TECHNOLOGY APPLICATION ANALYSIS

SITE

U.S. Department of Energy
Savannah River Site
A/M Area
Aiken, South Carolina

TECHNOLOGY APPLICATION

This analysis covers an effort to **pump and treat groundwater** contaminated with volatile organic compounds **(VOCs)** by above ground **air stripping.** Full scale treatment began in September 1985 and is one component of an ongoing environmental restoration program. This analysis covers performance through December 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The Savannah River Site's historical mission has been to support national defense efforts through the production of nuclear materials. Production and associated research activities have resulted in the generation of hazardous waste byproducts now managed as 266 waste management units located throughout the 300 square mile facility.
- The A and M areas at Savannah River have been the site of administrative buildings and manufacturing operations respectively. The Savannah River Laboratory is also located within the A area. Specific manufacturing operations within the M area include aluminum forming and metal finishing.
- The M area operations resulted in the release of process wastewater containing an estimated 3.5 million pounds of solvents. From 1958 to 1985, 2.1 million pounds was sent to an unlined settling basin which is the main feature of the M-Area Hazardous Waste Management Facility (HWMF). The remaining 1.3 million pounds was discharged to Tims Branch, a nearby stream, during the years 1954 to 1982.
- Discovery of contamination beneath the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot groundwater remediation system began operation in February 1983. Full-scale groundwater treatment began in September 1985.

Contaminants of Concern

Contaminants of greatest concern in the groundwater are:

1,1,2-trichloroethylene (TCE)
tetrachloroethylene (PCE)
1,1,1-trichloroethane (TCA)

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property at STP*	Units	TCE	PCE	TCA
Empirical Formula	-	$ClCH{=}CCl_2$	$Cl_2C{=}CCl_2$	CH_3CCl_3
Density	g/cm^3	1.46	1.62	1.31
Vapor Pressure	mmHg	73	19	124
Henry's Law Constant	$atm\cdot m^3/mole$	9.9E-3	2.9E-3	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	300-1334
Octanol-Water Partition Coefficient; K_{ow}	-	195	126	148

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*

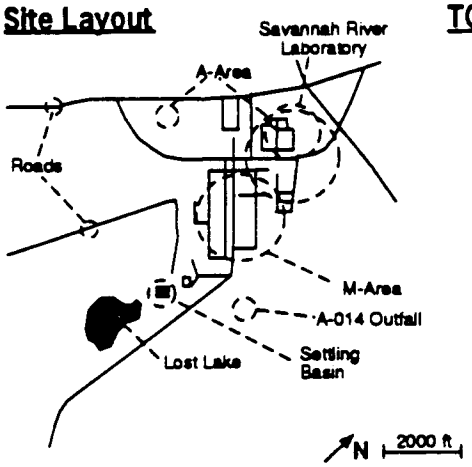
Nature & Extent of Contamination

- Approximately 71% of the total mass of VOCs released to both the settling basin and Tims Branch was PCE, 28% was TCE and 1% was TCA.
- The dissolved organic solvents are estimated to be 75% TCE. A continued source for dissolved phaseVOCs is contaminants sorbed to solids in the saturated zone or in the vadose zone.
- The area of VOC contaminated groundwater has an approximate thickness of 150 feet, covers about 1200 acres and contains contaminant concentrations as high as 223 ppm.
- Dense nonaqueous phase liquids (DNAPLs) were found in 1991 and present complications to long term remediation efforts.

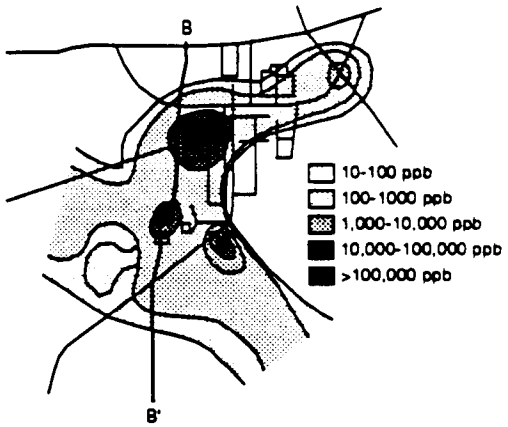
Contaminant Locations and Geologic Profiles

Data from hundreds of soil borings, groundwater monitoring wells and a variety of other investigative techniques has allowed the development of a three dimensional conceptual model of the site including groundwater behavior and contaminant concentration profiles for various geologic units. The following diagrams have been included here to provide a general understanding of site conditions. Data from the third quarter of 1985 is presented.

