Case Study Abstract

Pump & Treat of Contaminated Groundwater at Operable Unit B/C McClellan Air Force Base, California

Site Name:
McClellan Air Force Base, Operable Unit (OU) B/C

Location:
Sacramento, California

Contaminants:
Chlorinated Aliphatics
- Trichloroethene (TCE), cis-1,2-Dichloroethene (cis-1,2-DCE), Tetrachloroethene (PCE), 1,2-Dichloroethane (1,2-DCA)
- In an area of 7,800 million cubic feet, there is an estimated 33,000 kg of VOCs; percent of total mass for individual constituents is TCE (82.7%), cis-1,2-DCE (0.5%), PCE (16.7%), 1,2-DCA (0.1%)

Period of Operation:
Status: Ongoing
Report covers - 1988 to 1993

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Not Available

Technology:
Groundwater Extraction followed by Aboveground Air Stripping
- 7 extraction wells pump to a main treatment plant
- Air stripper - design capacity of 1,000 gpm; average flow rate of 250 gpm
- Supplemental Treatment - thermal oxidizer and caustic scrubber for offgases; two GAC units in series to polish liquid phase prior to discharge

Cleanup Authority:
DoD

SIC Code:
9711 (National Security)

Point of Contact:
Remedial Project Manager
McClellan AFB
Sacramento, CA

Waste Source:
Landfill; Underground Storage Tank; Disposal Pit; Open Burn Area

Type/Quantity of Media Treated:
Groundwater
- As of 1/94: Over 660 million gallons of groundwater treated since startup in March 1987
- Groundwater subsurface consists of 5 distinct monitoring zones (A through E); evidence points to hydraulic link among 5 zones
- Hydraulic conductivity ranges from 2.8 to 30.7 ft/day
- Transmissivity ranges from 100-2,000 ft^2/day

Purpose/Significance of Application:
Full-scale remediation of groundwater contaminated with VOCs using groundwater extraction and aboveground air stripping.

Regulatory Requirements/Cleanup Goals:
Final cleanup criteria have not been established at this time
- Current target is <0.55 µg/L VOCs for groundwater
- NPDES permit - acetone, MEK, and MIK to <1 mg/L and VOCs to <0.5 µg/L

Case Study Abstract

Pump & Treat of Contaminated Groundwater at Operable Unit B/C McClellan Air Force Base, California (Continued)

Results:
- Influent VOC concentrations have decreased from about 60 ppm in 1987 to about 4 ppm in 1993
- The effluent from the treatment system has been below the permitted discharge levels since operation began
- As of 3/94, approximately 44,000 lbs of VOCs have been removed since startup

Cost Factors:
- Total Capital Cost in 1987 - $4,000,000 (including over $1,700,000 for the incinerator, air stripper, scrubber, wells, and GAC tanks, and about $1,000,000 for heat exchangers, blowers, pumps, and compressors; control center)
- Total Annual Operating Costs - $1,240,000 (including contractor operations, utilities, sampling and analysis, project management)
- An estimated total cost for completing the cleanup is not available at this time

Description:
The McClellan Air Force Base in Sacramento, California was established in 1937. Operations at the 3,000-acre facility include aircraft, electronics, and communications equipment maintenance and repair, and a wide variety of hazardous materials have been used at the site. The site was added to the National Priorities List in 1987. Areas of contamination at the site include Operable Unit B (OU B) and Operable Unit C (OU C). Releases from OU B resulted from disposal/release of hazardous substances from landfills, underground storage tanks, storage lots, burial and burn pits. Releases from OU C were attributed to waste disposal activities. Extensive VOC contamination has been identified at the facility. The primary constituents of concern are TCE, cis-1,2-DCE, PCE, and 1,2-DCA.

A groundwater extraction and treatment system including air stripping was installed with operations beginning in 1988. Offgases from the air stripper are treated by thermal oxidation and caustic scrubbing. The effluent from the air stripper is treated using GAC prior to a NPDES-permitted discharge. The 1993 data on the influent to the air stripper show that the VOC concentrations have decreased to about 4 ppm from concentrations of 60 ppm (1987). An estimated 44,000 pounds of VOCs have been removed as of March 1994. The remediation was ongoing at the time of this report and final performance data are not yet available. In addition, the treatment system has been effective in treating groundwater to below the NPDES discharge limits.

The total capital costs for this system are $4,000,000 and the total annual operating costs are $1,240,000. The system has been on line 98% of the time. Problems of scaling and deposition in the air stripper from calcium and magnesium salt precipitation were remedied by changing to 2-inch packing from 1-inch packing in the air stripper. Corrosion was minimized through material changes to nickel-based commercial alloys and change in physical layout to improve flow.

TECHNOLOGY APPLICATION ANALYSIS

SITE

McClellan Air Force Base
Groundwater Operable Unit (OU) B/C
Sacramento, California

TECHNOLOGY APPLICATION

This analysis covers an effort to pump and treat groundwater contaminated with volatile organic compounds (VOCs) by above ground air stripping. The treatment began in 1988, was expanded in 1990 and is ongoing. This analysis covers performance through 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- McClellan Air Force Base (AFB), an Air Force Command Logistics Center, was established in 1937. Operations have included the management and repair of aircraft, electronics and communications equipment. These activities have involved the use, storage and disposal of a wide variety of hazardous materials such as petrochemical solvents, cleaners, electroplating chemicals, heavy metals, polychlorinated biphenyls (PCBs), low-level radioactive wastes and fuel oils and lubricants.
- In 1987, the base was placed on the National Priorities List as the highest priority U.S. Air Force Installation.
- Investigations of groundwater contamination beginning in 1979 have identified three areas containing VOC plumes onbase and offbase. Overall contamination at 254 confirmed and potential sites have been grouped within 11 OUs.
- Base operations within OU B resulted in the disposal or environmental release of a wide variety of hazardous materials at landfills, underground storage tanks, storage lots, burial pits and burn pits. The primary nature of base activities within OU C was waste disposal. The Industrial Waste Line (IWL) conveyed wastes from numerous facilities to OU B and C and is itself a major source of contaminant releases.

