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REMEDIATION OF PETROLEUM HYDROCARBONS USING BUBBLEX^{SM} TWO-PHASE EXTRACTION METHOD - A CASE HISTORY

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ABSTRACT

This paper presents the progress data from a case story for a soil and groundwater remediation by using the Bubblex^{SM}[1] method of two-phase extraction and hydrocarbon stripping. The remediation site is a former gasoline service station, located in Los Angeles, California. An aquifer test, a vapor extraction test, and a Bubblex^{SM} two-phase extraction test were performed before considering two-phase extraction as a remediation option for the site. The petroleum hydrocarbon affected groundwater extended offsite across the public street, with significant source of contamination in the soil. A Bubblex^{SM}, two-phase extraction system was designed and installed. Six (6) groundwater extraction wells and two (2) vapor extraction wells were connected to the system.

During the 15 months after installation, the system operated 4587 hours removing over 345,000 gallons (1,316,052 liters) of water and over 11,250 lbs. (5,103 kg) of hydrocarbon in vapor. The activated carbon use was minimal due to stripping effect in the Bubblex^{SM} extraction pipe.

INTRODUCTION

The purpose of this paper is to provide progress data from a soil and groundwater remediation project involving petroleum hydrocarbons. The uniqueness and interest to the scientific community of this project is that a new method of remediation technique (Bubblex^{SM} two–phase extraction) was employed with its own set of challenges. The subject site is a former fuel service station located in Southwest Los Angeles area. The site is currently used as a car dealership with an auto repair station. The remediation challenges were: to stop further spreading of the dissolved phase hydrocarbons; to remediate the onsite and offsite extent of the dissolved plume; and to remove the hydrocarbons from the unsaturated zone.

In this paper, we present a brief overview of the two-phase extraction with emphasis on Bubblex^{SM} modifications followed by the site information, site geology and hydrogeology, Bubblex^{SM} system description, operation and maintenance information, and our conclusions. The acknowledgement and the references are presented at the end of the paper.

Two-phase extraction is a method of vapor and water removal in a combined flow stream using a vacuum force. Several records related to scattered use of two-phase extraction, multiphase extraction and dual phase extraction methods in environmental clean up area can be found in literature going back to several years (Morrow, 1991; Mancini et al, 1994; Baker, 1996). The term *"two-phase extraction"* and *"dual phase extraction"* is being used interchangeably in several articles. However, in this paper, the authors reserve the term *"two-phase extraction"* for simultaneous extraction of the vapor and water in a combined flow stream as opposed to *"dual phase extraction"* which is simultaneous extraction of both vapor and water using two separate flow streams (i.e. down-hole pumps for water and vacuum pumps for vapor). The authors use the term *"multiphase extraction"* for the extraction of vapor, water and free phase hydrocarbons in a common stream. *The Bubblex^{SM} two-phase extraction method* uses one common flow stream for both vapor and water.

The challenges of performing a two-phase or multiphase extraction lie with overcoming the limitations of the vacuum when extracting water from depths greater than 33 feet (10.06 m) below ground surface (BGS). The maximum available vacuum lift for water is 33.9 feet (10.33 m; 29.92-inches [76 cm] of mercury) which is the displacement of the Earth's atmospheric pressure. In order to obtain greater lift the earlier studies suggested: (1) injecting air into the extraction pipe below the water table by the use of an external injection pipe connected to the side of extraction pipe (Mancini et al, 1994);

[1] Bubblex^{SM} is a service mark of Tait Environmental Management, Inc. (TEM) for bubbling extraction method, a patented method (Pat. No. 5,906,204) for extraction of contaminated groundwater and vapor in a combined stream and for simultaneous stripping the volatile hydrocarbons.

(2) injecting air into the extraction pipe below the water table with an air injection pipe placed inside the extraction pipe (Morrow, 1991); (3) or by placing the extraction pipe intake at the water table (Baker, 1996).

