zone remediation system. These activities address performance of existing systems (contaminant distributions, zone of influence, and process monitoring data), evaluation of suspect sources, evaluation of alternative/enhancement technologies, and initial development of remediation goals. In particular, the most recent A/M vadose zone remediation support activities (described in WSRC-RP-97-109) were completed and the results provide key documentation about system performance. Summary conclusions from the various activities are provided below:

- Due to operational changes, the total mass removal by the SVE systems in 1997 (approximately 118,000 lbs or 54,000 Kg) was more than twice the removal in 1996. The high 1997 extraction rates were decreasing late in the year, consistent with expected clean-up behaviors and with a few specifically identified operational issues. Planned actions to address operational limitations (e.g.,

[1] The A/M Area Groundwater Corrective Action Program is a comprehensive environmental restoration effort under the Resource Conservation and Recovery Act (RCRA). The overall program addresses clean up of soil and groundwater contaminated by historical releases and migration of chlorinated industrial/degreasing solvents (CVOCs) in the A/M Areas of the Savannah River Site (SRS). The program is being performed by SRS with regulatory oversight provided by the South Carolina Department of Environmental Control (SCDHEC) and with input from the Environmental Protection Agency, SRS Citizens Advisory Board, SRS Environmental Advisory Committee, National Academy of Sciences, and others. In addition to vadose zone remediation of CVOCs, the RCRA A/M Area Groundwater Corrective Action addresses the residual un-dissolved ("DNAPL") solvent, and contaminated groundwater throughout A/M Area (e.g., central sector, southern sector, western sector, and the northern/Crouch Branch sectors).

redevelopment of poorly performing wells) were identified. The zone of influence testing, combined with updated maps of contaminant distributions, indicates that the existing SVE systems are adequately addressing contamination at known sources.

- Selected manhole locations along the M-Area Process Sewer were investigated using a cone penetrometer and soil gas screening at selected depths. The data indicated that the highest concentrations were present near other known sources. A general pattern of "spot" contamination associated with the manholes was not observed.
- Three types of alternative and/or enhancement technologies were discussed: accelerated removal methods, system modifications, and polishing techniques. Technologies to accelerate clean up in the highest concentration sources areas include in situ heating methods using electrical resistance or steam heating, and pneumatic fracturing. The system modifications discussed ranged from innovative well development methods, to installation of packers and new wells. The vadose zone polishing technology discussed was passive SVE using barometric pumping. All of the alternative technologies discussed were incorporated as appropriate into the development of remediation goals and/or into recommendations for improving operation of the SVE units at existing sites.

Overall, the various studies that have been performed indicate that the A/M Area vadose zone remediation is performing well. Further, integration of the results from the support activities provides the basis for developing a clear and consistent flowchart for A/M Area vadose zone remediation goals. The flow chart is comprehensive, documenting historical and proposed A/M Area vadose zone activities. Following screening, initial soil vapor extraction (SVE) operation at known source areas is implemented. This is consistent with the current presumptive remedy concept for CVOCs in moderate to high permeability sites. Subsequent activities (characterization, monitoring and determination of clean-up status) are performed in stages. For clean up, three to four stages are proposed: active SVE, enhanced SVE if needed, passive SVE using barometric pumping, and "clean." Clear definition of the stages and the conceptual decision pathway defines the number and type of decision criteria to be developed.

The flow chart provides a conceptual path to completion for A/M Area vadose zone clean-up. The flow chart also serves as a tool to facilitate regulatory and management decisions. For example, once the conceptual approach of the flow chart is agreed, the small number of specific clean up targets associated with the specific remediation goals/claims are developed and negotiated in turn. We propose that the flowchart structure is general in nature (applicable to many sites), the specific decision criteria are site specific. These site-specific criteria incorporate nearby remediation activities (e.g., underlying groundwater clean-up, DNAPL remediation, etc.) and geology/technical performance data, as well as regulatory precedents. Initial development of decision criteria, and alternatives, are discussed in the sections on regulatory goals. The flowchart is an important and distinct development that will facilitate the general performance of the A/M Area Groundwater Corrective Action, and the particular performance of A/M Area vadose zone remediation.

1.0 INTRODUCTION AND OBJECTIVES

The historical information on contaminant concentrations, vadose zone remediation system operations and zone of influence, indicate that the vadose zone remediation has substantially improved the effectiveness of the A/M Area RCRA Groundwater Corrective Action. The concentration data suggest that the chlorinated solvents released to the subsurface have migrated downward and are currently trapped in the medium- to fine-grained sediments underlying the original sources. Further, the geologic stratification in the vadose zone of A/M Area creates substantial lateral zones of influence for the soil vapor extraction operations, primarily as the result of the capping provided by the shallow interbedded clays and silts which prevent rapid air infiltration or short circuiting from the surface. The primary sources have already been identified, and characterization and evaluation to date suggests that the zone of influence of the vapor extraction systems can provide adequate coverage of the contaminants with the current extraction wells or with minor modifications to the current wells. The total mass extracted more than doubled for CY-97 over the previous calendar year. In two and one-half years of operation through 1997, the vadose zone remediation units have removed and destroyed approximately two thirds as much solvent from the subsurface as the groundwater pump and treat system has over the course of twelve years. However, the recent increase in extraction efficiency is due in large part to increases in the allowable permit limits for air emissions and to decreases in the down-time associated with equipment failure or maintenance. The general trend for extraction rates near the end of CY-97 and into this year for all the operating units is downward. Current efforts are focused on determining to what extent this trend is based on expected decays in extraction rates due to depletion of residual solvents (i.e. mass transfer limits of low permeable source zones), versus reduced performance due to limits imposed by a particular system component (e.g. well clogging, screen locations, etc.).

The initial indications are promising, suggesting that relatively near term (circa 10 years) clean-up of the vadose zone in A/M Area may be achievable. However, additional data are needed to document the system performance and to optimize the system design to ensure that vadose zone clean-up levels will not impact groundwater above MCLs. This report formulates the approach to be used in the assessment, expansion, and completion of the vadose zone characterization and remedial activities. Parts of what is described in this report were presented previously as a sampling and analysis plan for monitoring and corrective action of the vadose zone (WSRC-RP-97-0109).

The ultimate goal of the vadose zone characterization and remediation program is to identify and remove the residual chlorinated solvents which serve as a source of groundwater contamination. Any plan must, of course, answer the elementary questions as to the location, concentration and movement of the contaminants. The objectives of this plan incorporate these elements and can be broken down into four primary focus areas as follows:

(1) To set remediation goals used to determine when the vadose zone is no longer a significant source for groundwater contamination.
(2) To assess the efficiency and progress of the current system towards source reduction.
(3) To investigate potential and suspect new sources.
(4) To evaluate alternative methods for source reduction.

It would appear that a remediation goal for the first objective could be chosen ad hoc. However, determination of a remediation goal must include information required for, and an understanding of the applicability and limitations of all of the other objectives. Furthermore, the vadose zone program is but one part of the RCRA Groundwater Corrective Action and the determination of the first objective must include an awareness of the more direct groundwater remedial goals and activities planned or in place, e.g., groundwater recovery well grids. The ensuing sections of this document present a discussion of each objective including the methods or tools used in each objective, a brief update on the status of each objective with an analysis of the recent characterization work, and an explanation of the proposed path forward.

2.0 EVALUATION METHODS / TOOLS

2.1 Introduction

Evaluation of the A/M Area vadose zone remedial program involves the use of several investigative tools, many of which are part of routine operations or standard site characterization procedures. In addition, methods for analyzing, manipulating and modeling the data acquired play an integral role in the decision-making processes. This section outlines the basic logic, methods and tools to be used in each of the primary focus areas.

2.2 Remediation Goals

2.2.1 Groundwater Impact

As mentioned previously, the ultimate goal of the vadose zone remediation program for the A/M Area is to remove the residual chlorinated solvents which serve as a source of groundwater contamination. Current South Carolina DHEC regulations require that acceptable maximum soil levels for VOC contamination be determined on a site specific basis. The choice of methods for determining a goal are based on the assumption that at present, the primary transport mode for VOCs to groundwater is through migration of a dissolved aqueous phase. This assumption is supported by depth discrete characterization data of VOC concentrations in the soil. The data show no evidence for residual levels that would support a continuous separate phase with sufficient head to supply free product to the water table. This finding is not surprising, given that releases to the environment were halted more than 15 years ago and remedial activities have been in place for three years. Therefore, the vadose zone no longer serves as a source of dense non-aqueous phase liquids (DNAPL) to the groundwater. However, residual solvent concentrations in the vadose zone suggest that DNAPL remain in the vadose zone retained by capillary forces in the small pores of low permeable layers and can serve as a source of a high concentration aqueous phase. Determination of the clean-up concentration levels for the A/M Area vadose zone will be based on one or a combination of the following methods:

- Analysis of actual core samples chosen from representative locations and strata using the Toxicity Characteristic Leach Procedure (TCLP) or an alternative water soluble fraction (WSF) leaching technique.

- Modeling using the T2VOC code to determine the time-concentration dependence of precipitation infiltration and vapor transport to the groundwater underlying vadose zone sources.

TCLP is an established EPA method designed to simulate the conditions encountered in landfills (EPA, 1986). Leaching results from different strata must include calculated dilution and attenuation factors (DAF) based on continued transport modes to the water table. For example, water that has leached through a shallow clay layer must travel through several sand and clay zones prior to reaching the water table. The DAF can be chosen based on simple one dimensional models or by establishing DAF with the T2VOC model used in the second method. T2VOC is a three-dimensional multiphase contaminant transport code that uses the integral finite-difference method. It assumes local equilibria between phases versus mass transfer limitations, and as such, is considered to provide "best case" clean-up times when used to model remediation processes. Therefore, for its proposed use here, it would be considered to provide a conservative or "worse case" estimate for migration to groundwater. The code was written by R.W. Falta (1992, 1995), currently at Clemson University, who has and continues to work with site technical personnel in support of DNAPL modeling efforts for the A/M Area. The code was developed with DOE funding, meets DOE quality assurance specifications, and has been validated extensively with experimental data. Such a dual method approach combining a standardized leach procedure corrected for factors which reduce mobility is a typical risk-based approach for determining acceptable endpoints in soils (American Academy of Environmental Engineers, 1997). With either technique, approved characterization data is required to obtain two or three dimensional grids of pertinent transport parameters, geochemical and geophysical parameters, contaminant concentrations, and estimates of contaminant phases.

Further discussions on the use of these two methods are presented in the ensuing chapters. Discussion of the type of characterization and contaminant distribution data is presented below and in ensuing chapters and appendices.

2.2.2 Vapor Extraction System Limits

In addition to goals associated with groundwater impact, there is a goal, or essentially, a limitation to the effectiveness of a given technology. This goal is based on physical and/or economic factors used to determine the feasibility of continued operation of a given technology. The chosen limit is precluded by other evaluations discussed below relative to observed poor extraction efficiency due to the inadequate performance of a system component. The current limit for the SVEU systems of 40 lbs/week (ref-RCRA Part B Renewal Application, Rev.4, 1996) is based on a simple comparison with observed asymptotic removal rates from groundwater recovery wells in the A/M Area that underlie the vadose zone sources. This limit will continue to be used as a flag indicating a need for additional investigations or evaluations. However, this number may be changed based on new characterization data or modeling as discussed elsewhere in this document.

2.3 Current System Evaluation

2.3.1 Off-gas and Soil-Gas Analysis

As part of on-going routine operations of the soil vapor extraction units, vapor samples are taken from the extraction units, extraction wells, and selected monitoring wells. A description of the sampling methods and analytical techniques are provided in Appendix A. Samples are taken at the extraction units on a weekly basis. These results are used to determine mass removal rates, the total mass removed, and to measure performance relative to goals discussed above. Current efforts are in place to reduce this sampling frequency to every other week based on historical behavior and the use of on-line screening sampling and analysis. Samples at individual extraction and monitoring wells are taken on an approximate annual frequency depending on the unit's performance. For example, when a unit's extraction rate reaches a minimum limit or exhibits a sudden drop.

2.3.2 Zone of Influence

Field Operations: Field tests are conducted on selected individual extraction wells and monitored using multiple observation wells located at different radial distances. Drawdown curves are obtained by monitoring changes in subsurface pressures at the observation wells and correcting for barometric conditions. Monitoring is conducted while the extraction well is stepped through two or three flow rates until an apparent steady state is reached at each condition. A more thorough description of the procedure used in field operations is provided in Appendix B.