Contaminants of Concern

The primary contaminants of concern (listed in order of frequency of detection) are:

Trichloroethene	(TCE)
cis- 1,2-Dichloroethene	(cis-1,2-DCE)
Tetrachloroethene	(PCE)
1,2-Dichloroethane	(1,2-DCA)

Contaminant Properties

Property at STP*	Units	TCE	cis-1,2-DCE	PCE	1,2-DCA
Empirical Formula	-	$ClCH{=}CCl_2$	$CHCl{=}CHCl$	$Cl_2C{=}CCl_2$	$C_2H_4Cl_2$
Density	g/cm^3	1.46	-	1.62	126@15°C
Vapor Pressure	mmHg	59	200	14	64
Henry's Law Constant	$atm\cdot m^3/mole$	8.9E-3	7.5E-3	2.3E-2	1.1E-3
Water Solubility	mg/L	1,000	3,500	150	8,690
Octanol-Water Partition Coefficient; K_{ow}	-	240	5	398	3
Organic Carbon Partition Coefficient; K_{oc}	-	126	32	661	14

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

Nature & Extent of Contamination

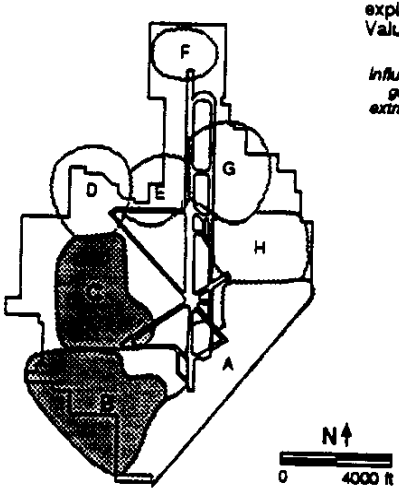
- Contaminants in groundwater have been found to exist in 3 separate phases at McClellan: sorbed to the soil matrix, solubized in porewater, or as free product. Contamination is additionally present dissolved in soil gas in the vadose zone.
- A drop in groundwater levels of 60 feet over the past 50 years has created a smear zone of contamination above the declining water table.
- In general, the concentrations of VOCs of concern in groundwater has decreased with time while the number of monitoring wells detecting the contaminants has increased.

Contaminant Locations and Geologic Profiles

Over 300 monitoring wells and 14 extraction wells have been installed basewide. In 1986, an extensive monitoring program was initiated to assess levels of volatiles, semivolatiles, metals, pesticides and dioxins. A small portion of this hydrogeologic and contaminant location data has been included here to provide a general understanding of site conditions.