Site Layout

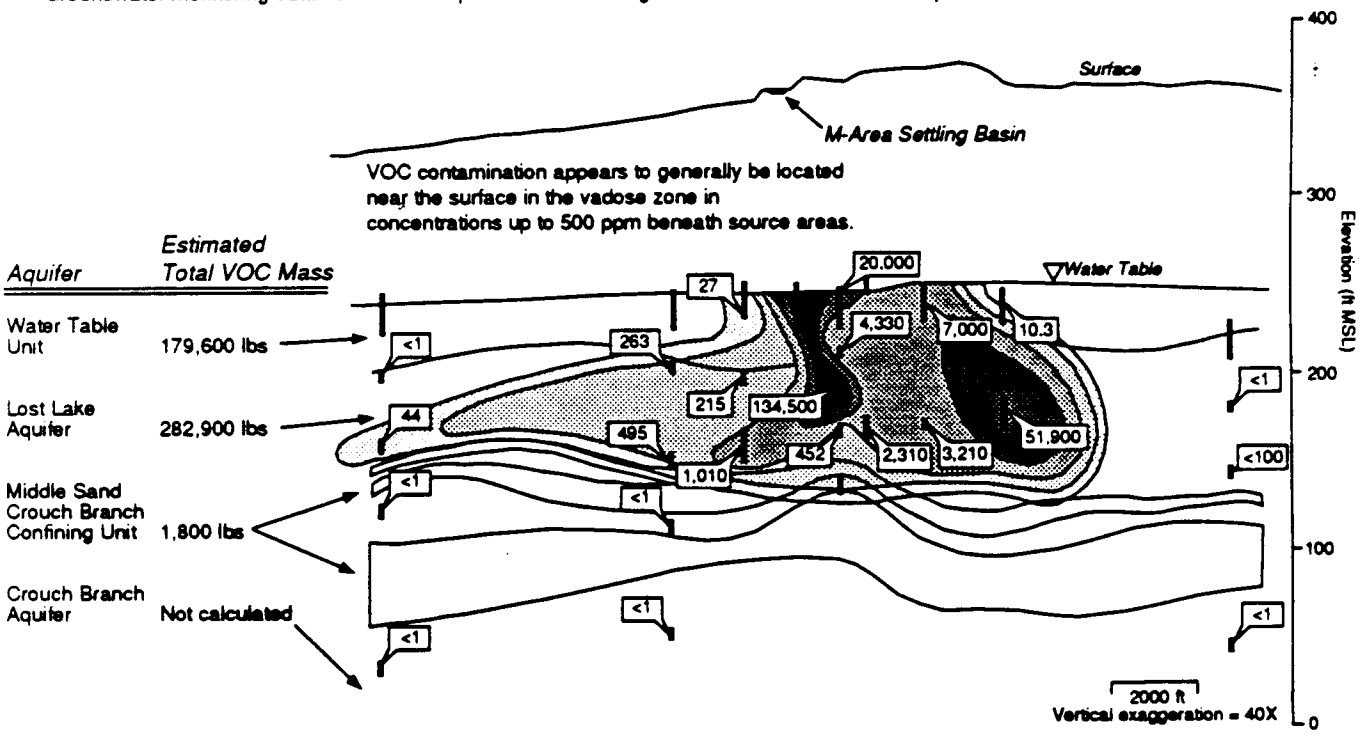


TCE Plume (Upper Lost Lake Aquifer Top View)



TCE Plume (Side View)

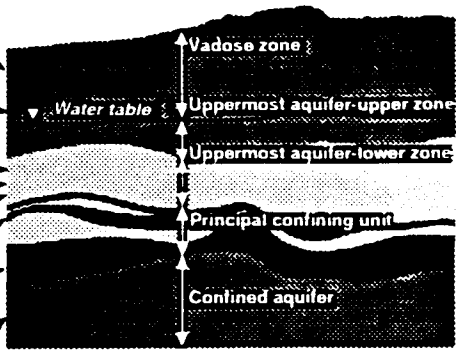
Groundwater monitoring data from the third quarter of 1985 along cross-section B-B' shown in top view



Contaminant Locations and Geologic Profiles (Continued)