Modeling Calculations: The transient pressure drawdown data is fitted using an analytical model GASSOLVE (Falta, 1996). The model calculates the permeability of the formation based on measured subsurface and pumping parameters. A nonlinear optimization routine is used to select the permeability, leakage, and anisotropy parameters best fitting the data. The model can fit more than one observation well at similar depths and different radial distances simultaneously. When data is available, multiple observation well fits are performed. The zones of capture, or radii of influence, are estimated by a forward, steady-state, analytical model (modified leaky confining zone with partially penetrating well) using the parameters obtained from the inverse model fits. The upper semi-confining zone depths are chosen based on available lithologic information (core descriptions and/or CPT logs). The zones of capture are determined by assuming that the limit of influence occurs at the distance where the pressure drop caused by the pumping well is less than 4 centimeters (cm) [1.6 inches (in.)] of water (Looney and others, 1991). This minimum drawdown is chosen based on typical observed diurnal barometric fluctuations that the extraction system must exceed to maintain influence.

2.3.3 Contaminant Distribution

There are two primary focus areas associated with evaluation of the contaminant distribution at known source areas:

(1) Determination of the lateral extent of contamination for comparison with predicted or observed capture zones determined above.

(2) Determination of changes in the vertical distribution of contamination for evaluation of the effectiveness of the extraction system relative to system design, alternative remedial actions, or clean-up criteria.

The methods used on-site in the past for evaluation encompass conventional, emerging, or developing characterization techniques. In addition to contaminant distribution, these same techniques are used to acquire lithologic and geotechnical information. The primary methods currently used include direct push techniques with a cone penetrometer test (CPT) truck and rotosonic drilling. CPT was chosen because it is minimally invasive, has a low relative cost, generates little or no waste, and offers the ability to acquire high resolution data in-situ. Rotosonic drilling is used in place of conventional coring techniques because it produces minimal volumes of investigative derived wastes (IDW). A brief listing of the types of sampling and information provided with these methods is given in the Table 2.1. Note that while CPT soil gas is used as a screening tool, soil gas sampling is limited to the more permeable sandy zones. Low permeable zones, which tend to retain higher concentrations of solvents, do not provide a sufficient volumetric flow to obtain a representative sample. A more thorough discussion of these and previous sampling and analysis techniques for characterization is presented in Appendix A.

There have been numerous field investigations in the A/M Area involving a wide variety of characterization techniques (WSRC-RP-97-109). As a result of these investigations, a large base of information can be used to correlate with new data obtained with less rigorous testing procedures. In particular, previous geotechnical and lithological data obtained with standard ex-situ methods on core samples can be correlated to data obtained in-situ using CPT (e.g. sleeve and tip stress ratio to intrinsic permeability). With such correlations, enhanced information can be obtained more quickly at a greater number of locations using CPT. A similar strategy has or is being used in investigations at other waste sites including the groundwater flow modeling for the R-Reactor Area (WSRC-OS-97-00006). To facilitate the development of these correlations as well as the tracking and evaluation of changes in contaminant distribution, a database of previous and current characterization results for the A/M Area vadose zone is being constructed.

Table 2.1 Description of current characterization methods for determining contaminant distribution, geotechnical, and geophysical parameters.

Characterization Method	Sampling	Data Analysis / Information
CPT	+ Electric Tip + Soil Gas + Core at Select Depths	+ Sleeve & tip resistance, conductivity, pore pressure => lithologic x-section / geotechnical parameters + VOC screening profile + VOC profile / core description => lithology / geotechnical parameters
Roto-Sonic Drilling	Continuous Core (split spoon equivalent)	+ Depth discrete VOC profile + core description => lithology / geotechnical parameters

=> Indicates additional information can be obtained through direct laboratory analysis or inferred from correlations with direct measurements.

2.4 Investigation of Suspect Sources

The primary initial objective of the new source characterization will be simple screening at suspect areas for the presence or absence of chlorinated solvents in the underlying vadose zone. The screening will consist of cone penetrometer with soil gas testing down to the water table. The cone penetrometer borings will be completed in the most probable (highest potential concentration) location(s) at each of the suspect source areas. Based on the screening results, a decision will be made to extend the characterization to more rigorous investigations and/or to assess the applicability of a remedial alternative for source reduction. The new A/M Area potential chlorinated solvent sources include:

- Specific sections of the major M-Area processing facilities (313-M, 320-M, and 321-M).
- The manholes of the process sewers in M-Area, as well as those leading to the A-014 Outfall. The manholes will be evaluated as a class (i.e., not all of the manholes will be tested). A representative selection of manholes will be tested along all of the suspect process sewer lines in M-Area.
- Releases in the SRTC area, Maintenance Areas and related A/M Area facilities. Initial investigations at these sources may also include drilling activities associated with groundwater corrective action characterization.

2.5 Evaluation of Alternative Technologies

Alternative technologies to SVE for vadose zone remediation will be evaluated for their applicability towards improving or replacing the current systems. Several different remediation technologies have been tested or implemented at the SRS that offer alternative methods for vadose zone cleanup. In addition, numerous technologies have also been tested at other DOE sites or as part of DoD and EPA programs. The choice and implementation schedule for these alternatives will, of course, be dependent on the results obtained in the other focus areas listed above. The types of alternative technologies can be place into three major categories:

(1) Enhancement Technologies: Applicable when SVE cleanup times or goals are inadequate.
(2) System Design Modifications: Applicable when the current system progress or efficiency is impeded by particular system components.
(3) Polishing Technologies: Applicable when residual contaminant levels can be handled through passive means or monitored natural attenuation.

In addition to alternative remediation techniques, alternative characterization and monitoring methods will also be evaluated. These methods, in large part, are associated with is-situ measurements using CPT to obtain chemical or geophysical information (e.g. moisture probes or chemical probes which use fiber optic techniques including laser induced fluorescence, Raman spectroscopy).

3.0 EVALUATION STATUS AND ANALYSIS

3.1 Introduction

This section presents results and discussions on the status of each focus area including recent characterization and monitoring activities.

3.2 Remediation Goals

3.2.1 Groundwater Impact

A dual method approach using a combination of analytical and modeling techniques was presented in the previous chapter. This section discusses the proposed numerical goals of these methods based on an assessment of current regulatory clean-up criteria and physical arguments.

An underlying factor affecting the decisions for selecting goals is that the vadose zone sources as currently characterized are situated within the recovery grid zone for the central A/M Area groundwater remediation system. Figure 3.1 is a map of the A/M Area outlining the 15 year groundwater recovery zone, the groundwater recovery well network for the M-1 stripper, and the vadose zone soil vapor extraction units (SVEU) and wells. Due in large part to the presence of DNAPL below the water table, the groundwater recovery system is expected to be operating beyond the current anticipated lifetime for vapor extraction. Therefore, goals for vadose zone sources as contributors to groundwater contamination should based on time dependent elements and include concepts similar to groundwater in which the choice of remedial approach is dependent on contaminant location and concentration. For example, groundwater remediation scenarios involve parallel or serial approaches which progress from pump and treat for primary source containment to recirculation wells or enhanced bioremediation at the distal edges of the plume to mixing zone modeling or natural attenuation in or when areas of the plume reach alternate contaminant levels (ACLs). Obviously, remediation goals for the vadose zone would have to be reevaluated and/or altered if successful technologies were found for DNAPL remediation below the water table.

The primary published regulatory clean-up criteria considered as applicable for the vadose zone are based on drinking water standards or risk analysis (ASTM, 1996). They are based on the likelihood of infiltrating precipitation migrating through the contaminated soils to groundwater and include the following:

- EPA Toxicity Characteristic Leach Procedure (TCLP) : Concentrations in leaching solution of 0.5 mg/l for TCE (DWS based) and 0.7 mg/l for PCE (risk based).
- Universal Treatment Standards for Waste Water (SCDHEC E/S Regs. R.61-79.264.40) : 0.054 mg/l for TCE and 0.056 mg/l for PCE.
- RCRA Groundwater Corrective Action : 0.005 mg/l for TCE (MCL) and 0.0007 mg/l for PCE.

These criteria will be used as measures for appropriate clean-up levels proposed in the next chapter.

3.2.2 Vapor Extraction System Limits

There are currently six SVE units operating in the A/M Area. At present, two of the units performance in terms of mass extraction rates have approached or dropped below initial indicator levels for evaluation relative to being either system design limited or approaching extraction technology limits. The units, 782-5M and 782-8M, are both located along the abandoned process sewer which fed the M-Area Basin. Based on existing and new characterization data, the assessment for each unit is as follows:

782-5M – New characterization data is consistent with the assumption that contaminant levels in the sediments near the extraction wells are approaching technology limits.

782-8M – Previous characterization data and current flow rates are consistent with the assumption that the unit is limited by well performance.

The monitoring and characterization data to support these assumptions is presented below. A discussion of the planned activities at these units is presented in the next chapter.

3.3 Current System Evaluation

3.3.1 Off-gas and Soil-Gas Analysis

The routine sampling and analysis results for the SVEUs over the last quarter of 1997 and totals for the calendar year are given in Table 3.1. The total mass removed for 1997 was more than twice that removed in 1996. As expected, the units at the three primary sources, 782-3M (A-014 Outfall), 782-4M (M-Area Seepage Basin), and 782-6M (Solvent Storage Tanks), are the largest and most sustainable producers. However, following initial maximum rates in the early part of the year, all of the units mass extraction rates were decreasing by the last quarter. This trend has continued into the first quarter of 1998. The decreases may be consistent with expected extraction rate decay as the more readily removed residual solvents are depleted from the sediments and the systems approach asymptotic mass transfer limits. While decays in extraction rates may be based on actual geophysical or transport limitations, testing has also revealed problems related to specific well flow rate performance. These wells include MVE-1 (currently clogged) at 782-6M, MVE-4 (currently partially clogged) and MVE-10 (currently clogged) at 782-3M, and AMH-6 (currently clogged) at 782-4M. The impact of the loss of these wells could be significant as the majority are located at the prime source area for each unit. There is a critical need to redevelop or replace these wells to maintain adequate zone of influence and removal of contaminants.

Table 3:1 - SVEU Extraction Performance for 4Q-97 and Year Totals

SVEU	Extraction Rate Range / Average (lb/hr)	No. of Sampling Events	Total Mass Extracted (lbs)	Approximate PCE:TCE Ratio
782-3M	6 – 12 / 8.4	16	61,500	10
782-4M	3 –5 / 4.0	16	24,250	9
782-5M	0.2 – 0.5 / 0.3	16	1,750	1
782-6M	3 – 5 / 3.9	12	26,550	2
782-7M	0.7 – 1.1 / 0.85	5(1)	3,090	> 2
782-8M	0.01 – 0.09 / 0.065	13	550	3

(1) Unit off-line for electrical and injection modifications.

Based on the observed low performance for 782-5M and 782-8M, the following actions were planned and or completed:

- 782-5M: Low concentrations were confirmed with sampling and analysis at individual extraction and monitoring wells. Testing was planned to evaluate the transient and sustained rebound extraction rates following an appropriate shutdown period. Characterization activities with VOC analysis of core were completed to determine residual contaminant levels near the extraction wells.
- 782-8M: Low flow rates were observed from the extraction wells (AMH-4 and AMH-5). The unit is currently shutdown as plans are completed for redeveloping the wells. Based on previous characterization data, significant contaminant concentrations exist in this area. Alternative wells may be installed.

The performance for 782-7M was low because this unit was down a large part of the year for modifications to start air, methane and nutrient injection operations as part of a biostimulation remedial system. When the injection system is operated, this unit will require a separate baseline comparison as it will involve multiple functions associated with vadose zone vapor extraction, groundwater stripping, and in-situ bioremediation.