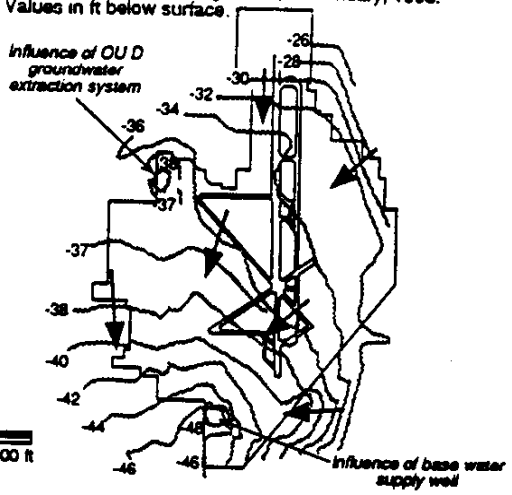
Site Layout

Operable Unit locations



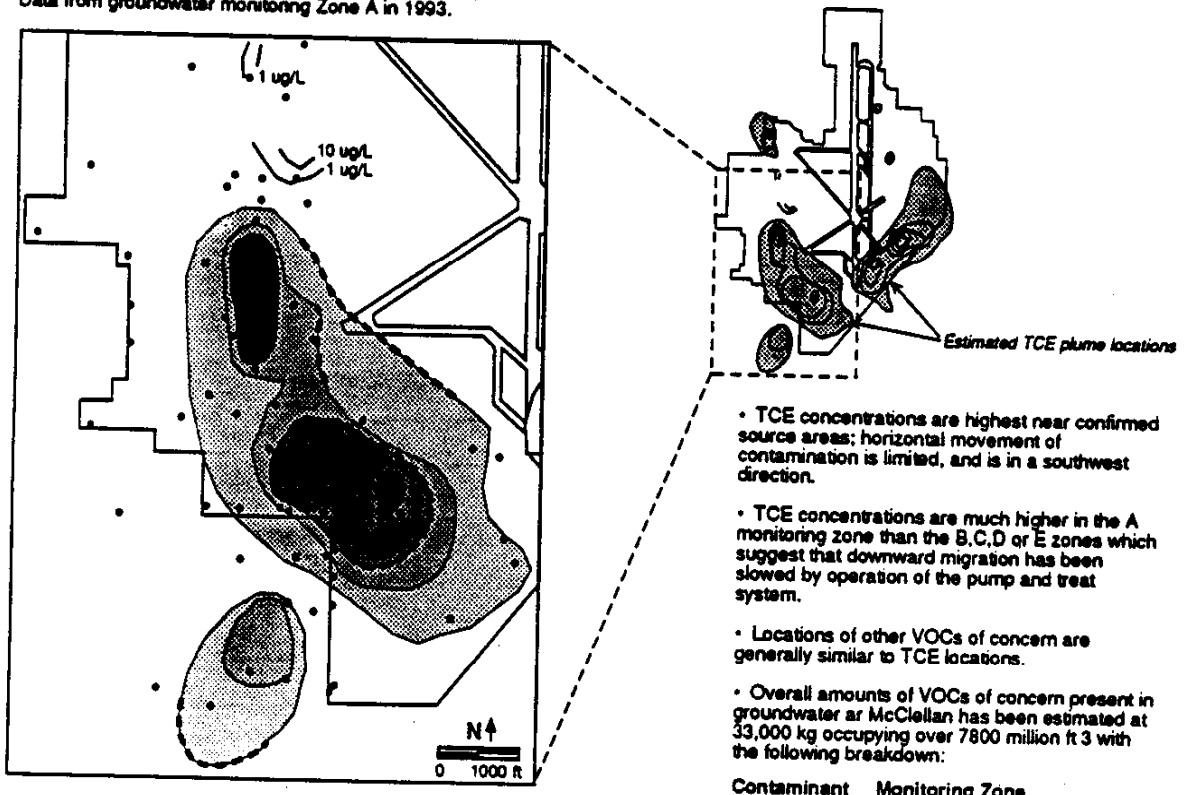
Groundwater Levels & Flow Directions

Data from groundwater monitoring Zone A (see p. 3 for explanation of monitoring zones) in January, 1993. Values in ft below surface.



TCE Plume

Data from groundwater monitoring Zone A in 1993.



Legend

all concentrations in ug/L

Monitoring or Extraction Well

Unbound Contour

0.1-1 ug/L
1-10 ug/L
10-20 ug/L
20-100 ug/L
100-1000 ug/L
>1000 ug/L

- TCE concentrations are highest near confirmed source areas; horizontal movement of contamination is limited, and is in a southwest direction.
- TCE concentrations are much higher in the A monitoring zone than the B,C,D or E zones which suggest that downward migration has been slowed by operation of the pump and treat system.
- Locations of other VOCs of concern are generally similar to TCE locations.
- Overall amounts of VOCs of concern present in groundwater ar McClellan has been estimated at 33,000 kg occupying over 7800 million ft 3 with the following breakdown:

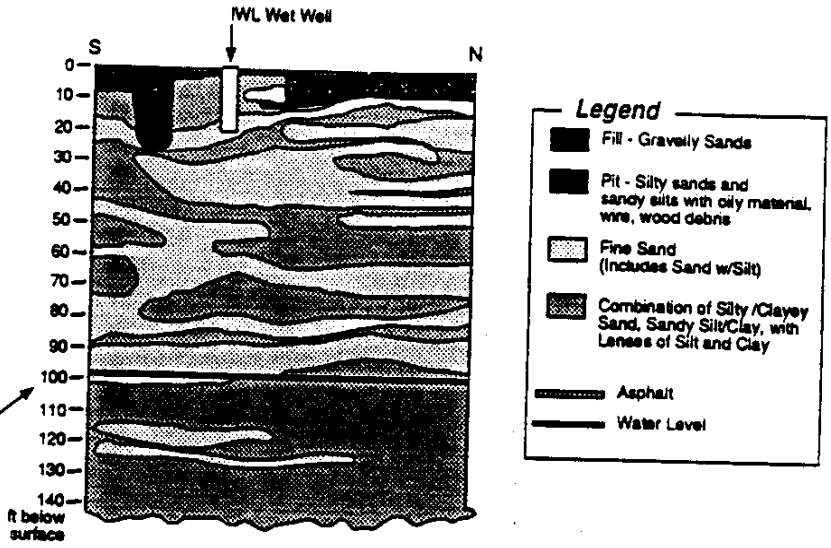
Contaminant of Concern	Monitoring Zone %A	%B	%C	% of Total Mass
TCE	38	42	20	82.7
cis-1,2-DCE	44	29	27	0.5
PCE	40	60	0	16.7
1,2-DCA	92	8	<1	0.1

Contaminant Locations and Geologic Profiles (Continued)

Hydrogeologic Profile

- Soils and geology at the base are a complex series of alluvial and fluvial deposits which were deposited, eroded and redeposited.
- Deposits of any one lithology are limited in horizontal and vertical extent: units rarely extend laterally for more than 50 ft.
- Extensive subsurface characterization has been performed to depths over 400 ft. below the surface which has aided understanding of the relative permeabilities of subsurface materials beneath each operable unit and within each monitoring well zone.

Soil boring data taken from a north-south cross section illustrates typical conditions beneath source area waste pits and the industrial waste line.



Site Conditions

- McClellan Air Force Base occupies nearly 3,000 acres and is located approximately 7 miles northeast of downtown Sacramento. Land use immediately adjacent to the base includes residential areas supplied by private well water for nonpotable uses. (Connection of residences west of the base to municipal rather than private water supplies was a remedial action initiated by the base in the late 1980s.)
- Topography is generally flat and sloping gently from the east side at 75 ft mean sea level (MSL) to the west side at 50 feet MSL.
- Climate is characterized by hot, dry summers and cool, moist winters with average annual temperature of 60° F and precipitation of 17 inches.
- Regional groundwater levels have dropped over 60 ft in the last 50 years, including a drop rate of 1.5 to 2 ft/yr for the past 10 years, due to pumping for agricultural irrigation, domestic use and base use.