Hydrogeologic Units

Aquifer	Subunit	Description	Thickness
	Upland	Poorly sorted mix of sand, cobbles, silt & clay.	~57 ft
	Tobacco Road	Moderate to well sorted, fine to medium sand containing some pebbles; 13% silt & clay.	0-97 ft
	Dry Branch	Moderately to well sorted medium sand; 18% silt & clay.	30-55 ft
Water Table Unit		Moderate to well sorted fine sand with some calcareous zones; 25% silt & clay; 14% silt and clay beds.	16-34 ft
Lost Lake Aquifer	Upper	Well sorted fine to medium sand; 16% silt & clay; 7% silt & clay beds.	14-60 ft
	Discontinuous clay beds containing 70% silt & clay		
	Lower	Moderate to well sorted medium sand; 17% silt & clay; 7% silt & clay beds.	4-44 ft
Crouch Branch Confining Unit		Clay, clayey silt, and poorly sorted fine to coarse, clayey sand; 62% silt 7 clay; contains 2 major clay layers the lower of which is 10-56 ft thick and is the principal confining unit for the Black Creek Formation.	32-95 ft
Crouch Branch Aquifer		Very poorly to well sorted, medium to coarse sands; 5% sand & clay beds; an important production zone for water supply wells in the M-Area.	152-180 ft



Site Conditions

- The A/M-Area is approximately one mile inward from the northeast boundary of the 300 square mile Savannah River Site. Adjacent to the site boundary are rural and farming communities.
- The Savannah River Site includes a complex hydrogeology arising from heterogeneities in the multilayer aquifer system and discontinuous sand & clay layers.

Key Aquifer Characteristics

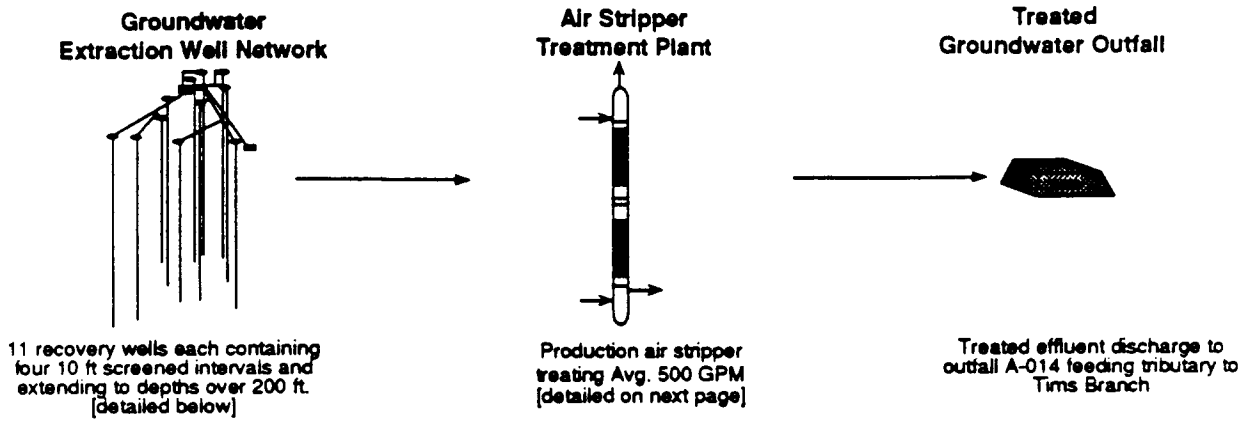
Aquifer parameters beneath the A/M-Area have been estimated as:

Unit	Hydraulic Conductivity [ft/day]	Transmissivity [gpd/day]	Flow Direction
Water Table Unit	9	175	Flow in the unconfined water table unit within the McBean Formation is complex but radial flow is expected outward from a plateau (at 244 MSL) surrounding most of the A/M-Area.
Lost Lake Aquifer	Avg. 40	Avg. 1750	Ranged from southwest to northeast near the A/M-Area in the Upper Lost Lake. Mainly east and south in the Lower Lost Lake during 1985-86.
Middle Sand Crouch Branch Confining Unit	29	1600	Mainly southeast during 1985-86.
Crouch Branch Aquifer	73	12,500	Mainly southeast during 1985-86.