3.3.2 Zone of Influence

Field tests to determine the zone of influence have been completed at the four major SVEU systems (782-3M, -4M, -5M, and –6M). The parameter estimates and radius of influence (ROI) were determined for the vertical well systems using GASSOLV as described previously. The results are presented in Table 3.2. The results for the middle sandy zones (approximately 70 – 80 ft bgs) for each unit are similar, predicting permeabilities on the order of 20 to 40 darcy and ROIs on the order of 100 to 200 feet. There are greater variances between and within systems at both shallower and deeper depths. These variances are explained by two factors. First, the shallow and deep regions have greater vertical heterogeneity; i.e. there tends to be a higher frequency of clay stringers coupled with sandy or even gravelly strata in these zones. These heterogeneities may not be horizontally continuous and can produce radial boundary conditions that vary with flow rate. Second, these zones are near vertical boundaries, either the surface semi-confining zone or the water table, and as such, are more prone to exhibit prediction limitations inherent in the simple analytical model used. Even with the variability observed in these zones, the lateral extent of contamination is still typically within the calculated ROI. However, previous and recent characterization data as presented below, suggests that the bulk of the residual contamination resides in these upper and lower zones and further evaluation may be warranted. More rigorous models that include vertical stratification may give a better prediction of the observed data. Discussions of alternative modeling techniques are presented in the next chapter.

The zone of influence for the three horizontal well systems are based on vertical well calculations from tests performed on nearby wells for SVEU 782-7M and on direct field test measurements for SVEU 782-4M. As a result of the observed poor well performance of AMH-4 and AMH-5, no testing or estimates were performed for SVEU 782-8M. For SVEU 782-7M, the calculated permeability of 42 darcy and ROI of 300 ft at a flow rate of 500 scfm given by Looney (1991) compares favorably with the calculated results presented in Table 3.2. The tests performed for SVEU 782-4M included monitoring at the water table wells located on the southern, eastern, and northern sides of the M-Area Seepage Basin (MSB-1A, -2A, and –3A respectively). In addition, select vadose zone wells at shallower depths were also monitored at the eastern and northern edges of the basin. All of the deeper observation wells showed drawdowns in excess of 2 inches of water at a typical flow rate of 300 scfm, indicating that the zone of influence extends out beyond the edges of the basin. The horizontal well, AMH-7, is located at a depth of 110 ft. Due to the anisotropy introduced by layered interbedded clays and sands, the vertical zone of influence is more restricted than the horizontal. This was apparent in the low drawdowns (< 1 inch of water) observed for monitoring wells at intermediate depths of 60 to 80 ft bgs. While characterization data presented later suggest that shallow contamination has not spread out from the basin, the current configuration is not likely to affect shallow contamination immediately beneath the basin.

A map illustrating the ROI for each of the extraction wells is given in Figure 3.2. An average ROI of 150 feet is obtained based on predicted or observed values for mid-level flow rates of from 200 to 300 scfm. One exception to the calculated average ROI is observed at MVE-4 located at the A-014 Outfall. An ROI of 50 feet was used for this well based on the average predicted values obtained at low-level flow rates (< 100 scfm) since this well could not sustain flow rates in excess of 100 scfm during testing. In addition, no ROI are given for clogged wells (MVE-1 and MVE-10).

An additional observation was made during the testing of the SVEUs. Many of the primary vapor extraction wells are located within 15 to 30 feet of water table monitoring wells (MSB-31C at 782-3M's MVE-9, MSB-16C at 782-5M's MVE-5, and MSB-23 at 782-6M's MVE-2). The well screens extend above the water table and in some instances beyond the bottom of adjacent extraction well screens. Since the water table wells are not sealed, they offer a means for short-circuiting of surface air which could limit radial influence at or near the water table.

Table 3.2 - Calculated Permeabilities and Radius of Influence (ROI) for Vertical Well Systems

SVE Unit / Extraction Well	Observation Wells	Average Depth (ft, bgs)	Calculated Radial Permeability (darcy)	Flow Rate (scfm)	Calculated ROI (ft)
782-3M / MVE-9	MVC-2A/3A	107	5.7	92	42
				236	> 133(1)
				405	> 133(1)
	MVC-2B/3B	71.5	26.5	92	66
				236	191
				405	280
	MVC-2C/3C	51.5	25.8	92	38
				236	144
				405	228
782-6M / MVE-2	MBC / MTC	49	119	118	< 24(2)
				262	< 50(2)
				369	< 92(2)
	MVC-1A	127	10.5	118	62
				262	113
				369	137
782-5M(3) / MVE-5	MVC-4B	79	36	150	62
				300	106
				400	134

(1) Observed ROI was greater than that predicted by the model parameters
(2) Observed ROI was less than that predicted by the model parameters
(3) Additional model fit parameters provided in WSRC-RP-97-0109. Representative result for middle sand zone presented here for comparison.

3.3.3 Contaminant Distribution

This section presents an up-date of the pre-remedial vadose zone characterization results presented in WSRC-RP-97-0109. The previous results were based on characterization data obtained prior to 1991.

The updated results presented here include data from 1992 to the present. Table 3.3 gives a listing of the areas investigated, the associated extraction unit or site classification, the characterization methods employed, and the primary focus of each investigation. In addition, Figure 3.3 is a map of the areas investigated and identifies the characterization methods used.

Table 3.3 Characterization Investigations, 1992 - 1997

Area Investigated	SVEU / Classification	Characterization Methods (1) [No. of boreholes/wells]	Primary Focus Areas
M-Area Process Sewer	New source	CPT – soil gas [13]	Screening investigation at process sewer manholes
A-014 Outfall	782-3M	CPT – soil gas [3] Rotosonic – VOC core [1]	Lateral extent of and change in vertical contaminant distribution
311-M Solvent Storage Tanks	782-6M	CPT – soil gas / VOC core – 1996 [14/6] Rotosonic – VOC core [2]	Lateral extent of and change in vertical contaminant distribution
M-Basin Process Sewer: North	782-5M	CPT – VOC core [3] Rotosonic – core [1]	Vertical contaminant distribution versus extraction system limit
Central	782-7M	HSA(2) – VOC core[8]and Monitoring wells – soil gas [5] –1993	Change in vertical contaminant distribution
South	782-8M	HSA(2) – VOC core – 1992 [6] & 1993 [17] Monitoring wells – soil gas – 1994 [13]	Change in vertical contaminant distribution
M-Area Basin	782-4M	Rotosonic – VOC core [1]	Lateral extent of and change in vertical contaminant distribution

(1) 1997 characterization work unless date provided
(2) HSA – hollow stem auger

The data includes results obtained in the following reports and recent field activities listed chronologically [when applicable, the corresponding SVEU is provided in brackets]:

- 1992, Unpublished data from "SITE-2" (horizontal well characterization study for AMH-3 and AMH-4): Characterization included core sampling with VOC analysis, description and geophysical logs obtained with hollow stem auger drilling at MHT-15 through MHT-20, and MHM-19. [SVEU 782-8M]

- 1993, Preliminary technology report for in-situ bioremediation demonstration (methane biostimulation), WSRC-TR-93-0670 (Hazen, 1993): Characterization included core sampling for VOC analysis obtained with hollow stem auger at MHC-8 through 15 & soil gas sampling in existing monitoring wells (MHV-1 through 5) [SVEU 782-7M]
- 1993 / 1994, Post-test heating demonstrations, WSRC-TR-93-0459 (Eddy-Dilek, 1993) and WSRC-TR-93-0678 (Eddy-Dilek, 1994): Characterization included core sampling (< 60' bgs) with VOC analysis obtained with hollow stem auger at MHV-20 through 41 and soil gas sampling (MHV-20 through 29, MHV-30, MHV-40, and MHV-41) [SVEU 782-8M]
- 1996, Solvent Storage Tanks (311-M): Unpublished data from shallow (< 60' bgs) CPT investigation of soil gas and cores with VOC analysis and moisture content. [SVEU 782-6M]
- 1997: The following characterization activities were completed in CY-97. A more detailed description of these results will be presented in a separate characterization report to be completed later this fiscal year.
    - A-014 Outfall (SVEU 782-3M); three CPT soil gas screen and one rotosonic core with field description and VOC analysis.
    - M-Basin (SVEU 782-4M): one rotosonic core with field description and VOC analysis.
    - Solvent Storage Tank (SVEU 782-6M); two rotosonic core with field description and VOC analysis.
    - M-Area Basin Process Sewer North (SVEU 782-5M); three CPT core and one rotosonic core with CPT log, field description, and VOC analysis.

The data from these investigations is presented in Figure 3.4. The map identifies investigated locations with either a filled symbol or open symbol delineating those areas in which soil or soil gas concentrations were above or below set action limits, respectively. The lower limit criteria are set at a total VOC (TCE + PCE) concentration of 100 ppbw (μg/kg) for soil and at 5 ppmv for soil gas. These criteria are based on physical arguments. Soil with a VOC concentration of 100 ppbw would, if fully saturated and with complete partitioning into the water, produce a water concentration of approximately 500 ppbw which is the TCLP limit. This conversion is based on available core data of soil densities and pore volumes (O'Brien and Gere, 1991). Pore water, with a concentration near the waste water treatment standard (approximately 50 ppbw), would produce an equilibrated vapor concentration of roughly 5 ppmv based on ambient temperature Henry's constants for TCE and PCE. The filled symbols are further delineated by color with respect to proposed choices of remedial activities for a given soil or soil gas concentration range. These choices of remediation technologies are discussed further in the next chapter

The following is a brief synopsis of the characterization results:

- SVEU-782-3M (A-014 Outfall) – The primary focus was on regions down stream from the immediate vicinity of the outfall to assess the lateral extent of contamination and to reassess soil gas concentrations at existing vapor monitoring wells (MVC-2 at the outfall and MVC-3 approximately 200 feet downstream).
  Lateral extent: CPT investigations showed low to moderate soil gas concentrations located primarily near the water table (< 100 ppmv). The highest soil concentrations are found just above water table at < 2 ppmw and show little change since the original CH2M Hill investigation (1990). Moderate decreases in concentrations were observed in the shallow and middle sands.
  Reassess vapor monitoring wells: Little change in soil gas concentrations were observed except for decreases in middle sand zone. Very high soil gas concentrations (> 5000 ppmv) were still observed at shallow and deep locations near the outfall (MVC-2).
- SVEU-782-4M (M-Area Basin) – The primary focus was on determining the lateral extent of contamination immediately adjacent to the basin cap and to reassess the vertical distribution relative to earlier characterizations (MSB-22, Gordon, 1982). The contaminant concentrations down to a depth of 90 feet ranged from below detection to less than 50 ppbw. High contaminant concentrations (> 100 ppmw) consisting primarily of PCE were observed at deep locations (95 – 110 ft bgs). The vertical distribution is consistent with pre-remedial characterization. However, the concentrations are higher at the borehole completed in 1997 which was located nearer the basin.
- SVEU-782-5M (Northern M-Basin Process. Sewer)– The primary focus was on vertical distribution relative to implementation of an alternative operating mode (e.g. rebound or pulse testing) or an alternative technology. The only soil contaminant concentrations above 1 ppmw (1.7 ppmw) consisted primarily of TCE and were located at MVE-5 at a depth of 99 feet. The concentrations in this zone were similar to those observed by Gordon (1982) at MSB-16. Shallow PCE contamination at concentrations less than 1 ppmw were found at the southern end of this area near MVE-7. Soil gas

monitoring at the extraction wells and monitoring wells (MVC-4 and MVC-5) confirmed the low soil levels with no vapor concentrations greater than 100 ppmv.

- SVEU-782-6M (Solvent Storage Tanks) – The primary focus was on determining the lateral extent of contamination and assessing changes in the vertical distribution. Very high soil concentrations (> 1000 ppmw) were observed at shallow depths (< 50 ft bgs) and consist primarily of PCE. The shallow contamination is confined to the immediate vicinity of tanks on the eastern and southern sides of the pad. The shallow concentrations showed very little change since initial CH2M Hill report (1990). Moderately high concentrations < 10 ppmw are observed down to water table where TCE predominates.
- SVEU-782-8M (Southern M-Basin Process Sewer) – The primary focus was on comparing historical data with the low vapor concentrations observed with the extraction unit. Previous investigations and demonstrations conducted in this area show high contaminant concentrations (> 100 ppmw) at shallow and deep locations associated with low permeable regions. This information combined with the low flow rates observed from the extraction wells has resulted in a shut-down of this SVEU until the wells can be redeveloped or new wells installed.