Key Aquifer Characteristics

- The groundwater subsurface has been divided into five distinct monitoring zones (A, B, C, D and E) layered atop one another. However, there is strong evidence that the units are hydraulically linked. Each of the highly heterogenous zones have similar water levels, flow directions, vertical gradients and concentrations of inorganic species.
- Groundwater quality is characterized as a calcium-sodium-bicarbonate type excellent for irrigation and domestic use.
- Flow direction is mainly south in OU B/C in the A, B and C zones and is significantly influenced by a base water supply well in OU B. The supply well draws water at a rate of 1200 GPM from several screened depths up to 400 ft.
- Other key aquifer parameters have been estimated as

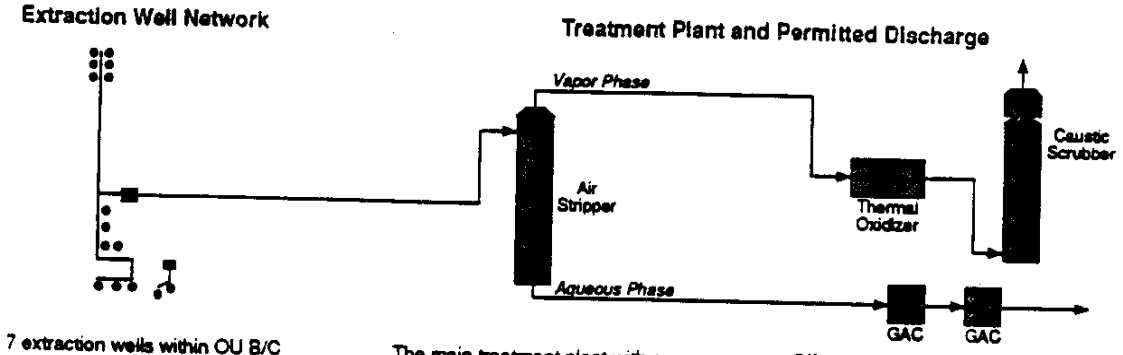
Zone	A	B	C
Transmissivity (ft^2/day)	100-900	250-500	500-2,000
Hydraulic Conductivity (ft/day)	2.8-25.7	3.8-7.7	7.7-30.7
Zone Thickness (ft)	35	65	65

- Other physical characteristics of the aquifer materials were measured during a series of basewide remedial investigations:

Parameter	Range
Organic carbon content, foc:	0.001 to 0.003
Moisture content, wet percent:	0.25 to 0.25
Porosity:	0.35 to 0.45
Bulk density, g/cm^3:	1.2 to 1.3

TREATMENT SYSTEM

Overall Process Schematic

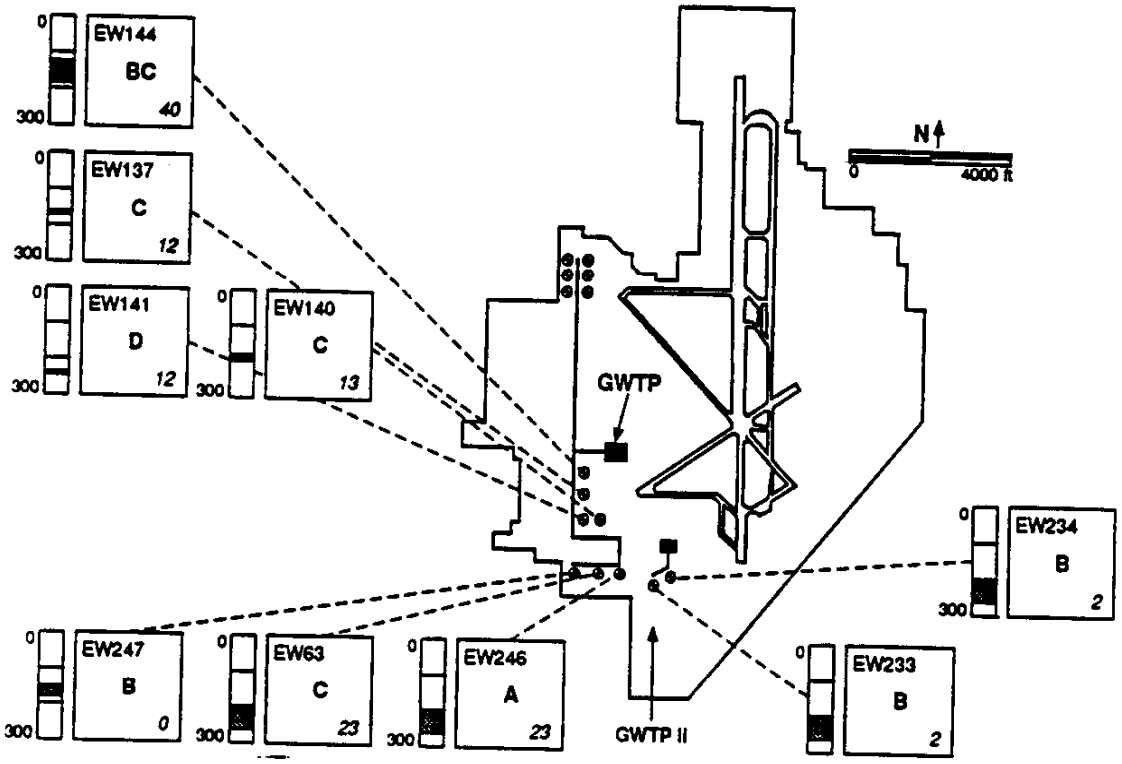


7 extraction wells within OU B/C pump water to a centralized treatment plant.
2 wells pump water to a small treatment unit within OU B

The main treatment plant with a capacity of 1000 GPM treats an average flow rate of 250 GPM by air stripping

Offgases are thermally treated and scrubbed before release to the atmosphere. Liquid effluent is polished by granular activated carbon (GAC) before discharge to a nearby stream.