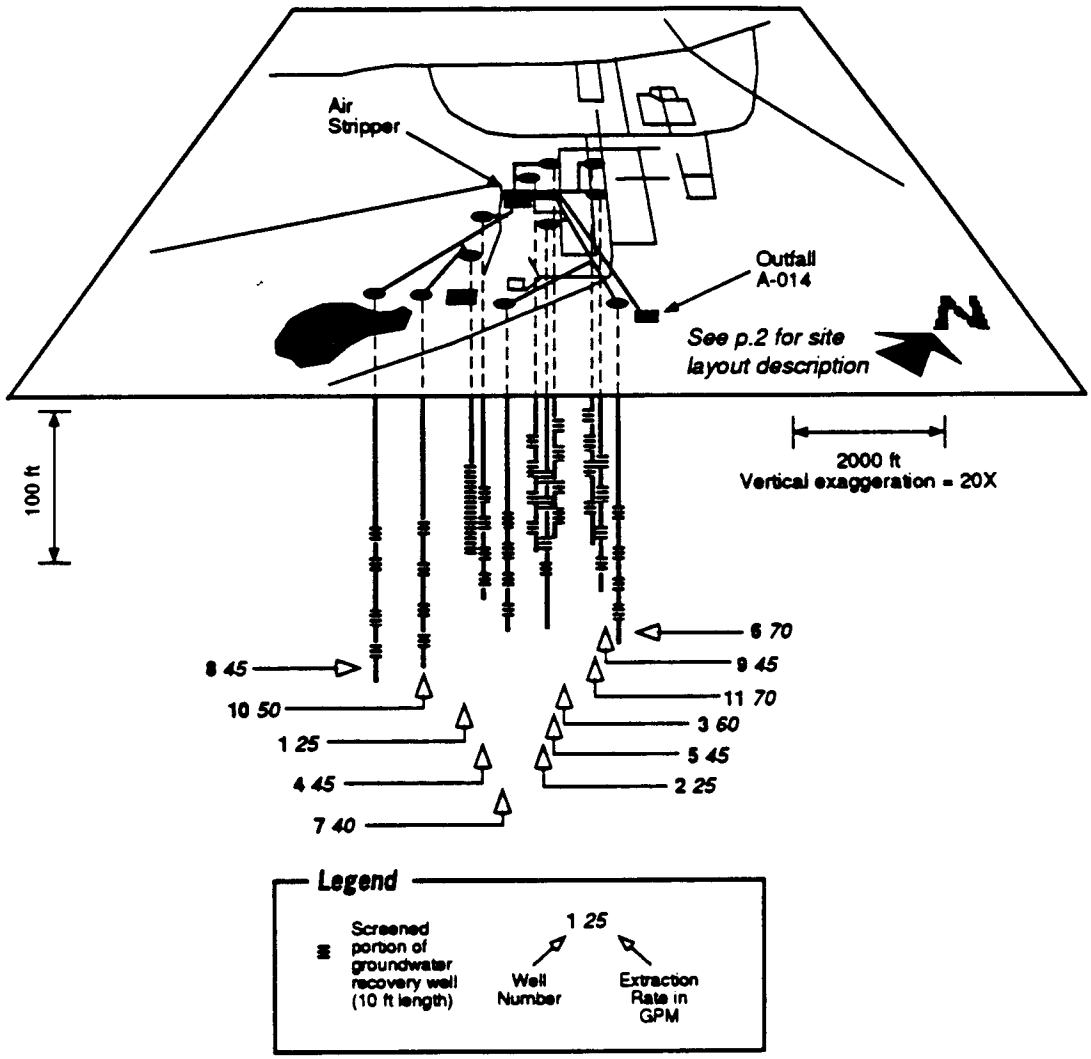
- A wide range of values has been used to describe regional aquifer characteristics. Uncertainties stem from difficulties in aquifer testing and interpretating methods applied to the hydrogeological complexities noted above under Site Conditions.
- A moderate downward gradient appears to exist beneath the M-Area. Vertical flow rates have been estimated to be from 2 to 8 feet per year.
- Radial flow outward from a groundwater plateau surrounding most of the A/M-Area within the water table unit and Upper Lost Lake aquifer is approximately 15 to 100 ft/year.