3.4 Investigation of Suspect Sources

Thirteen selected manhole locations of the M-Area Process Sewer were investigated in 1997 using CPT with soil gas screening at selected depths (see Figure 3.3 and 3.4). Based on arguments similar to those presented for identifying soil and soil gas criteria in the previous section, a critical soil gas screening concentration of 500 ppmv is chosen. This value is an estimate, based on Henry's constants, of the vapor concentration for a soil at a concentration of approximately 1 ppmw with a corresponding water concentration of 5 ppmw. The 1 ppmw soil concentration criteria is presented in the next chapter as a proposed cut-off for using passive venting techniques. Eleven locations had maximum soil gas concentrations less than 500 ppmv. Two locations, one northwest of building 320-M and one east of building 321-M showed soil gas concentrations in excess of 1000 ppmv located in the middle sandy zones. These areas will be investigated further with core sampling methods.

3.5 Evaluation of Alternative Technologies

Based on an initial review of site specific demonstrations, the following alternative technologies are being assessed for use at the SRS:

Enhancement Technologies:

- In-Situ Heating:
  - Low frequency resistive (LFR) using multi-phase AC electrode patterns. This technology was successfully demonstrated at the Integrated Demonstration Site located along the M-Area process sewer near the basin (Gauglitz, 1994) and more recently used at an industrial site in Illinois.
  - Dynamic underground stripping (DUS) using steam injection combined with LFR. This technology was successfully tested at Lawrence Livermore National Laboratory (Newmark, 1994) on a light non-aqueous phase liquid (LNAPL) site and is currently being used successfully at an industrial DNAPL site in California.
- Pneumatic fracturing. This technology was tested as part of the EPA SITE program (EPA, 1993) and is also commercially available. It would provide an alternate or complementary method to in-situ heating for remediating low permeable zones.

System Modifications:

- Well redevelopment . Alternate means to water flushing are being investigated to avoid the possibility of increasing solvent migration to the groundwater. Proposed methods range from simple air injection to a technology developed in Russia and used in the oil and gas industry that employs a device for delivering high pressure pulsed nitrogen injection at select screen depths.
- Packers and or new wells with selected screen depths and intervals set to target flows through or near higher contaminant concentration zones.
- Seal adjacent water table wells to eliminate point recharge and expand the ROI.

Polishing Technologies:

- Barometric pumping. This technology has been studied extensively at the SRS and other DOE facilities (Rohay, 1993) and is currently being implemented at the Metallurgical Laboratory in the lower 700 Area and is being tested at the Miscellaneous Chemical Basin located southwest of the A/M Area. The latter investigation also includes studies on the addition of solar heating methods to enhance the barometric pumping removal efficiency.


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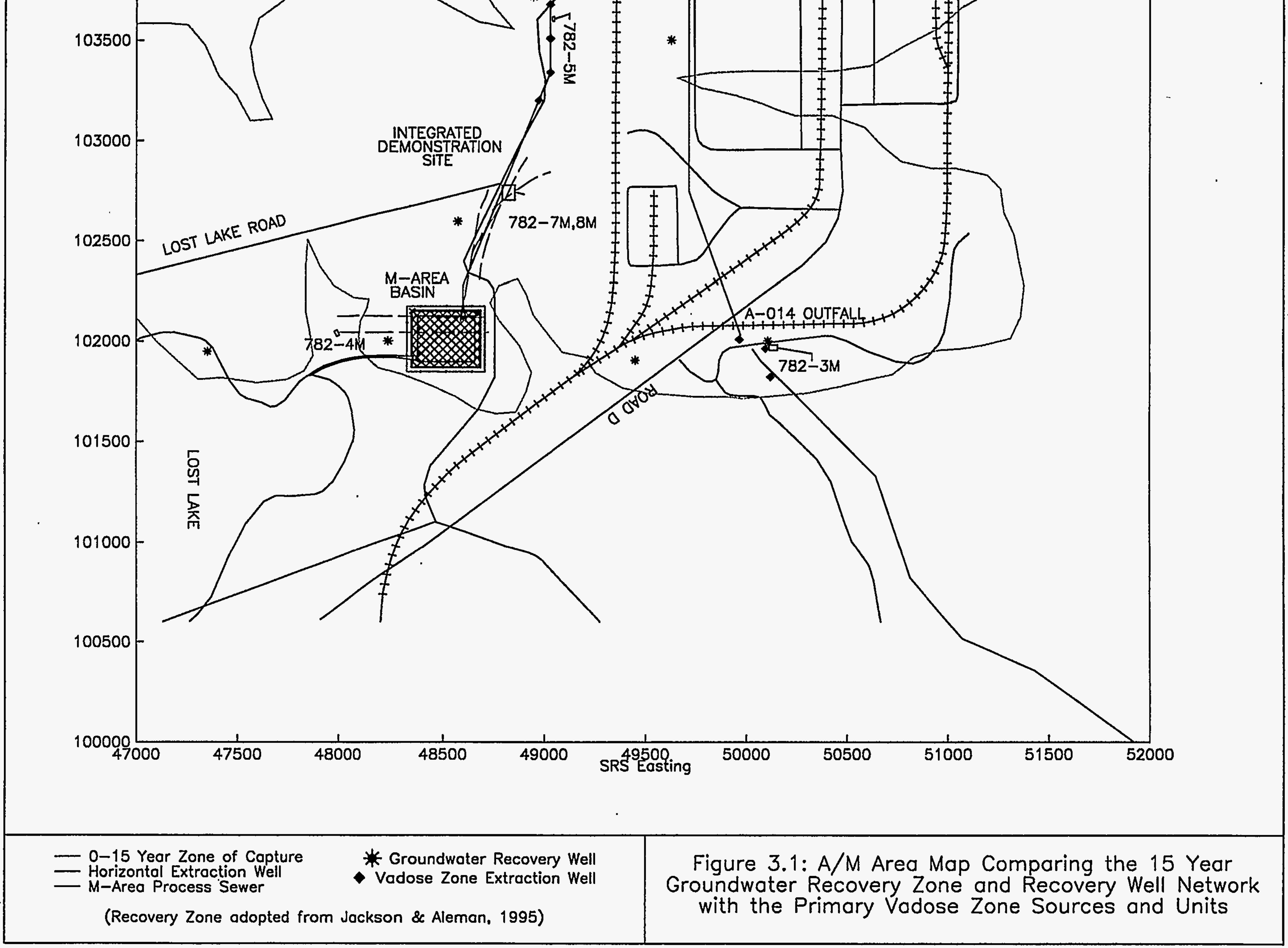
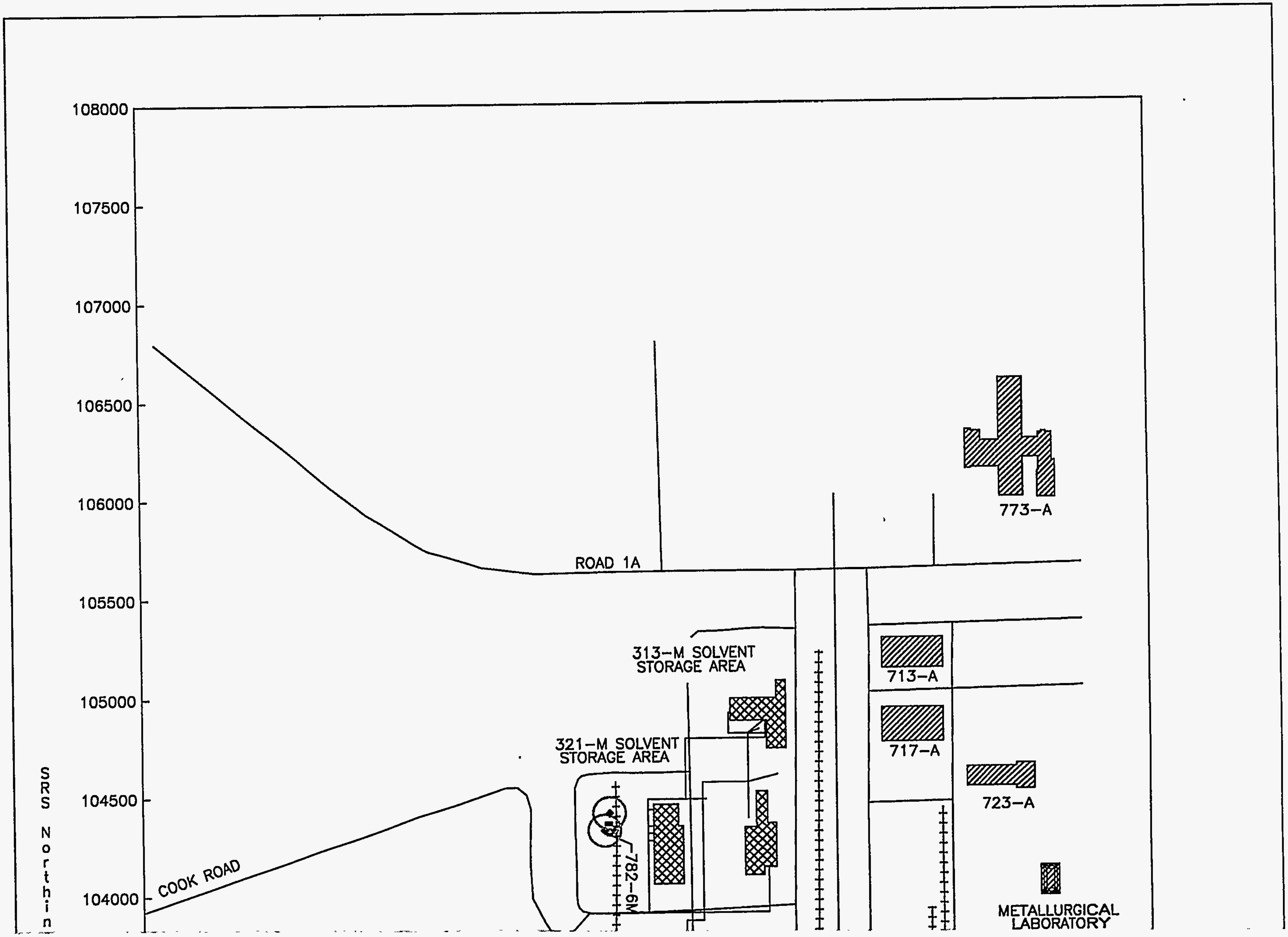