The Bubblex^{SM} method allows a limited amount of air/vapor from the unsaturated zone and a limited amount of water from the saturated zone to enter the extraction pipe through a modified screen. The modified screen is prepared by placing slots or orifices on the extraction pipe above and below the water table. When vacuum is applied to the extraction pipe, water from the screen below the water table and vapor from the orifices above the water table enter into the extraction pipe and flow in a common stream. Both vapor and water flow in a combined stream in the extraction pipe until it reaches to the separation tank. The new design of the extraction pipe screen facilitates lifting water from depths greater than 33 feet (10.06 meters), extracting vapor from the vadose zone and stripping volatile hydrocarbons from the extracted water (Figure 1. Typical Bubblex^{SM} Well Detail). The extracted water and vapor are then separated in a separation tank. The vapor is sent to a thermal/catalytic oxidizer, and the water is discharged through an activated carbon (AC) polishing unit to a storm drain under a National Pollution Discharge Elimination System (NPDES) permit.

SITE SETTING

The site is a 75-foot (22.86 m) by 105-foot (32 m) commercial lot located in Southwest Los Angeles, California (Figure 2. Site Plan). The site was used as a gasoline service station until 1992. The site is situated at an elevation of approximately 117 feet (35.66 m) above mean sea level (AMSL), and slopes gently to the southwest.

The former service station contained three (3) 10,000-gallon (37,850 liters) gasoline underground storage tanks (USTs), three (3) 3,000-gallon (11,355 liters) gasoline USTs, one (1) 1,000-gallon (3,785 liters) gasoline UST, one (1) 1,000-gallon (3,785 liters) waste oil UST and one (1) 280-gallon (1059 liters) waste oil UST. In addition, a three-stage concrete clarifier and two (2) hydraulic lifts, associated with the service bays, were located within the building.

All nine tanks were removed in 1992. The follow up investigations showed that petroleum hydrocarbon-impacted soil and groundwater exist at the site with dissolved hydrocarbon plume in groundwater extending approximately 70 feet (21.34 m) outside the property boundary.

GEOLOGY AND HYDROGEOLOGY

The site is located approximately 7 miles (11.26 km) east of Santa Monica Bay (Pacific Ocean) and approximately 10 miles (16.09 km) south of the Santa Monica Mountains. This location places the site within the Ballona Gap portion of Santa Monica Basin (DWR, 1961). The Ballona Gap consists of a stream-cut erosional gap, which extends from the eastern end of the Baldwin Hills to the Santa Monica Bay.

Surficial deposits in the site vicinity have been mapped as unconsolidated Holocene fluvial-alluvial deposits consisting of clay, silt, fine sand and gravel. Locally, the upper Holocene member is approximately 100 feet thick and likely includes the Ballona aquifer (50-Foot Gravel) in its base members. The Ballona rests unconformably on the Pleistocene San Pedro Formation (DWR, 1961).

Groundwater beneath the site is encountered at 35 feet (10.67 m) BGS in the sand zone. Silt and some clay layers in the lower portion of the water-bearing zone appear to provide a lower-confining layer for the perched water zone.

The maximum depth of drilling reached at the site is 55 feet (16.76 m) BGS. The soil, encountered in the shallow subsurface, consisted of moist, stiff, brown, silty clay, approximately 6 feet (1.83 m) BGS. At 6 feet (1.83 m), a brown, moist, medium dense, silty sand was encountered. The silty sand grades into gray-brown, moist, loose sand with gravel at approximately 15 feet (4.57 m) BGS. The sand was observed from 15 feet (4.57 m) to approximately 35 to 40 feet (10.67 to 12.19 m) BGS, where brown sandy silt was observed. The perched groundwater was encountered during drilling activities at approximately 33 to 35 feet (10.06 to 10.67 m) BGS.

FEASIBILITY STUDY

Before the selection of the remediation alternative for the soil and groundwater, a feasibility study was performed which included a vapor extraction test and a groundwater pump test. The vapor extraction test revealed that the soil at the site has adequate permeability for airflow, without excessive pressure drop. It was concluded that the volatile hydrocarbons could be successfully removed by using in-situ venting. The zone of influence up to 100 feet (30.48 m) in VE-1 and 80 feet (24.38 m) in VE-2 was calculated from the test results. Air permeability values were estimated to range from 29.35 to 38.72 Darcys. Based on the vapor sample results of 16,000 to 23,000 ppmV TPH-G concentrations, a removal rate of 1,300 to 1,700 pounds (589.68 to 680.4 kg) per day was estimated for the initial operation of the system. The removal rate was expected to be reduced as remediation progresses.