Extraction Well Network



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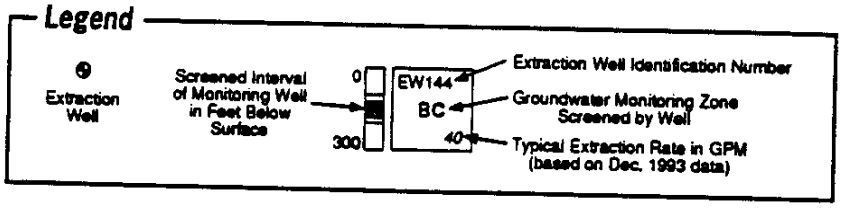
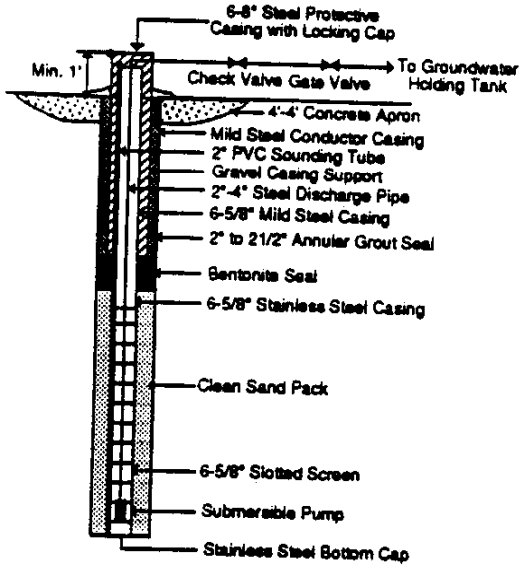


Extraction Well Detail

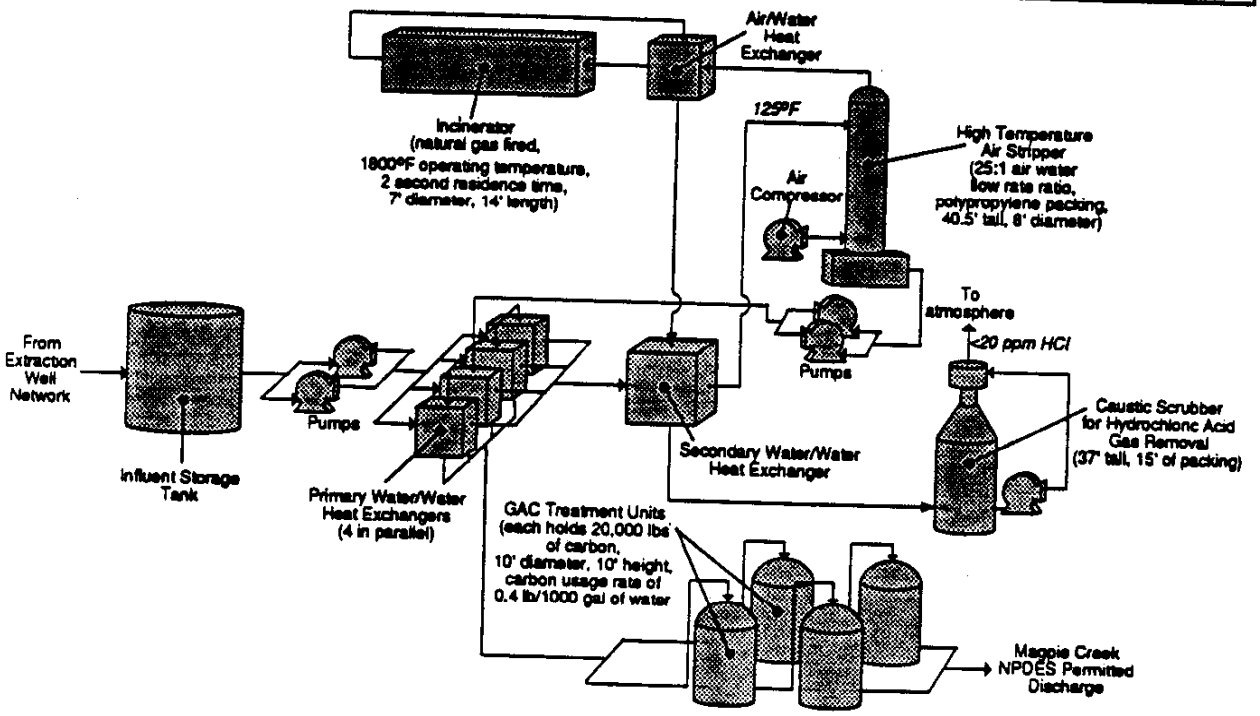


Design Evolution

The GWTP has undergone several significant redesigns. The current configuration presented below reflects changes made to minimize scaling problems in the configuration of heat exchangers as well as to accommodate lower influent flow rates and VOC concentrations. The configuration shown has been used for all but few months of the GWTP operation. Specific design changes have included:

- Introduction of recycle loops to allow air stripper operation at lower than originally anticipated flow rates. The original design was based upon an influent stream of 1000 GPM while actual rates have ranged from 100 to 250 GPM.
- Reduction in maximum system water temperature from 188°F to 120°F as a result of improved internal recycling of aqueous streams.
- Replacement of carbon steel air-water heat exchanger with nickel-based commercial alloy equipment to decrease susceptibility to corrosion from acid gas condensation.
- Rearrangement of heat exchange network to reduce susceptibility of scaling from precipitation of calcium and magnesium salts.
- Replacement of air stripping packing material to a medium with larger void space to reduce susceptibility of fouling from scaling buildup.
- Elimination of activated sludge treatment process for kerosene removal, which followed the granular activated carbon (GAC) treatment, once influent ketone concentrations fell below detection limits.