Figure 3.1. A/M Area Map Comparing the 15-Year Groundwater Water Table Aquifer Recovery Zone and Recovery Well Network with the Primary Vadose Zone Sources and SVEUs.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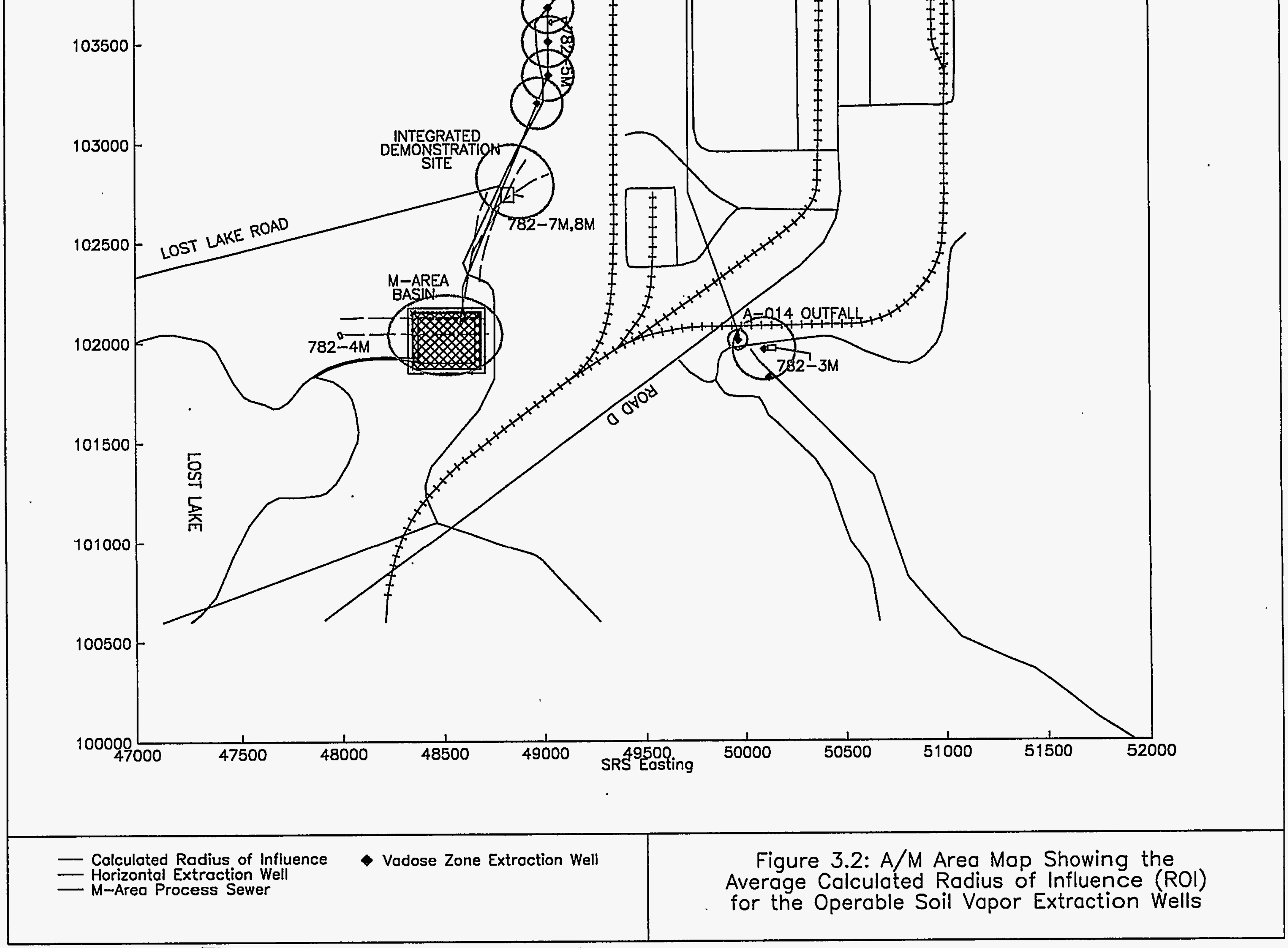
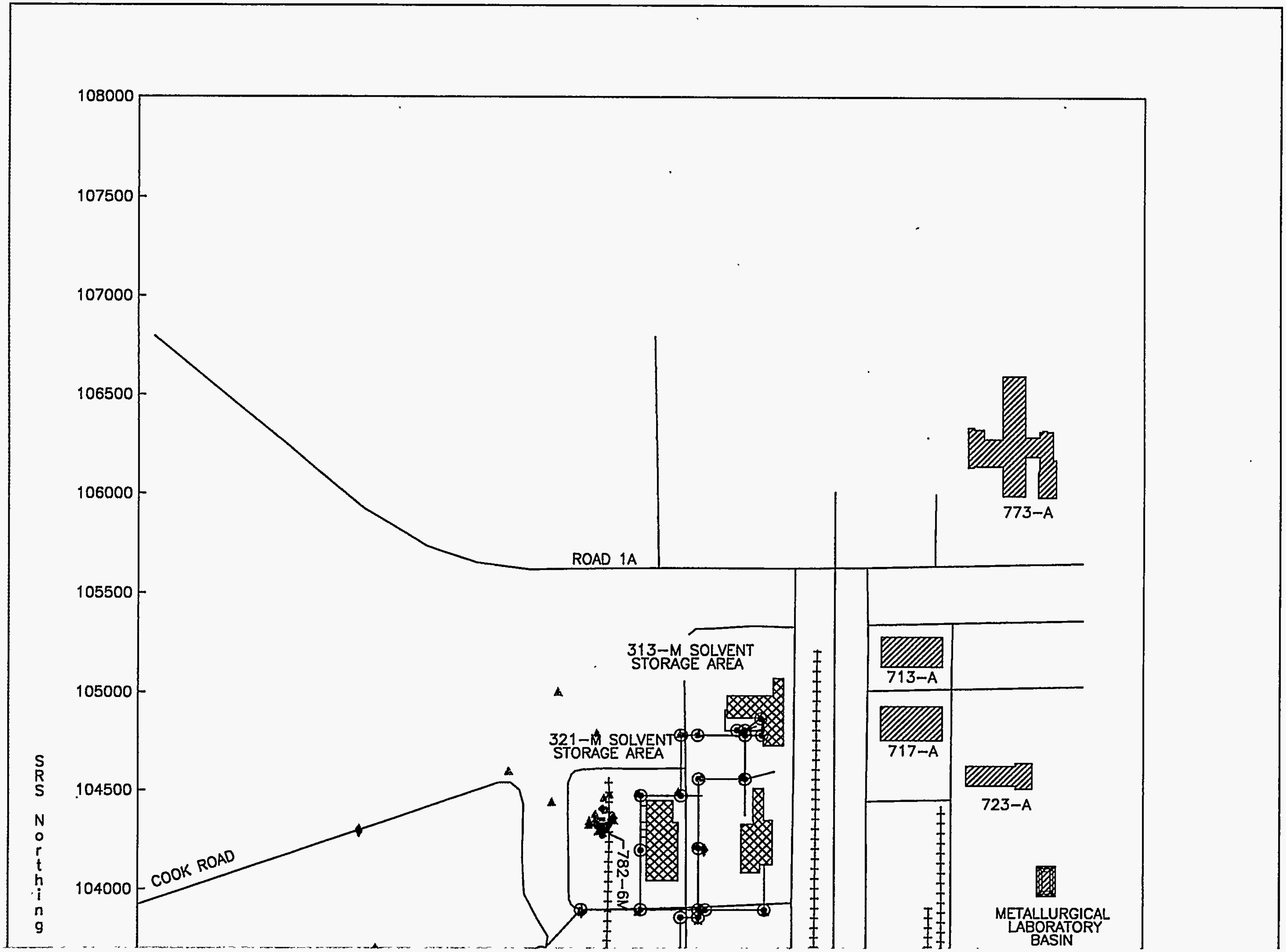


Figure 3.2 A/M Area Map Showing the Averaged Calculated Radius of Influence (ROI) for the Operable Soil Vapor Extraction Wells.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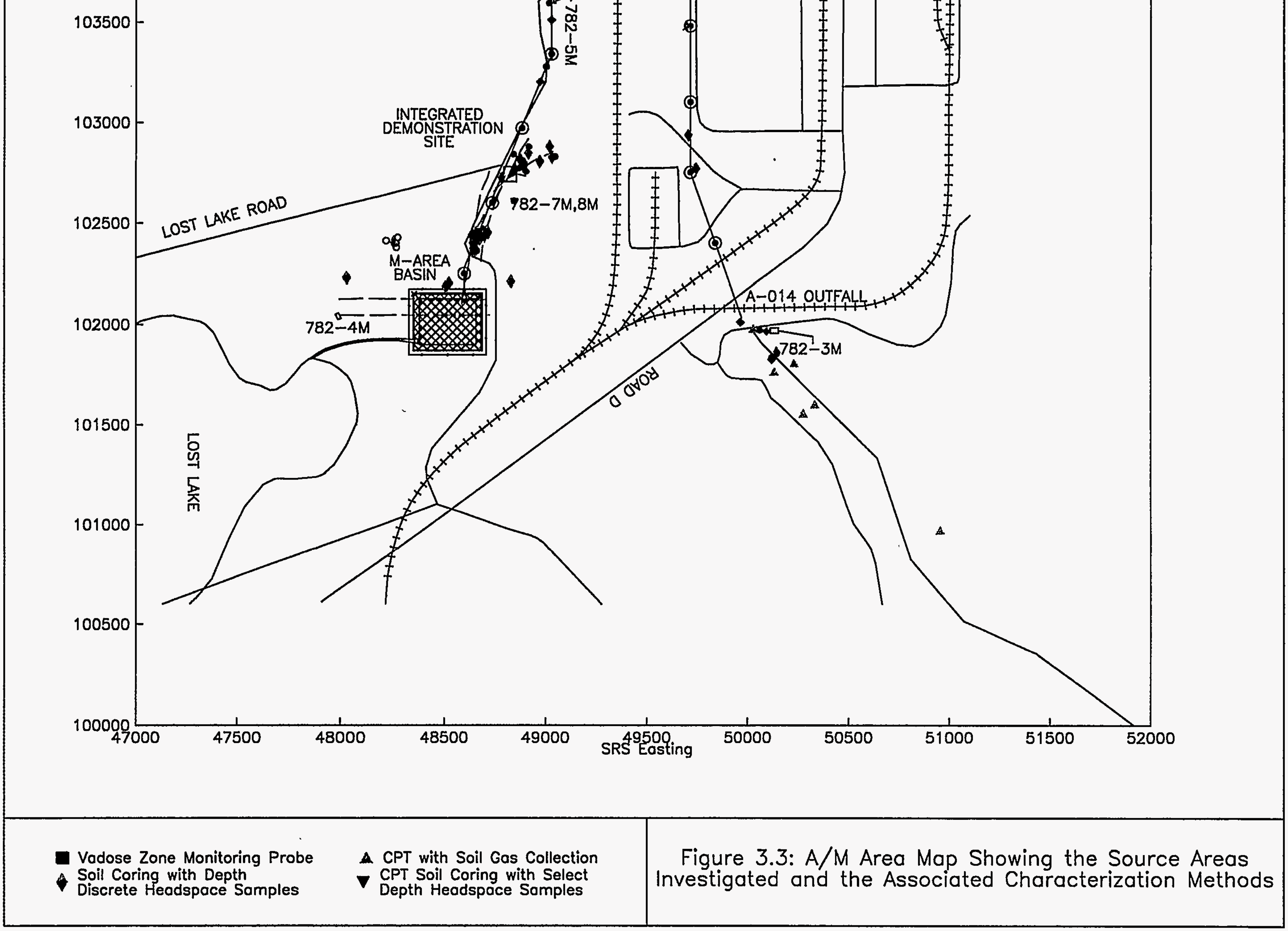
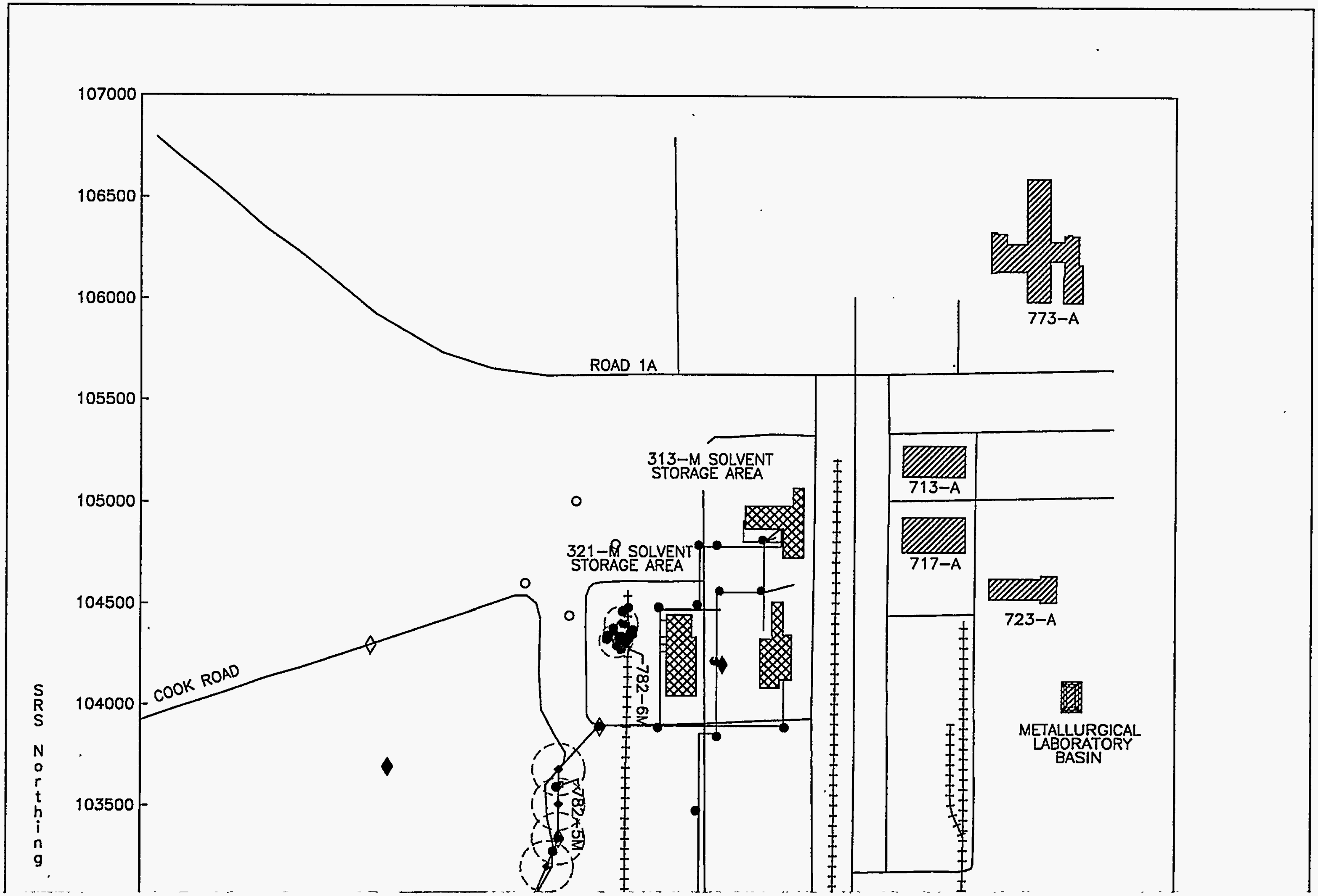