In order to assess the hydraulic characteristics of the water bearing units, two (2) slug tests, one (1) step drawdown test and one (1) 6-hour pump test were performed. Five (5) observation wells (MW-1 and MW-3 through MW-6) were used to measure the influence of pumping from the extraction well MW-2. The test data were evaluated using AQTESOLV and QUICKFLOW aquifer test analysis and groundwater modeling software developed and marketed by Geraghty & Miller (Duffield and Rumbaugh, 1991, Rumbaugh, 1991). The results of the aquifer test data analysis of drawdown and recovery data using Theis type-curve matching and Theis recovery methods yielded maximum transmissivity and hydraulic conductivity values of 67.68 ft^2/day (6.29 m^2/day) and 4.51 ft/day (1.38 m/day), respectively. Additionally, based on the two-dimensional groundwater model simulation, it was estimated that 1 gpm flow rate for each of the two (2) proposed recovery wells (MW-13 and MW-14) is sufficient to contain the majority of the existing dissolved-phase plume at the site.

On February 13, 1997, a Bubblex^{SM} two-phase extraction test was performed using MW-14 for extraction. The results indicated that the well yield was nearly double for the comparable drawdown observed during the aquifer test in a similarly constructed well. The well yield was higher when the vacuum was higher. The hydrocarbon concentrations in the extracted water were up to 95 % lower than the concentrations observed in the pretest groundwater samples (demonstrating that up to 95 % stripping occurred in the extraction pipe). The increased recovery rates were incorporated into the QUICKFLOW groundwater model by keeping the other model parameters unchanged. The results of the groundwater model using higher pumping rates available with Bubblex^{SM} showed an increased capture zone.

SYSTEM OPERATION AND MAINTENANCE

System Description

The Bubblex^{SM} remediation system (Figure 3. Bubblex^{SM} System Detail) consists of a 200-cfm vapor destruction system with a liquid ring pump, which creates the high extraction vacuum within the wells. Groundwater is removed from the wells and drawn through the system piping using high vacuum (approximately 8-12 inches [20.32-30.48 cm] of Hg). The vapor is stripped from the groundwater Using Bubblex^{SM} extraction pipes. The liquid ring pump pumps groundwater into an air/water separation tank to separate the vapor and water. Then the groundwater is pumped through two, 500-pound (226.8 kg) vessels of AC placed in series, prior to discharge. The vapor is then removed from the air/water separation tank and destroyed by a thermal/catalytic oxidizer. Supplemental gas is used to maintain a constant temperature within the catalytic oxidizer chamber. A chart recorder keeps a constant record of temperature and flow through the catalytic/oxidizer. A flow totalizer measures the cumulative discharge to the storm drain.

System Operation

We started the two-phase extraction system operation on April 8, 1998, after obtaining all the necessary permits and making utility connections (natural gas, electric and water). The system was started with two wells (MW-13 and MW-14) yielding up to 7,000 gallons (26,495 liters) of water per day with vapor flow rate ranging from 150 to 200 CFM (70,792.5 cu cm/sec to 94,390 cu cm/sec).

Two weeks after the system began operation, due to complaints from the neighbors about noise, a timer was installed to limit the hours of operation from 6:00 AM to 10:00 PM. The modifications apparently satisfied the neighborhood complaints.

On April 29, 1998, we collected several water samples from the extraction stream during operation of the system to evaluate the system effectiveness in stripping hydrocarbons and to estimate the life of the AC vessel. Two (2) extraction wells (MW-13 and MW-14) were used for the stripping test. The following is the description of the five water samples collected for each test:

- One sample before the test from the extraction well using a disposable bailer (MW-13A and MW-14A);
- One sample from the extraction well during the test outside the extraction pipe using a disposable bailer (MW-13B and MW-14B);
- One sample from the extraction pipe at the top of the each wellhead (MW-13C, MW-14C);
- One sample from the extraction pipe before the AC polishing unit (MW-13E and MW-14E); and
- One from the discharge point after the AC unit (MW-13F and MW-14F).