TREATMENT SYSTEM

Overall Process Schematic

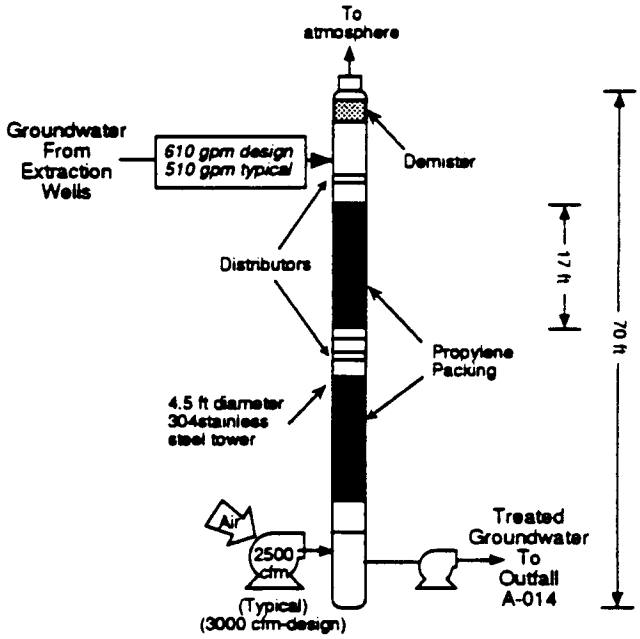


Extraction Well Network



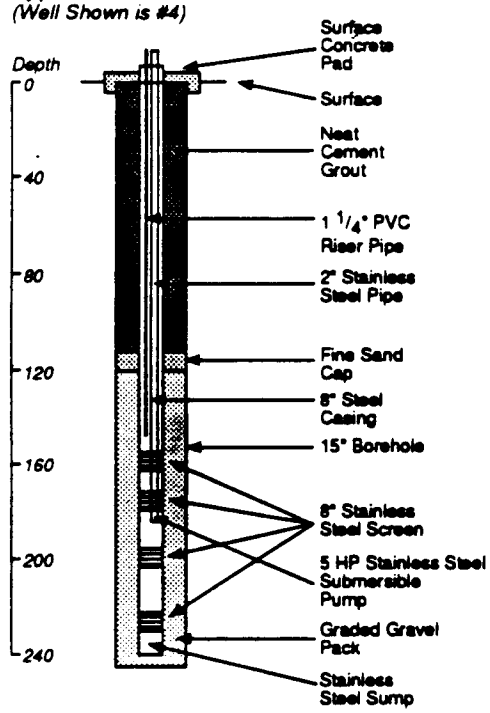
Air Stripper System Schematic

- In 1988, the original pall ring packing was replaced with cascade mini-rings to provide more surface area and less pressure drop across the system.
- In 1990, system in flow was upgraded from 400 gpm to 510 gpm.
- Drawing not to scale.



Extraction Well Close-Up

Typical Extraction Well
(Well Shown is #4)



Key Monitored Operating Parameters

- Water flows
- Air flows

(to assess system operation)

- Pump discharge pressures
- Groundwater levels

(to assess zone of capture)

- Contaminant concentrations in treatment plant influent & effluent

(to assess treatment effectiveness)

- Contaminant concentrations in groundwater

(to assess achievement of remediation goals)

PERFORMANCE

Performance Objectives

- Achievement of Groundwater Protection Standards (GWPS) established as part of a RCRA permit for the M-Area. The GWPS are based on EPA's Maximum Contaminant Levels (MCLs) of 5 ppb for TCE and PCE and 200 ppb for TCA.
- Prevent migration of contaminated groundwater toward the Savannah River Site boundary and downward into the confined aquifer (Black Creek Formation).
- Achieve cleanup goals within 30 years.

Treatment Plan

The overall long-term environmental restoration strategy for the A/M-Areas involves an integrated approach containing three major elements. Only the larger A/M air stripping effort is fully detailed in this analysis:

- Operation of **pump-and-treat** systems to hydraulically **contain** contaminant plumes and **remove contaminant mass** from groundwater.

  One 600 GPM capacity air stripper treats an average water flow of 510 GPM drawn from 11 extraction wells throughout the A/M area; a second stripper treating an average of 55 GPM from 1 extraction well near the Savannah River Laboratory in the A-Area.

- **Further characterization** of nature and extent of contamination with increasing focus on dense nonaqueous phase liquid (**DNAPL**) contamination.

  The use of minimally invasive techniques, such as the cone penetrometer and geophysical techniques, are currently recommended for future use to fully characterize the extent of DNAPL contamination.

- Development, demonstration and implementation of **technologies to supplement pump-and-treat** efforts with increasing focus on **source area, DNAPL and vadose zone** remediation.

  Soil vapor extraction, in situ air stripping, in situ heating, and surfactant flushing techniques are in various stages of implementation or demonstration.

Initial Process Optimization Efforts

Air stripper viability was tested through a succession of field programs:

Pilot Air Stripper	→	Prototype Air Stripper	→	Full Scale Production Air Stripper
Constructed and operated for 24 months beginning in 1983; 34 ft high; 20 GPM capacity; removed 16,100 lbs VOCs.		Stainless steel construction; operated for 14 months; 46 ft high; 50 GPM capacity; removed 15,800 lbs of VOCs.		Stainless steel construction; 70 ft high, 610 GPM design capacity; removed 270,000 lbs of VOCs since startup in 9/85.

Operational Performance

System Throughput

- For 1993, 243 million gallons of groundwater were pumped from 11 recovery wells to the production air stripper.
- Average water flow rate was 479 GPM and average air flow rate was 2,489 cfm through the air stripper during 1993.
- 19,500 lbs of VOCs were removed in 1993 which produced an average air emission rate of 2 lbs/hr.