Figure 3.3 A/M Area Map Showing the Source Areas Investigated and the Associated Characterization Methods.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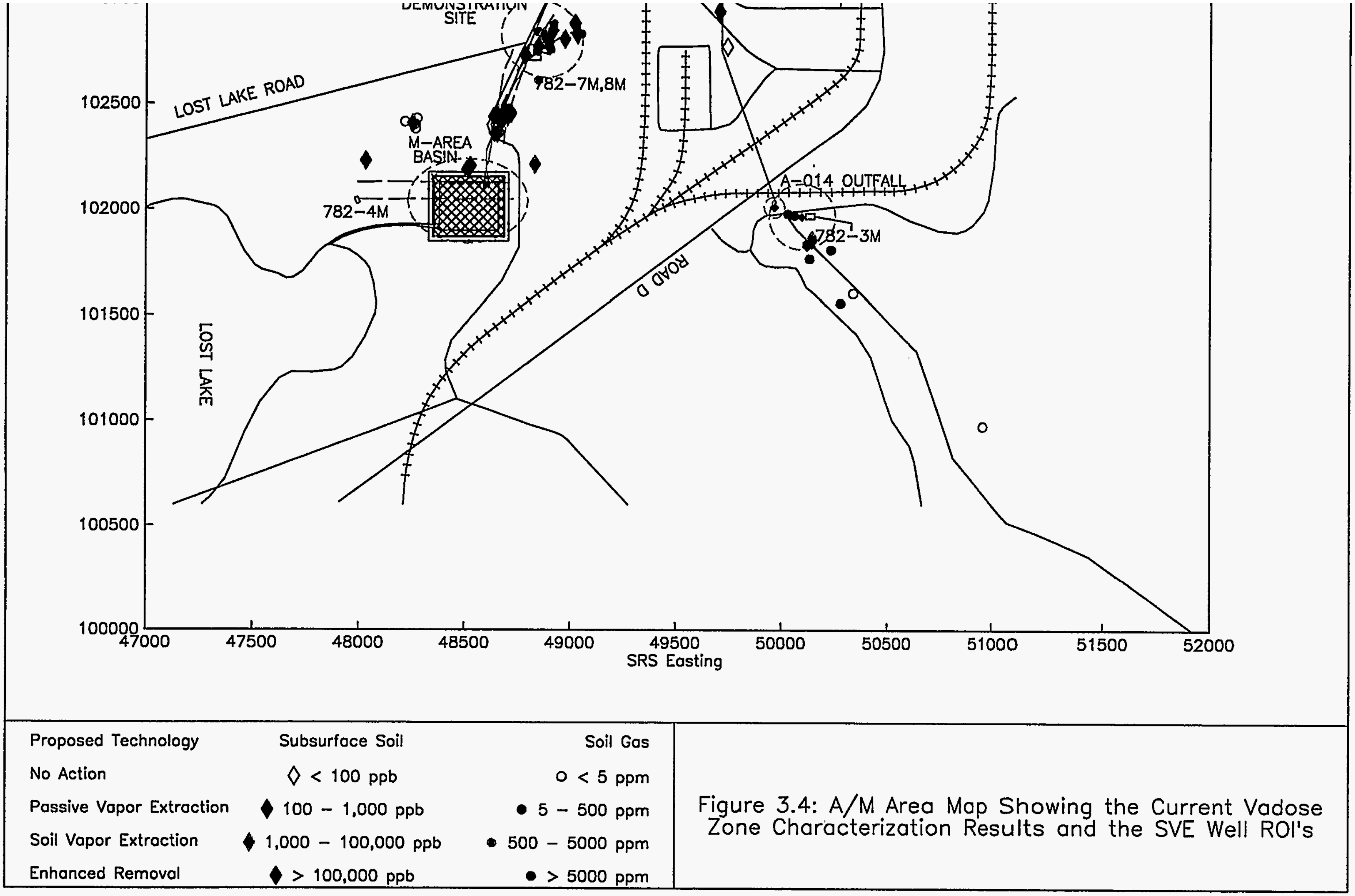

Figure 3.4 A/M Area Map Showing the Current Vadose Zone Characterization Results and the SVE Well ROI's

4.0 PROPOSED MONITORING PLAN

4.1 Introduction / Flowchart

This chapter presents the proposed vadose zone monitoring plan (VZMP) which includes elements from each focus area. A simplified flow chart identifying the status, interrelationships between, and pathway through elements of the focus areas is presented in Figures 4.1 and 4.2. The first chart gives a more detailed description of each major element consisting of an action or decision making step. The second chart shows the progression of steps including the initial line of approach used to reach the current SVE remediation strategy. The basic approach is a four step cyclic process:

(1) Obtain site characterization data to establish baseline levels, to determine the relative severity or extent of contamination, and to determine parameters required for future decision making processes.
(2) Based on the characterization data and ultimate remediation goals, evaluate alternative remedial technologies relative to their corresponding regions of applicability.
(3) Implement the chosen technology until a predetermined performance limit is reached.
(4) Recharacterize the site and repeat the evaluation process until an ultimate goal is achieved.

The remaining sections provide more detailed discussion on the focus areas of the proposed plan and anticipated schedules for near term work activities.

4.2 Remediation Goals

4.2.1 Groundwater Impact

The following are the proposed methods for determining clean-up concentration levels for the vadose zone soils:

(1) Lab extraction of representative samples from select vertical strata with TCLP procedure or alternate water soluble fraction (WSF) method (AAEE, 1997) to leachate levels at a concentration al to SCDHEC E/S Regs. R.61-79.264.40 for waste water of 54 ppbw (0.054 mg/l) for TCE and 56 ppbw (.056 mg/l) for PCE for deep strata > 80 ft bgs and to TCLP levels of 500 ppbw (0.5 mg/l) for TCE and 700 ppbw (0.7 mg/l) for PCE for shallow strata (< 80 ft bgs).
(2) T2VOC Model – Passive vapor transport and precipitation infiltration ("leaching") producing groundwater concentrations at an MCL of 5 ppbw (.005 mg/l) after 30 years of no vapor extraction. This time dependent goal is based on the current estimated lifetime of operation for the M-1 and A-2 stripper systems.

The modeling method will require establishment of two or three dimensional grids of transport parameters based on direct measurements and/or correlations. These same grids can be used to alter the depth specific criteria chosen for the extraction method or provide a DAF as a function of depth. Work on establishing grids based on available core description information will be completed in FY-99. Modeling with T2VOC for dissolved phase VOC migration via infiltrating rainwater leaching to the water table will be performed when grids are completed. Collection of samples for TCLP or an alternative WSF analysis method will be incorporated into on-going characterization activities as discussed below.

4.2.2 Vapor Extraction System Limits

The current goal for an individual extraction system is based on a sustained asymptotic removal rate of less than 40 lbs/week (approximately 0.25 lb/hr or 30 ppmv at a nominal flow rate of 300 scfm). Once this limit is reached, the following protocol for rebound/cycle testing is proposed:

(1) The unit is placed in shutdown for a period of at least two to three months. During this time, vapor sampling and analysis at the individual extraction wells and nearby monitoring wells is performed.

(2) Following the shutdown period, the unit is restarted and brought to pre-shutdown operating conditions. If the unit cannot sustain extraction rates above shutdown levels for a period of at least two weeks, the unit is again shutdown for a period of at least four to six months. If acceptable extraction levels are sustained for greater than two weeks, the unit will be operated until extraction rates drop again to shutdown levels. At this time, the rebound procedure will be repeated.

(3) In parallel with or following an initial rebound test, characterization with select or depth discrete VOC analysis of cores will be performed at locations within the zone of influence for each extraction well. If all VOC concentrations in the soils are at or less than 1 ppmw (mg/kg), the unit is assessed for switchover to passive venting either with existing extraction wells or new wells installed with select screen depths and intervals for optimal removal. If any soil concentrations are from 1 to 100 ppmw (mg/kg), an assessment is made for either extraction well modification (e.g. packers) or installation of new extraction wells with screened intervals selected to target the high concentration zone. If any soil concentrations are in excess of 100 ppmw (mg/kg), an assessment is made for the use of an alternative enhancement technology that targets the high concentration zone(s).

Modifications to these concentration ranges may be made based on the results of modeling or analysis performed as per 4.2.1 or through changes in the applicability of a given alternative technology.

SVEU 782-5M is the only unit currently being operated in this rebound/cycle mode. Following an initial shutdown, the unit was restarted and maintained a removal rate of approximately 60 lb/week for a period of two months. The unit will continue to be monitored. Based on the historical operating performance of the other units, it is not anticipated that removal rates will reach minimum limits during FY-99.

4.3 Current System Evaluation

4.3.1 Off-gas and Soil-Gas Analysis

Routine biweekly sampling and analysis of the SVEUs will continue to be monitored for anomalous trends or the approach of limiting extraction rates. When such trends or limits are observed, soil gas monitoring at individual extraction and monitoring wells will be conducted. The frequency and methods used will be periodically evaluated and updated as a historical data base is established or as new techniques become available.

4.3.2 Zone of Influence

The proposed plan for zone of influence evaluation will involve a staged approached using successively more rigorous models that can more accurately describe subsurface heterogeneities and boundaries. This need is borne out by the fact that subsurface contamination is predominantly located in low permeable and highly heterogeneous zones that are near flow boundaries. The progression will focus primarily on modeling subsurface pressure contours and flow paths but may also include the ability to predict contaminant transport. The primary focus will require the establishment of cross sections and/or grids that account for complex geometries involving spatially dependent transport properties (vertically heterogeneous permeabilities and anisotropy). In addition to the gridding required above, transport modeling requires an accurate description of the contaminant spatial distribution and phase partitioning (e.g. adsorbed, absorbed, and free phase fractions and locations relative to pore distributions). The phase partitioning component can only be inferred from total contaminant concentrations and a thorough description of the geotechnical parameters. As such, transport modeling without an accurate physical description of the contaminants can produce erroneous results. However, transport modeling with simplified assumptions can provide "best case" predictions that facilitate decision making. The currently proposed models in this staged approach are as follows:

1. AIRFLOW/SVE : A soil vapor extraction modeling package developed by Waterloo Hydrogeologic Software©. It uses a two-dimensional finite element method to describe axisymmetric (radial) vapor flow. While it can account for the layered heterogeneities observed on site, it can only model a single

vertical extraction well. Transport simulation is based on a simplified phase partitioning within each element and includes both mass transfer rate coefficients and equilibrium assumptions.

2. AIR3D (Geraghty and Miller) or MODAIR/P3DAIR (S.S. Papadopoulos & Associates) : Both models are based on the USGS MODFLOW package and use a three dimensional finite difference code that allow for multiple extraction wells and horizontal wells. They can be used to model pressure and velocity fields to delineate flow paths and capture zones.
3. T2VOC : This code was described previously in discussions on the determination of groundwater clean-up criteria. It can be used to provide the same information available from AIR3D or MODAIR/P3DAIR, as well as, provide multiphase transport modeling based on local equilibrium assumptions.

As stated above with regard to modeling for groundwater impact, modeling for zone of influence is also contingent on the completion of grids of geophysical and hydrodynamic properties. When these grids are completed, a decision as to what additional modeling for zone of influence is required will be made.