The test results indicated that up to 99% of the benzene, toluene, ethylbenzene, and xylene (BTEX) and gasoline fraction of the total petroleum hydrocarbons (TPH-G) were removed during extraction between the water table and the wellhead (between the sample points B and C). Additionally, 55 to 99% of the remaining hydrocarbons were removed in the extraction pipe between the wellhead and AC unit (between the sample points C and E). Figure 4 and 5 present the results of the Stripping Test. Figure 3 shows the sample locations. Based on the concentrations observed in sample MW-13B (190,000 ug/L TPH-G) and the AC loading capacity of 10%, the 500 lbs of AC would last about 11 days when pumping at a rate of 2 gpm. The calculated AC use was 2080 days when using the concentrations of TPH-G observed in sample MW-14E (1,000 ug/L). Equation 1 - 4 below illustrates the AC use (polishing) calculations for the extracted water after the Bubblex^{SM} stripping:

TPH-G concentrations in extracted water after stripping in the Bubblex^{SM} extraction pipe.

$$1{,}000 \text{ ug/L} = 0.000001 \text{ kg/L} \qquad (1)$$

Daily water removal
2 gpm = 7.57 liters/min.
= 7.57 X 1440 = 10900.8 liters /day (2)

Daily TPH-G mass removal:
10900.8 l/d X 0.000001 kg/L = 0.011 kg/day (3)

AC loading capacity = 10%
10 % of 500 lbs = 50 lbs = 22.68 kg

Number of days will take to load 10 % of the AC:
22.68 / 0.011 = 2061 days (4)

As shown above when we use Bubblex method we need not change AC for over 2000 days. If we did not use Bubblex[SM] method we would be changing the AC every 13 days. We would be spending $42,000 a year on AC change out alone at $1500 per change.

During one year of Bubblex[SM] system operation, the AC midpoint samples did not show any sign of breakthrough. The AC was changed after one year due to increased back-pressure caused by silt deposits in the AC bed.

The drawdown achieved in the wells and the groundwater modeling results was periodically compared to evaluate if the system had been achieving the predicted groundwater capture zone. The system yield was reduced due to decreased well yields and scaling in the liquid ring pump. The pump was cleaned and additional wells including two vapor extraction wells were turned on to achieve the targeted removal rate of groundwater and vapor. A chemical metering system using a scale inhibitor chemical solution was installed to prevent the scaling on the liquid ring pump and piping.

The extracted vapor concentrations during the vapor extraction test conducted on February 27, 1996, were 23,000 ppmV and 17,000 ppmV from the vapor extraction wells VE-1 and VE-2 respectively. During Bubblex[SM] test conducted on February 13, 1997, the vapor concentrations from the Well MW-14 (extraction well) ranged between 930 to 3200 ppmV. The extracted vapor concentration was 1076 ppmV TPH-G on March 3, 1999.

We estimated the amount of the hydrocarbon removal using the last measured vapor concentration of 1076 ppmV, an average flow rate of 190 CFM, and the molecular weight of gasoline = 95 g/mole (Johnson, 1990). The estimated amount of hydrocarbon removed since the startup of the system (a total 4587 hours of operation) is approximately 11,250 lbs.

Quarterly groundwater monitoring results showed that the trend of the hydrocarbon concentrations in the groundwater started to decrease after the system start up with significant reductions in TPH-G and BTEX concentrations. Figure 6 shows graph of TPH-G concentration in two offsite wells (MW-9 and MW-10) located on the groundwater flow path directly down-gradient of the former tank locations. The concentrations were increasing in most wells before the start of the Bubblex[SM] system.

CONCLUSION

The authors conclude that two-phase extraction was successful for meeting the remediation challenges of this site.

The Bubblex[SM] two-phase extraction method has been successful in capturing dissolved phase hydrocarbons from offsite areas and removing vapor from the vadose zone at the same time. The system has been operated a total of 4587 hours, treated and discharged 347,702 gallons of water and removed an estimated 11,250 lbs. of hydrocarbons from the vadose zone and from the groundwater as of June 29, 1999.

The system has been successful in stripping up to 99 % of the hydrocarbons from the extracted groundwater. As a results of the stripping in the extraction pipe the AC was only changed once due to increased back-pressure in the vessel after one year of operation.