System Downtime

- Average utility for 1993 was 96.4%. Cumulative average utility since 1985 is 95.3%.
- 1993 experienced 316 hours of downtime.
- Causes of downtime included scheduled maintenance, operator training, power outages, and equipment repair.

Hydrodynamic Performance

- Current estimates of the 30 year zone of capture of the pump and treat system have determined that portions of the existing plume will not be effectively controlled. Contaminated groundwater beneath the Savannah River Laboratory and southeast of the settling basin are beyond the anticipated capture zone. However, contaminated groundwater in the source areas and areas of highest VOC concentration is contained.

- The downward gradient across the Crouch Branch Confining Unit, and consequently the driving force for downward contaminant migration to the confined aquifer in the Crouch Branch Aquifer, has been reduced due to pumping effects.

- The groundwater recovery wells are screened in the more permeable areas of the shallow aquifer which increase hydraulic control yet limits access to silt and clay layers where retention of contaminants may be strongest.

Treatment Performance

Effects on Plume

- Reductions in contaminant plume size and concentration as a result of remediation are evident (the >100,000 ppb contaminant concentration zone has disappeared) but are generally limited to areas near recovery wells.

- Significant progress is evident in the Lost Lake Aquifer where initial contaminant concentration and hydraulic conductivity are highest.

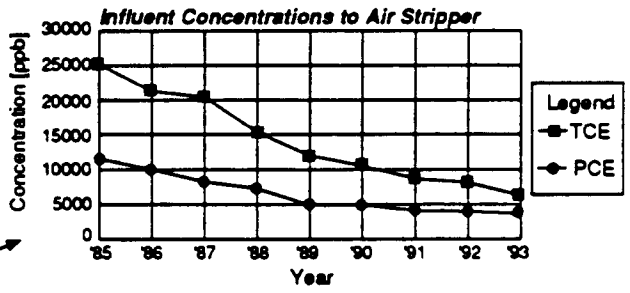
- Downward migration of VOCs to the Crouch Branch Aquifer beneath the settling basin and north of the M-Area is evident. VOC concentrations have increased slightly in the confined aquifer since 1985.

TCE & PCE vs Time at Influent

- The concentration of TCE in extracted groundwater has varied widely over short (one year) time frames for individual wells. Some wells have shown short term increases in contaminant concentration, some decreases and others no clear trend.

- The trends may indicate plume redistribution and may also represent a decline in plume strength.

- There has been a clear reduction in overall contaminant concentrations sent to the air stripper.



Air Stripper Influent vs Effluent

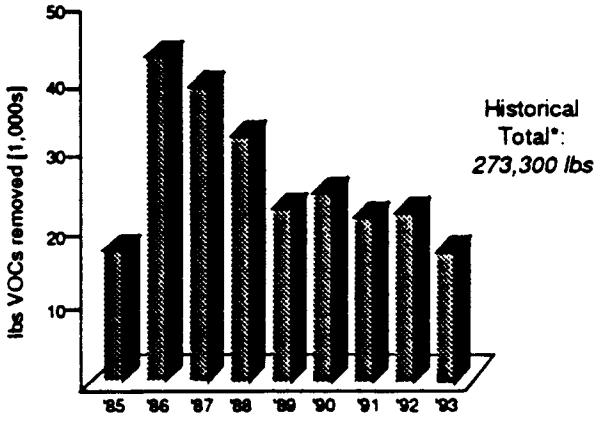
- Average VOC removal efficiency >99.9%

- All VOCs treated below discharge criteria.

Compound	Average Concentration* [ppb] Influent	Effluent
TCE	15,006	<1.01
PCE	6,705	<1.0
Total	21,711	<1.12

*data from September 1985-1993

Total Pounds VOCs Removed



*based on data from Sept. 1985 through end of 1993

COST

• The production air stripper was designed and constructed in 1984-1985. The major capital cost elements associated are provided below. Annual operating costs based upon data from 1985 through 1990 are also listed. All information is based on an analysis performed in 1990 and all costs are in 1990 dollars.

• During 1985 to 1990, the average volume of water treated by the air stripper was 198 million gallons per year. Using the operating costs detailed below (in 1990 dollars), the total cost of operation and maintenance is $0.75 per 1000 gallons treated.

• An assessment of total cost and duration of operation for the pump and treat system to complete the cleanup is not possible due to the multi-phased approach to environmental restoration of the A/M Area. As detailed on page 6, the overall treatment plan for the site includes future identification and implementation of technologies to achieve cleanup goals. The extent to which the pump and treat system will be part of that effort has not yet been determined therefore projected costs to cleanup can not be estimated.