4.3.3 Contaminant Distribution

The proposed plan calls for continued investigations based on system performance set by criteria presented in 4.2.2 using the characterization methods described in this report. Additional characterization to further investigate geotechnical and geophysical parameters may be conducted if existing data proves inadequate in producing reliable grids for modeling. The three primary source zones to be investigated in FY-99 are the Northern Sector area near SRTC, the A-014 Outfall, and areas around the processing facilities in M-Area (313-M and 320-M). The Northern Sector area is a suspect source and work activities are discussed below. The A-014 Outfall is a primary source at which current characterization data is both inconsistent with the high extraction rates for the SVEU operating at the site and is insufficient for developing adequate modeling parameters. Work at the M-Area processing facilities is a follow-up to recent screening characterization completed at the process sewer manholes.

4.4 Investigation of Suspect Sources

Based on the initial screening data obtained for the M-Area Process Sewer manhole locations, additional investigations with core sampling methods are planned at select locations. These will be used, in part, to establish a correlation between soil and soil gas concentrations. The majority of the manhole sites investigated had maximum soil gas concentrations with associated depths similar to those seen in investigations conducted at the Metallurgical Laboratory area (Pemberton, 1997). Based on this similarity, these sites are also being considered as candidates for remediation with passive well venting.

Additional suspect sources that require further characterization include the following:

- Northern Sector investigations of solvent releases in the SRTC complex including the A-01 Outfall and drainage area. Work in this area will include both screening methods and continuous coring techniques.
- Screening investigations of potential solvent contamination beneath existing M-Area process facilities (313-M, 320-M and 321-M). These investigations will be similar those conducted at the M-Area Process Sewer manholes. Scheduling of

4.5 Evaluation of Alternative Technologies

The proposed plan calls for continued evaluation of alternative technologies. The use of enhancement methods will be based on available project funding. Passive extraction is currently being tested and implemented on site (Riha, 1997). Current efforts are focused on predicting the efficiency of the passive technique with modeling using T2VOC. Well AMH-6 at SVEU 782-4M has been successfully developed using forced air from the units blower. Current temporary modifications are in place to use compressed air as a means of redeveloping horizontal wells at SVEUs 782-7M and 782-8M. Discussions have been held with the developers of the high pressure pulse nitrogen device for applications at both vadose zone extraction and groundwater recovery wells.

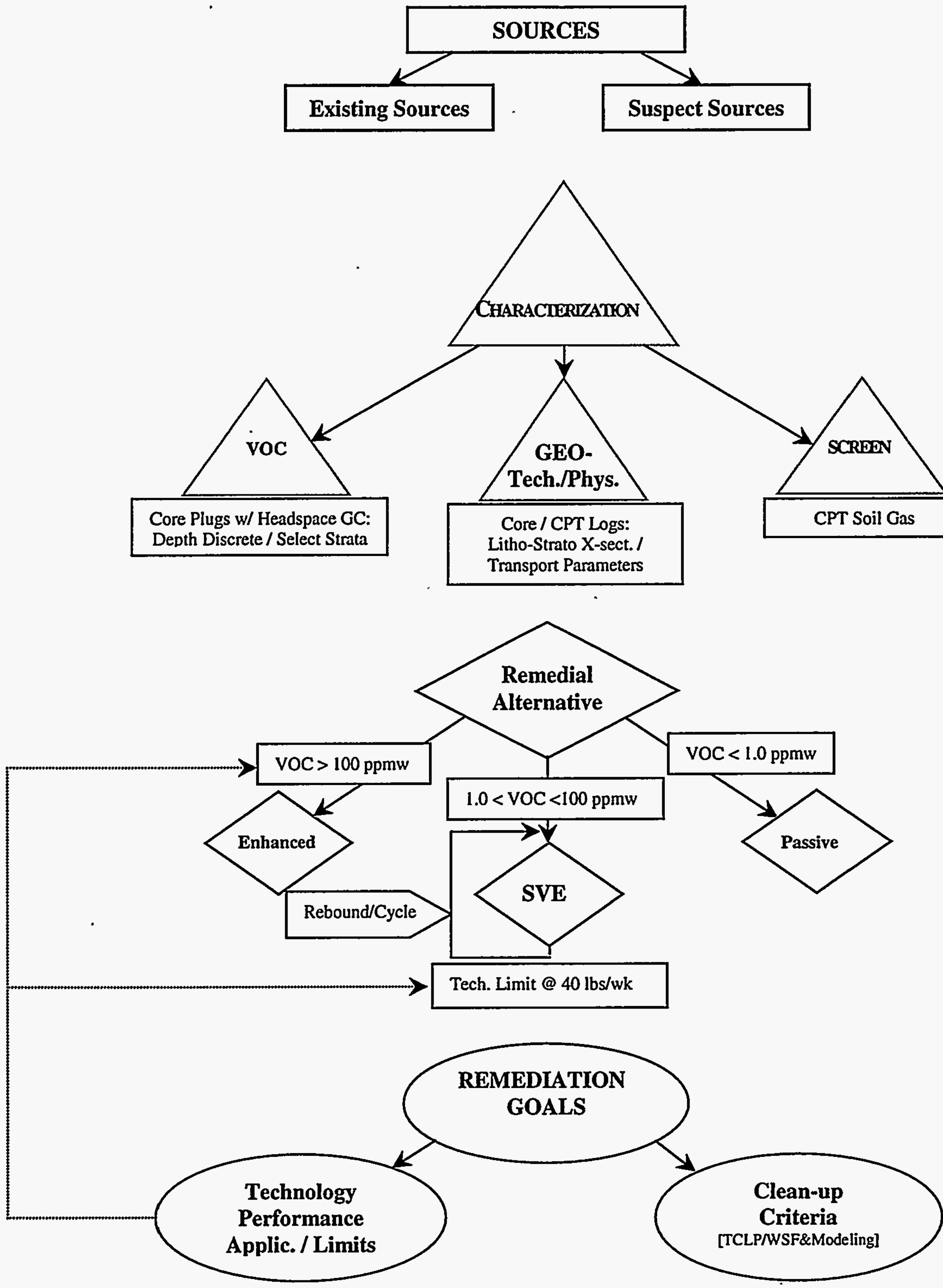

Figure 4.1 Description of Vadose Zone Monitoring Plan (VZMP) Flowchart Elements

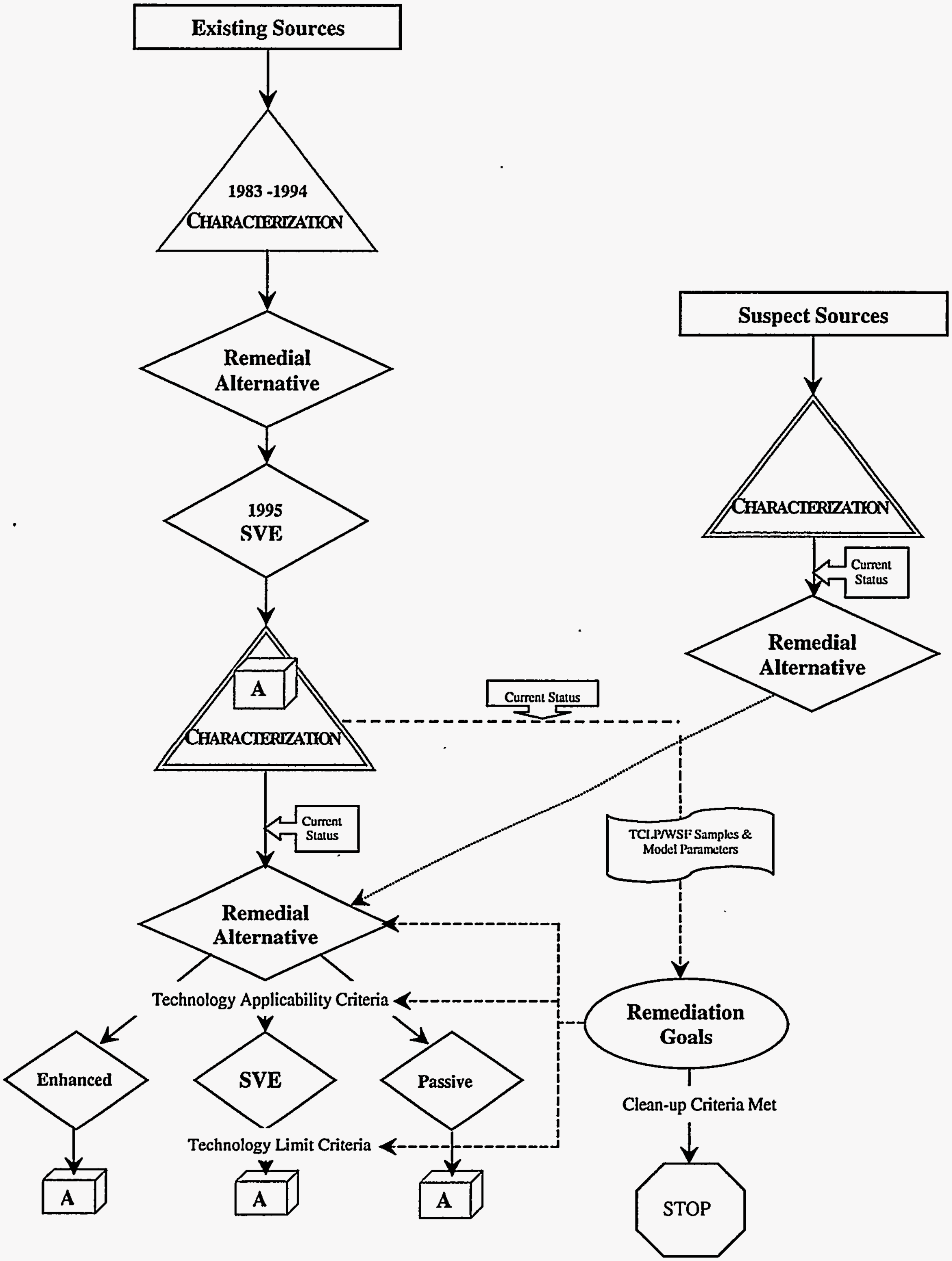

Figure 4.2 VZMP Flowchart

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APPENDIX A. PROPOSED SAMPLING & ANALYSIS TECHNOLOGIES AND METHODS

A.1 Proposed Sampling Technologies and Procedures

The following text describes methods of obtaining and preparing vadose zone soil gas and soil samples. These methods will be performed to obtain chemical information for use in mapping the extent and distribution of contaminants. Additionally, geophysical information obtained in-situ or from undisturbed samples will be used to produce lithographic cross sections and obtain hydrogeologic parameters, both of which are necessary for flow and transport models.

A.1.1 Vapor Sampling

Vapor samples are obtained from extraction process equipment, directly at the well head, or during CPT pushes. Samples are typically obtained using Teflon vacuum pumps and collected in 1 liter Tedlar bags for on-site analysis using gas chromatography. Prior to collecting the sample, all collection lines, pump, and sample bags are purged with soil gas for an adequate time to ensure that a representative sample is obtained (typically from 10 to 15 minutes). Bags are filled and purged twice prior to collecting the volume to be analyzed. The Tedlar bags have both a stainless steel valve for filling and purging and a septum port for extracting volumetric aliquots to be analyzed.

In addition to off-line sampling, a split stream from the pump effluent may also be directed into an on-line analytical instrument, typically a Bruel & Kjaer (B&K) photo-acoustic infrared detector. At least 10 volumes will be purged through the sampling system to clean the lines between sampling depths. This validation step helps to insure a representative soil gas sample is collected by allowing contaminant concentrations to reach a steady state and by using CO_2 as an indicator of soil gas. This method reduces the problem of inaccurate soil gas measurements due to leaking sample lines and non-steady-state values. Soil gas CO_2 levels are orders of magnitude higher than ambient CO_2 levels and are correlated to contaminant concentrations since the CO_2 is produced by biological oxidation of carbon (contaminants). Once the samples are validated with the B&K, the sample bags will be purged with soil gas three times, filled with approximately one liter of gas, and taken to the lab for analysis. Analysis with the B&K is performed on select depth discrete monitoring wells, passive vent wells, and for in-situ soil gas analysis with CPT using a Cone Sipper. The Cone Sipper consists of a metal frit section of the drill string located above the normal sensor tool. Vapor samples are drawn through the frit into a chamber that is connected with Teflon or nylon tubing to a surface vacuum pump.