Treatment System Schematic



- The plant operates 24 hours/day, 365 days/year and is staffed by 4 full time employees working two 12 hour shifts and 1 part time secretary. At least one operator is on duty at all times.
- The plant has full spare backup pumps and blowers and backup GAC and heat exchange capacity at low flow rates.
- GWTP II which operates within OU B is a simple arrangement of two groundwater extraction wells pumping approximately 2 GPM each through a double-contained pipeline equipped with a leak detection system to a holding tank. The groundwater is then pumped through a bag filter and treated by two GAC adsorption units in series.

PERFORMANCE

Performance Objectives

A primary objective of the GWTP and its associated extraction well network within OU B/C is to limit the offbase subsurface migration of contamination plumes beneath the OU.

Additional groundwater operable unit priorities include:

- Control of concentrated areas of contamination or hot spots.
- Remediation of contamination between the hot spots and plume boundary.

Remedial Action Plan

The remediation strategy for OU B/C includes:

Ongoing

Pumping and treatment of groundwater to prevent further migration of pollutants. This effort is the focus of this analysis.

Future

- Continued implementation of existing technologies and possible upgrade to accommodate higher flow rates of contaminated groundwater from other areas on the west side of the base. A similar treatment plant is proposed as a remedial alternative for the east side.
- Incorporation of innovative technologies within current efforts particularly to address hot spot (>500 ug/L VOCs) areas. These technologies include in situ anaerobic biodegradation, soil vapor extraction with air-sparging, cometabolic treatment, and dual-phase extraction.

Operational Performance

As of January 1994 the GTWP had treated over 660 million gallons of groundwater since startup in March 1987.

During 1993 the GWTP:

- Treated over 73 million gallons of groundwater
- Was online 98% of all available time
- Experienced 2 major repairs
- Experienced 9 minor repairs
- Consumed 2.2 million ft^3 of natural gas, 200,000 kwhrs of electricity, approximately 650 gallons of sodium hypochlorite, and over 50 gallons of sodium hydroxide

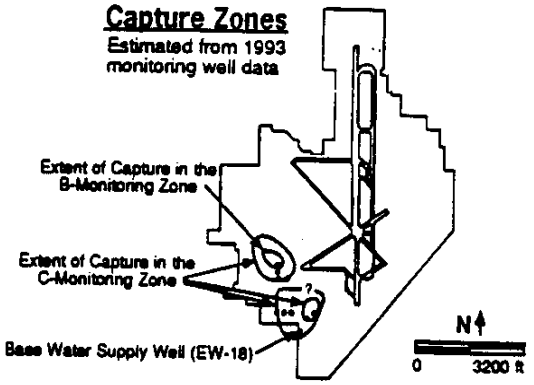
GWTP II had processed a total of 7.9 million of groundwater as of January 1994 and had only one minor repair during 1993 which allowed for a 98% total system uptime percentage.

Hydrodynamic Performance

- Within OU B the five existing extraction wells pump water either to the GWTP or the local carbon treatment unit (GWTP II). In addition, a base water supply well is located within OU B and creates a radius of influence of approximately 500 to 700 ft in the A and B zones and a slightly higher influence in the C zone due to a larger screened interval.

- The four extraction wells in OU C capture approximately 90 GPM from the A, B and C zones but do not contain the known groundwater contamination areas.

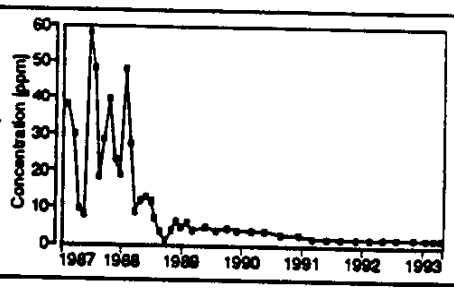
Capture Zones
Estimated from 1993 monitoring well data



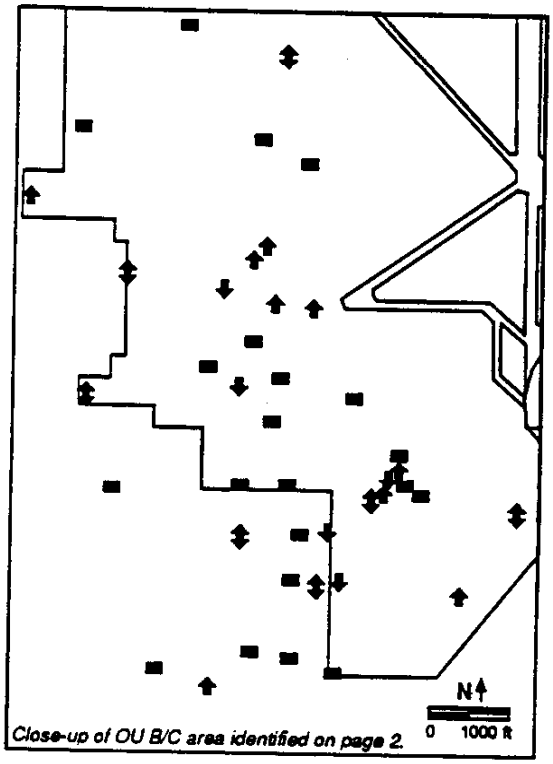
Treatment Performance

Influent & Effluent Data

- The concentrations of contaminants in the GWTP influent has varied over short time periods but has exhibited a significant downward trend since startup.
- Influent VOC concentrations were approximately 60 ppm in 1987 and have decreased to approximately 4 ppm.
- The GWTP has consistently removed VOCs to below established discharge criteria for primary contaminants since startup.
- Over 44,000 lbs of VOCs have been removed since startup.