Capital Costs

Design	$420,000
Contracts (permitting, modeling, etc.)	368,000
Site Development	28,000
QA Engineering	18,000
Control Building	211,000
Electrical	877,000
Instrumentation	466,000
Piping/Construction	925,000
Tower Installation	132,000
Control System	230,000
Erect/Test Tower	428,000
Total	**$4,103,000**

Operating Costs

Electrical Power (@ $0.052/kwh)	$26,000
Maintenance	
Labor (@ $35/hr)	13,500
Equipment repair & replacement	13,000
Operation	
Operation & daily inspections	45,700
Well sampling & lab analysis	15,000
Engineering support	36,000
Total Annual Operating Cost	**$149,200**

REGULATORY/INSTITUTIONAL ISSUES

• The production air stripper is part of the M-Area Hazardous Waste Management Facility which is permitted under the Resource Conservation and Recovery Act (RCRA). The air stripper unit is permitted as a waste water treatment facility requiring South Carolina certified Class-D physical/chemical operators. The air stripper unit is not regulated as a RCRA treatment, storage, disposal (TSD) facility.

• The air stripper has a South Carolina Bureau of Air Quality Control permit allowing the release of 34 tons/year (or 7.9 lbs/hr) of VOCs to the atmosphere.

• Recent Clean Air Act requirements mandate that industrial off gas systems be retrofitted with an off-gas treatment system. Catalytic oxidation has been demonstrated as an effective off-gas treatment and the M-Area air stripper is being retrofitted. The system will be installed by 1995, even though regulations for mitigation will not require retrofit until 2000.

• Treated water effluent from the stripper is released through an National Pollution Discharge Elimination System (NPDES) permitted outfall. The EPA Maximum Contaminant Levels (MCLs) listed under "Cleanup Criteria" below apply to this discharge.

• The facility's RCRA Part B permit requires periodic sampling at the recovery wells, air stripper and NPDES outfall.

• Eight production wells drawing from the Crouch Branch Confined Aquifer currently supply process and drinking water for A/M-Area Site operations.

Cleanup Criteria

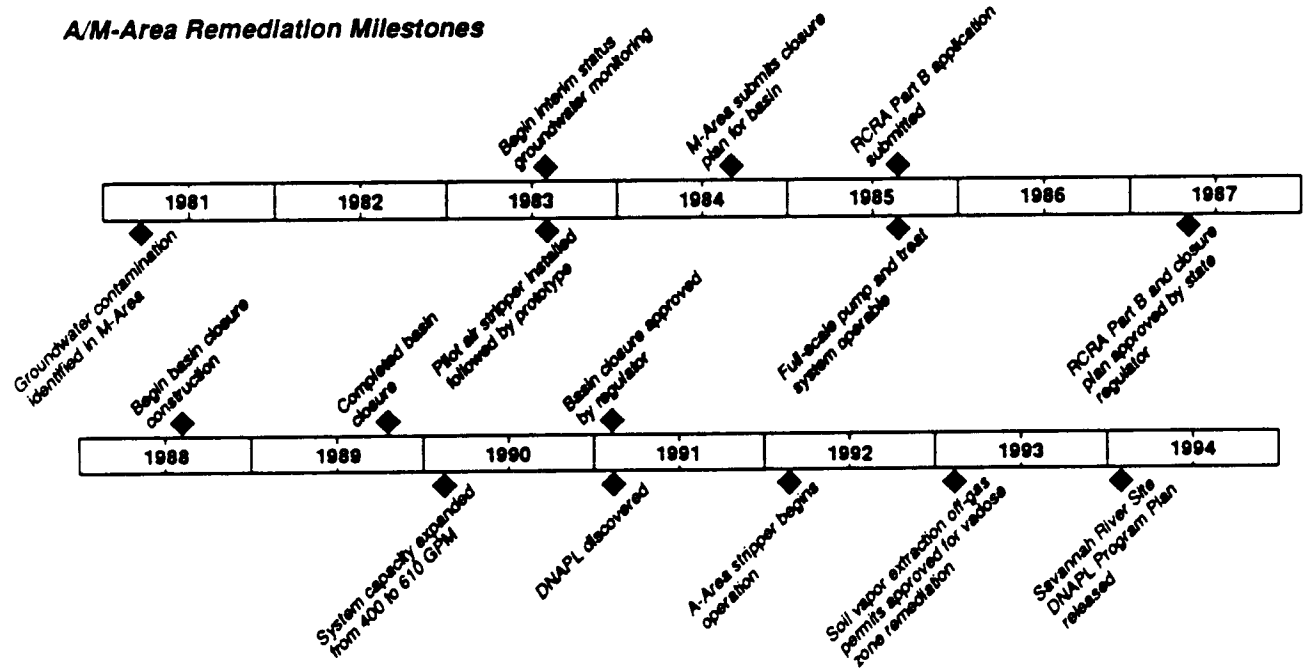
• During initial remediation efforts in 1985, a cleanup goal of removal of 99% of VOCs over a 30 year period was used. A CERCLA baseline risk assessment was not developed or required.