A.1.2 Sediment Sampling

The methods used for obtaining sediment information will include the use of direct push techniques with a cone penetrometer test (CPT) truck, and continuous coring techniques using one of several technologies including rotosonic and hollow stem auger drilling. The CPT method general provides data in-situ (including contaminant information through soil gas as discussed above), but the technique can be used to obtain cores at select depths. Continuous coring techniques produce samples for ex-situ analysis that provide information related to either chemical contaminant analysis (soil plugs) or soil classification, geotechnical, and geophysical data (core analysis).

Ex-Situ Core Sampling:

At continuous or selected sampling depths, soil cores are collected using split spoon samplers or the equivalent with either a hollow stem auger or rotosonic drill rig (standard split spoon: hollow stem auger - typically 2 inch diameter and 2 to 4 foot length; split spoon equivalent: rotosonic - typically 5 inch diameter and 5 to 20 foot length) or a CPT truck (using an approximately 1 inch diameter and 2 foot long MOSTAP™ soil sampler). Split spoon samples are used to obtain field core descriptions, to provide samples for microscopic studies, and to collect soil plugs for VOC analysis.

Thin-wall tube samplers, commonly called Shelby tubes, are used to take relatively undisturbed soil/sediment samples. The equipment, procedures, and sample handling for this method is described in WSRC Manual 3Q5, Chapter 6, Section 5.4 (ASTM D-1587). The sampler is a steel or brass tube with a beveled edge at one end. The sampler is attached to the drill rods and is pushed into the bottom of the bore hole in one continuous motion. The sampler is then withdrawn and sealed for laboratory analysis. The analysis performed on Shelby tube samples is predominantly for geotechnical/physical properties.

VOC Samples: During continuous coring operations, samples will be collected every 3 m (10 ft) at a minimum. In addition, two samples will be collected at every depth where there is a major lithologic change, one sample approximately 8 cm (0.25 ft) above the interface and one sample an equal distance below. This sampling protocol has been successfully used in past studies and provides a high quality detailed profile of contamination at a reasonable cost. After the core is brought to the surface, an approximate 2 cubic centimeter (cc) plug sample is collected using a modified plastic syringe. The plug is transferred to a 22 ml glass headspace vial and 5 ml of nano-pure water is added. The vial is then sealed with a crimped Teflon-lined septum top for head-space analysis. Duplicate samples will be collected at each depth and all samples will be stored at 4°C until analyzed (maximum allowed storage time is 14 days). Approximately 20 percent of the duplicate samples will be analyzed. Two field blanks (equipment blanks) consisting of a 5 ml nano-pure water sample will be prepared for each borehole. These blanks will also used to establish the tare weight for the soil samples.

Core Samples: The cores will be extruded in the field onto a PVC trough approximately 3.2 m (10 ft) long, examined, and described in the field by a geologist. The core samples will then be wrapped in plastic and placed in water-resistant plastic boxes. The boxes will be labeled in the field to designate the corehole number, run number, depth of each run, and percent recovery. For the wells in which the core is not collected, drill cuttings will be collected while drilling with hollow stem augers or mud rotary techniques and sampled with a field sieve. The samples will be described in the field by a hydrogeologist/geologist.

In-Situ Sediment Sampling:

The cone penetrometer test (CPT) is a proven method for rapidly providing depth-discrete soil classification. The CPT data collected will be tip pressure, sleeve resistance, pore pressure, and electrical conductivity. The ratio of the sleeve resistance to tip pressure provides the friction ratio where a higher ratio indicates finer grained sediments. The ratio is used to define the sandy and clayey layers during each push to select the soil gas or sediment sampling locations. This technique has been successfully applied at SRS and has provided detailed information on the distribution and nature of the sediments in the subsurface during several hundred CPT test borings conducted across the site. The CPT is conducted continuously from the surface to the desired depth, or until further penetration is impossible, and it is capable of defining lithology with a resolution on the order of 2 cm (1 in.). This detail is generally not possible using standard drilling techniques.

A.2 Proposed Sample Analysis

A.2.1 VOC Analysis

Vapor Samples:

Tedlar bag samples are stored away from light at constant temperature and analyzed within 4 hours of sampling to avoid sample loss or degradation. Each sample is analyzed on the HP 5890 Series II or the SRI 8610 gas chromatograph (GC) using direct injection. The GC is calibrated using certified gas standards containing the compounds of interest (cis-DCE, CCl_4, Freon-11, $CHCl_3$, Freon-113, Freon-12, PCE, TCA, TCE, and Vinyl Chloride) at typical concentrations of 1, 10, 100, 500, and 1000 ppmv and laboratory air blanks.

For CPT applications, a Bruel & Kjaer (B&K) Model 1302 gas monitor is used to measure the soil gas for TCE, PCE, and CO_2 before sample collection. The B&K 1302 uses a photoacoustic infrared detector with select optical windows for speciation.

Sediment Samples:

The technique used to prepare and analyze soil samples for VOC analysis is a modified version of EPA Method 5021 which has been used successfully at the SRS since 1991. Each sample is weighed.and then analyzed on the HP 5890 Series II gas chromatograph using an automated head space sampler at 70^{o}C for equivalent water concentrations. The GC is equipped with an electron capture and flame ionization detector connected in parallel. The column is a Supelco - VOCOL™ megabore borosilicate glass (60 m x 0.76 mm ID x 1.5 µm film thickness) specifically developed for volatile priority pollutants (EPA Methods 502, 602, and 8240). Mass soil concentrations (ppb, µg/kg) are calculated based on an equal head space volume from 7.5 ml of water standards and nominal 7 ml of water/soil matrix and are corrected for the mass difference between the soil and water. The gas chromatograph is calibrated using either stock methanol solutions made with neat (pure) solvents or purchased certified mixtures in methanol that are diluted in deionized water to specific concentrations. Two reagent blanks of pure deionized water will also be included to ensure the transfer lines and column are being adequately flushed of residual solvents. The standard concentrations used for each head space sample run are: 3, 5, 10, 50, 100, 1,000, and 10,000 ppb (µg/ml). The samples will be analyzed for Vinyl Chloride, Freon-11, Freon-113, 1,1-DCE, trans-DCE, cis-DCE, $CHC1_3$, 1,1,1-TCA, $CC1_4$, TCE, and PCE.

A.2.2 Geotechnical / Geophysical Analysis

Standard Undisturbed Core Test:

Geotechnical tests and methods as used in previous site reports are listed in Table A-1 (Eddy and others, 1993a)

Table A-1. Proposed Geotechnical Parameters

Test Parameter	Method
Vertical Permeability	Corps of Engineers EM1110-2-1906
Horizontal Permeability	Corps of Engineers EM1110-2-1906
Specific Gravity	American Society of Testing and Materials D854
Mechanical Grain Size	American Society of Testing and Materials D422
Hydrometric Grain Size	American Society of Testing and Materials D422
Atterberg Liquid and Plastic Limits	American Society of Testing and Materials D4318
Water Retention, Drainage Curves	American Society of Testing and Materials D2325
Water Retention, Wetting Curves	Methods of Soil Analysis Chapter 26
Unconfined Compressive Strength	American Society of Testing and Materials D2166
Porosity	Corps of Engineers EM1110-2-1906
Moisture Content	American Society of Testing and Materials D2216
Unit Weight	American Society of Testing and Materials D2937
Cation Exchange Capacity	Methods of Soil Analysis 57-2.1
Total Organic Carbon	Environmental Protection Agency Method 9060
Exchangeable Acidity	Environmental Protection Agency Method 305.1

Field Core Description

The field geologist in the field will prepare detailed geologic logs. Grain-size classification will be based upon a Udden-Wentworth Scale in accordance with Chapter 5 of WSRC 3Q5. A summary of grain size classification is as follows:

Grain Size Classification	Diameter (mm)
Pebbles	4 – 64
Granules (very fine pebbles)	2 – 4
Very Coarse Sand	1 – 2
Coarse Sand	1/2 – 1
Medium Sand	1/4 - ½
Fine Sand	1/8 - ¼
Very Fine Sand	1/16 - 1/8
Silt	1/256 - 1/16
Clay	<1/256

Size fraction percentages will be based upon visual inspection and comparison with percentage charts. The degree of sorting present in the sample will be based upon visual analysis. The following sorting classification system will be used:

Well Sorted	90% of sample within two size classes
Moderately Sorted	90% of sample within four size classes
Poorly Sorted	90% of sample within five to six size classes
Very Poorly Sorted	90% of sample greater than six size classes

Color descriptions will be based upon comparisons with a standard Munsell™ color chart. The features described on the logs will consist primarily of major sediment type, grain size distribution, color, textural characteristics, cement and/or matrix materials, sedimentary structures, fossils, and accessory minerals. In general, grain sizes, color, and roundness will be described by comparison with charts. The cores will be sent to an onsite lab for a foot-by-foot description. Sieve analyses will be conducted on selected core samples for determination to the proper screen slot size and filter pack.

Additionally, microscopic studies of core samples may be conducted. These core descriptions will be done using the standard WSRC core logging procedure (WSRC ESSOP-2-15: "Microscopic Examination of Sediment Cores"). Descriptions made using this procedure reflect a "whole-rock" lithologic classification of the sediment as samples are homogenized over a given 0.3 m (1 ft) interval for examination. Variations at a scale of less than a foot are not reflected in the descriptions. Hence, these descriptions do not necessarily account for lithologic interpretation based on depositional geometry. For example, an interval containing 40% sand-sized material and 60% mud-sized material in discrete interbeds would be classified as a sandy clay. An interval containing the same percentage distributions but with the mud fraction dispersed throughout the interval as matrix would also be classified as a sandy clay. It should be noted that two such intervals will appear identical on a geologic cross section despite significant differences in depositional environment and hydrologic properties.

Moisture Content

In addition to more standardized methods for moisture content determined with Shelby tube samples (e.g. ASTM D2216), a gravimetric method is also used for soil plug samples collected from split spoon cores. The gravimetric moisture is the difference in weight between the "dry" and moist (original) sediment expressed as a fraction of the moist weight. The volumetric moisture content can be estimated with the gravimetric moisture content using bulk density, porosity, and specific gravity measurements made for similar sediment classes. The method involves placing a 5 to 6 cc sediment plug into a preweighed vial and sealing. In the laboratory, the vials are reweighed, opened, and placed in a drying oven at 60°C. The samples are reweighed daily until the variance between the individual weighings is small.

APPENDIX B. FIELD OPERATIONS PROCEDURE FOR ZONE OF CAPTURE MONITORING

A constant flow of air and soil gas is maintained through the extraction unit during each test to avoid potential problems with the catalytic oxidation unit control system. Generally, this flow rate is approximately 680 sm^3/hr (400 scfm). The unit initially receives this flow from the surface-air dilution port (no flow from the test well). The target well valve is opened so that the desired flow rate is obtained from the well. The adjustment to the target well valve is made as quickly as possible so that a transient analysis of the monitoring wells can be made. A rapid, transient analysis is desired because of the ease of interpretation this type of test affords, without the complicating effects of atmospheric pressure changes and subsurface pressure dynamics responding to those atmospheric pressure changes (Rossabi and others, 1994). The tests is continued until an apparent steady-state is reached (3 – 4 hours), in order to enable future corroboratory modeling. The true steady- state will typically require times in excess of five to six hours to achieve, however, determination of this endpoint becomes complicated by variations in barometric pressures over that time span. Two to three different flow rates are usually achieved for each extraction well, followed by a recovery test after the final steady-state had been reached. Pressure drawdown curves are obtained from differential and/or absolute pressure transducers attached to the observation well. Observation wells include depth-discrete sampling ports of permanent monitoring wells (nested clusters installed using hollow stem augers), depth-discrete ports of temporary FLUTe wells (installed using cone penetrometers), or deep "ports" using water table wells with screens extending into the vadose zone. Keller and Lowry (1990) describe the FLUTe well, also known as SEAMIST. A microprocessor-controlled data acquisition system is used that is specifically designed to accommodate the logging of multiple pressure monitoring locations with a single transducer. Subsurface pressure data collected in the field is adjusted for lag-time and damping effects relative to surface monitored barometric pressures.