Effects on Plume



Close-up of OU B/C area identified on page 2.

- A comparison of individual monitoring well data from 1986 to 1993 was performed to determine trends in VOC concentrations.

- Monitoring Zone A: Most wells exhibited static trends. There is no observable overall trend for OU B wells. More wells within OU C than OU B exhibit increasing trends which may indicate continued contaminant release from the vadose zone to OU C.

- Monitoring Zones B through D: Most data is static which may suggest that groundwater impacts within the deeper zones are equilibrated. OU B data within the B and D zones presents much uncertainty. Zone C shows more increasing wells which, in the case of OU C, may represent preferential migration from other OUs.

Legend

- Wells with constant risk values
- Wells with increasing risk values
- Wells with fluctuating risk values
- Wells with decreasing risk values

COST

• The groundwater extraction and treatment system at McClellan was built in several phases from the late 1980's to early 1990s. The data below was provided by McClellan personnel based upon available records. Pump and treat efforts have removed over 42,000 pounds of VOCs at the base as of March 1994. This corresponds to dollars per pound removal rates of approximately $80/lb VOC based on operating costs alone (based upon an analysis done with first year operation data) and approximately $150/lb VOC including treatment system direct costs. Cost bases and assumptions are detailed below:

Capital Costs

Direct Costs	
Incinerator	$300,000
Air Stripper	400,000
Scrubber	300,000
Water to Water Heat Exchanger	200,000
Gas to Water Heat Exchanger	50,000
Gas to Gas Heat Exchanger	50,000
Electric Motors (6)	180,000
Blowers (2)	40,000
Pumps (6)	180,000
GAC Tanks (4)	360,000
Water Holding Tank	40,000
Berm and Foundation	150,000
Air Compressors (2)	60,000
Water Pipes to Plant	300,000
Wells and Pumps (10) (a)	300,000
Control Center and Trailer	80,000
Control Center External	60,000
Subtotal Direct Costs	3,090,000
Indirect Costs	910,000
Total Capital Cost in 1987 (b)	**$4,000,000**

Operating Costs

Contractor Operations	
Labor	$300,000
Operation Support	350,000
Reimbursables	200,000
Other Direct Costs	150,000
Utilities	
Electricity for Extraction Wells	30,000
Electricity for Treatment Plant	50,000
Natural Gas	40,000
Sampling and Analysis	40,000
McClellan Staff Labor	80,000
Total Annual Operating Costs	**$1,240,000**

(a) Three additional extraction wells were added within the OU B in 1990. McClellan estimates the cost of developing and extraction well at the site to be approximately $100,000.

(b) The small treatment plant within OU B was constructed in 1991 for a total cost of approximately $1,000,000 broken down as follows (Numbers taken from an estimate prepared while construction was ongoing and all values rounded to the neared multiple of $5,000):

Direct Costs		***Indirect Costs***	
Extraction/Monitoring Wells	$145,000	Contingency (@5%)	30,000
Piping and Fittings	55,000	Fees (@15)	90,000
Pumps	10,000	Construction Management (@15%)	90,000
Holding Tank	15,000	Startup (@10%)	60,000
GAC Treatment Units	60,000	Sampling (@10%)	61,000
Discharge Piping and Fittings	5,000		
Contaminated Soil Disposal	95,000		
Site Work (@25%)	100,000		
Piping/Valving (@5%)	20,000		
Instrumentation (@5%)	20,000		
Controls (@5%)	20,000		
Electrical (@15%)	60,000		

The yearly operating costs of the system is approximately $70,000 and is largely for GAC replacement.

REGULATORY/INSTITUTIONAL ISSUES

- The GWTP currently has a National Pollution Discharge Elimination System (NPDES) which permits a 0.36 MGD discharge with a total allowable discharge of 1.45 MGD (30-day average) from additional groundwater extraction systems.

- The NPDES permit for the GTWP sets forth sampling requirements and limitations for discharge into Magpie Creek, an onbase stream. The primary treatment requirements are that the plant remove acetone, methyl ethyl ketone and methyl isobutyl ketone to less than 1 mg/L, and remove all other VOCs to less than 0.5 ug/L.

- Air permits from the Sacramento Metropolitan Air Quality Management District require sampling and specify certain operation conditions and procedures. A risk assessment of the facility was performed as part of the permitting process

- McClellan AFB has developed positive working relationships with federal and state environmental regulators which has facilitated planning and implementation of remedial measures.

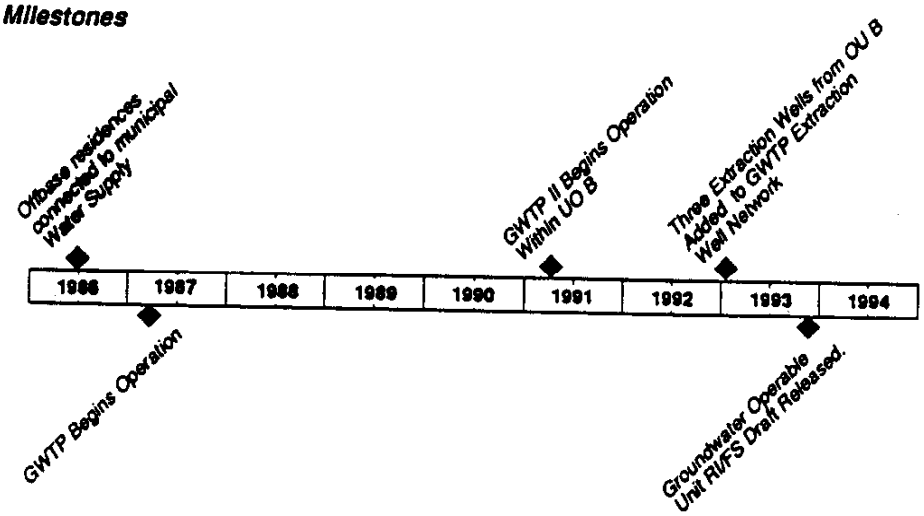
- McClellan AFB has extensive ongoing public involvement programs which have been instrumental in overcoming initial apprehensions about the GWTP.