• In 1990, groundwater protection standards based upon EPA MCLs were adopted during modifications of the facility's RCRA permit. The standards are:

Compound	*Criteria Level [ppb]*
TCE	5
PCE	5
TCA	200

SCHEDULE

A/M-Area Remediation Milestones



LESSONS LEARNED

Implementation Considerations

• An integrated treatment program consisting of pump and treat for hydraulic control and dissolved plume mass removal combined with source/DNAPL targeted technologies has been determined to be the most effective long term remedial solution for the M-Area VOC plume at Savannah River.

• Technologies to supplement the pump and treat systems are in various stages of development, demonstration or implementation. These technologies focus on either the source area, DNAPL or vadose zone contamination and include soil vapor extraction, in situ air stripping, in situ bioremediation, in situ heating and surfactant flushing.

• There is a recognized need for supplemental site characterization efforts to redirect ongoing remediation activities at the site. Further characterization will focus on DNAPL contamination and will involve minimally invasive methods such as the cone penetrometer and geophysical techniques.

• Significant volumes of VOC-contaminated purge water are generated from sampling the extensive network of over 250 monitoring and compliance wells. Modifications to the air stripping system were implemented to treat this groundwater. The system changes include addition of a 10,000 gallon carbon steel receiving tank and associated piping.

Technology Limitations

• The presence of DNAPLs represents a significant long-term limitation to pump and treat due to residual DNAPL above and below the water table combined with mass removal limitations.

• Hydraulic factors, combined with the nature of contaminants, has inhibited the pump and treat system's ability to affect the fringes of the plume. However, the contaminated groundwater in the source areas and areas of highest VOC concentration is contained.

• Pump and treat is effective for plume restoration only where DNAPL source areas have been contained or removed.

Future Technology Selection Considerations

• Early M-Area remediation efforts did not address the long term prospect of removing residual levels of contamination. Future cleanups at sites with chlorinated solvents must carefully look for DNAPL during site characterization and address DNAPL and residual contamination removal as part of an overall remediation plan.

• The original aim of the pump and treat system in the M-area was for broad plume containment and destruction of 99% of the VOCs. This goal was later changed to achievement of EPA MCL based groundwater protection standards. Future pump and treat systems should consider the actual environmental and human risks, be highly designed, and address realistic elements of overall cleanup goals.

• Pump and treat for containment of dissolved contaminants is a viable tool for dissolved phase VOC removal and can be an element of presumptive remedies for such sites.

• A phased approach to site assessment and remediation is beneficial. Early actions to control plume migration and remove contaminant sources, when properly designed and implemented, can reduce risks posed by contaminated groundwater.

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CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

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Savannah River Operations Office
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SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 5,7,8 and 9
Treatment System:	Source #s 5,6 and 7
Performance:	Source #s 1,2,3,5 and 7
Cost:	Source # 5
Regulatory/Institutional Issues:	Source # 5
Schedule:	Source #s 1,5, and 7
Lessons Learned:	Source #s 1,3, and 4.

Chronological List of Sources and Additional References

1. *Personal communications with J.E. Jordan,* Westinghouse Savannah River Company, April 1994.

2. *Corrective Action System Operation and Performance (Draft),* Fourth Quarter 1993 and 1993 Summary, WSRC-RP-93-67-4, February 1994.

3. *Savannah River Site DNAPL Technical Program Plan,* J.E. Jordan, et.al., Westinghouse Savannah River Company, February 1994.

4. *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration,* Interim Final, U.S. EPA, September 1993.

5. McKillip, S.T., K.L. Sibley and J.G. Horvath, *Air Stripping of Volatile Organics Chlorocarbons: System Development, Performance, and Lessons Learned,* Proceedings of Waste Managment '90, Roy Post, editor, 1990.

6. *Well logs for recovery wells (undated).*

7. *Evaluation of Ground-water Extraction Remedies: Phase II* EPA Publication 9355.4-05A, February 1992.

8. *Evaluation of Ground-water Extraction Remedies,* EPA/540/2-89-054, September 1989.

9. *Preliminary Technical Data Summary M-Area Groundwater Cleanup Facility,* DuPont - Savannah River Laboratory, October 1982.