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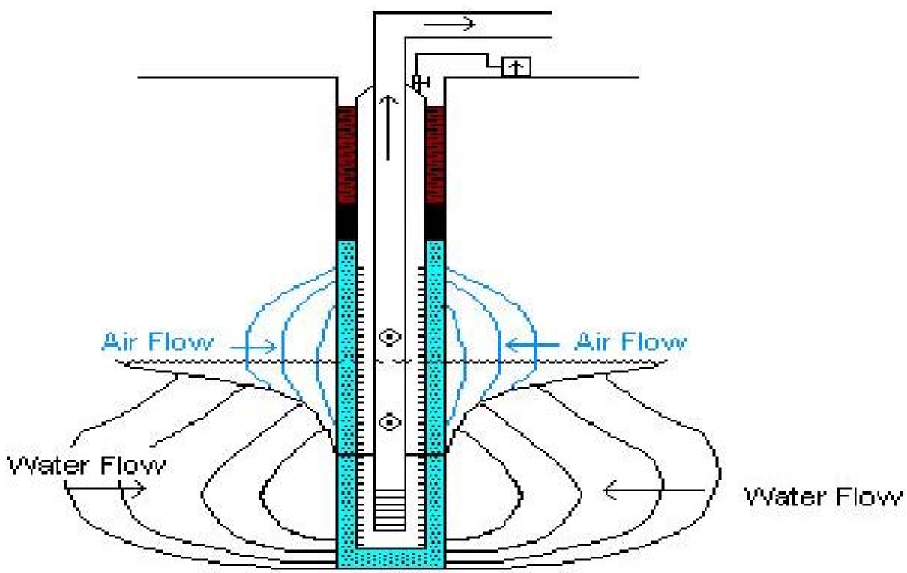


Figure 1. Typical Bubblex^{SM} Well Design: Modified design of the extraction pipe and wellhead assembly facilitates lifting water in the vertical pipe, stripping volatile hydrocarbons and allowing monitoring for the several critical parameters such as annulus vacuum, water levels and collection of the water samples from the well and from the extraction pipe.