Cleanup Criteria

- While final cleanup criteria have yet to be determined for groundwater beneath Operable Units B and C, treatment requirements mandate removal of the principle VOCs of concern to less than 0.55 ug/L. The base and regulators are currently evaluating cleanup scenarios based upon remediation to Maximum Contaminant Levels (MCLs), lifetime individual cancer risk levels less than 1E-6 (more stringent), or background levels (most stringent).

SCHEDULE

Major Milestones



LESSONS LEARNED

Design and Implementation Considerations

• Major changes in the quantity of extracted groundwater and changes in VOC influent concentrations have necessitated changes in GWTP design and operation. Currently the plant has excess treatment capacity requiring internal recycle of groundwater to sustain efficient treatment which raises operating costs. These and other process changes have optimized performance at lower flow rates.

• Existing extraction systems at McClellan capture a small portion of the groundwater contamination present at the site. The system must be significantly expanded to create a zone of capture encompassing other known areas of contamination. The success of the existing design has established it as a candidate system of choice for future remediation efforts.

• Scaling and deposition within the air stipper from precipitation of calcium and magnesium salts affected initial operation. The problem was minimized by substituting 2 inch packing for 1 inch packing in the air stripper.

• Corrosion was observed in the hot vapor train due to condensation of acid gases. The problem was minimized through both substitution of materials of construction from carbon steel to nickel-based commercial alloys and changes in physical layout which reduced turbulence, improved laminar flow and eliminated stagnant regions.

Technology Limitations

• Influent concentrations to the treatment plant have shown a significant downward trend since startup, however, that trend has stabilized in recent years. Groundwater monitoring data largely exhibits static trends in VOC concentrations despite the removal of over 40,000 lbs of VOCs from OUs B/C and OU D.

• Among the organic compounds being treated, acetone is the only compound that the air stripper has had difficulty removing because of its solubility in water. Biological treatment was initially required but has been discontinued after acetone was no longer encountered in the GWTP influent.

• Pump and treat efforts at McClellan must be augmented with vadose zone source area remediation efforts so that continued seepage of contamination into groundwater does not require indefinite pump and treat operation.

Future Technology Selection Considerations

• Pump and treat efforts have been successful at containing further migration of contamination. Only low concentrations of VOCs are anticipated to migrate beyond the established zones of control.

• The above ground treatment system has been effective at consistently reducing VOC levels below discharge criteria.

• The air stripper/incinerator/scrubber treatment train has proven to both efficient and effective.

• Although incineration has proved to effectively treat VOCs from the air stripper offgas, feasibility studies for future treatment capacity at McClellan consider catalytic oxidation and vapor-phase granular activated carbon as additional options for handling air stripper offgas. Vapor-phase granular activated carbon is considered to generate less community acceptance problems and would reduce permitting complexity.

• The use of activated charcoal is cost effective for treatment of low water flow rates in the range of 2 to 10 GPM which generally corresponds to a carbon replacement occurring every three years. For relatively high flow rates, such as 200 GPM, and VOC contamination in excess of 10 ppm, charcoal alone is not cost effective due to the high frequency of carbon replacement.

• Ongoing feasibility studies at McClellan have identified air stripping and liquid granular activated carbon as the preferred groundwater treatment technologies for the east side of the base. These would be implemented along with demonstration and evaluation of innovate technologies primarily targeting hot spots.

ANALYSIS PREPARATION

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CERTIFICATION

This analysis was prepared in cooperation with and was reviewed by McClellan personnel.
Critical assistance was provided by Badrul Hoda and Alec Elgal.

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 4, 5, 6 and 7
Treatment System:	Source #s 1, 3, 4, 5, 6, 7 and 8
Performance:	Source #s 1, 2, 3, 4, 6 and 7
Cost:	Source #s 1 and 7
Regulatory/Institutional Issues:	Source #s 4 and 8
Schedule:	Source #s 1, 3, 4, 5, 6 and 7
Lessons Learned:	Source #s 2, 4 and personal communications with Alec Elgal, McClellan AFB (916) 643-0827

Chronological List of Sources and Additional References

1. *Data Package provided by Alec Elgal, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base,* February - April, 1994.

2. Personal Communications with Alec Elgal, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base, May-June, 1994.

3. *GWTP Weekly Reports*, prepared by Metcalf and Eddy Services for McClellan Air Force Base, through 10 January 1994.

4. *Draft Copy, Groundwater Operable Unit Remedial Investigation/Feasibility Study Report*, prepared by CH2M Hill for McClellan Air Force Base, November 1993.

5. *Basewide Groundwater Operable Unit, Groundwater Well Specific Data Report*, prepared by CH2M Hill for McClellan Air Force Base, 1993.

6. *Preliminary Groundwater Operable Unit Remedial Investigation (PGOURI)*, prepared by Radian Corporation for McClellan Air Force Base, September 1992.

7. *Operable Unit B, Engineering Evaluation/Cost Analysis*, prepared by Radian Corporation for McClellan Air Force Base, October 1990.

8. *Operation and Maintenance Manual, McClellan Air Force Base Groundwater Treatment Facility*, prepared by Metcalf and Eddy for McClellan Air Force Base, Undated.