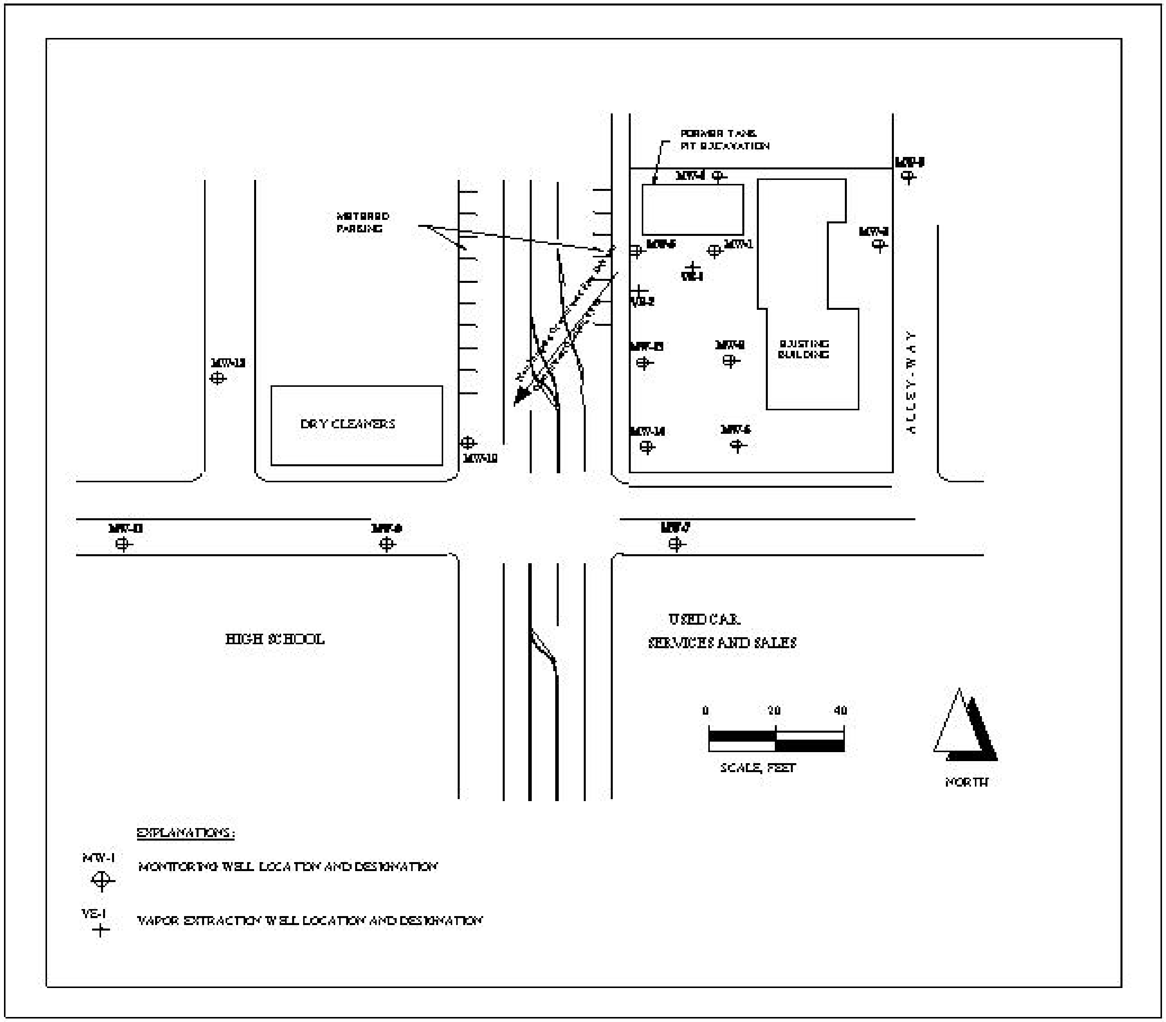


Figure 2. Site Map

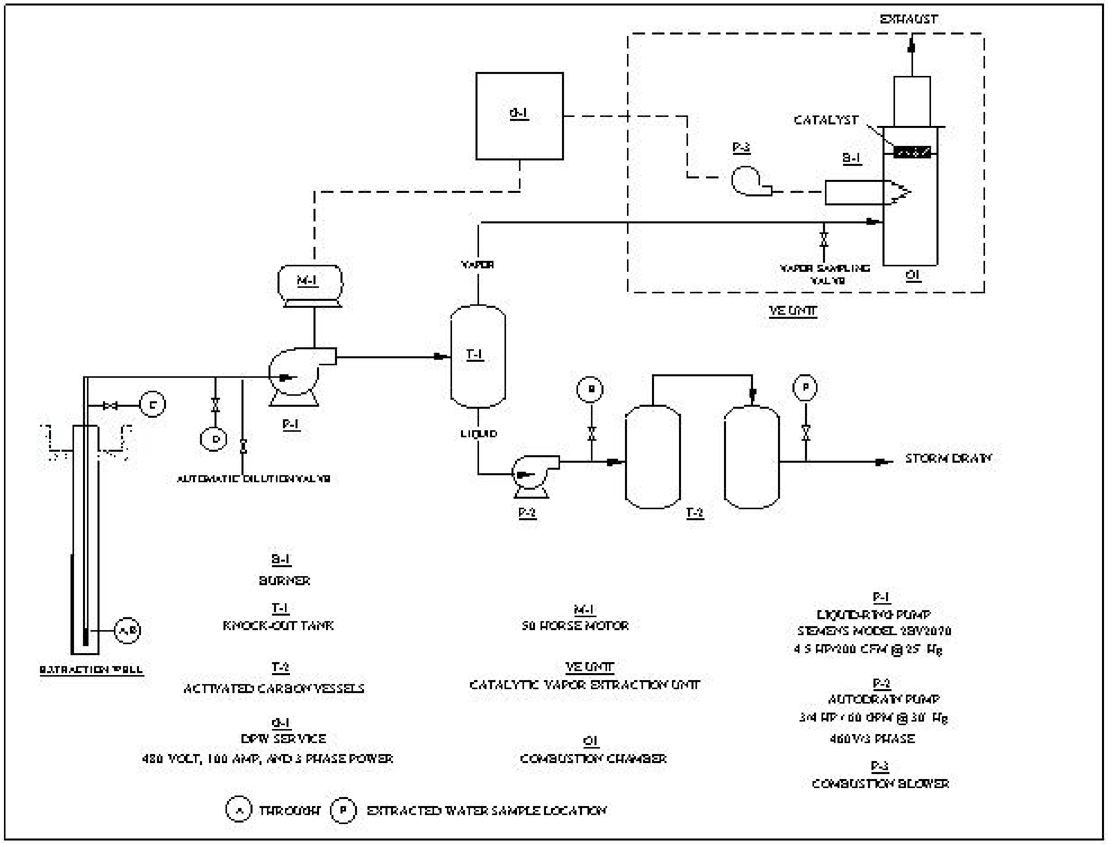
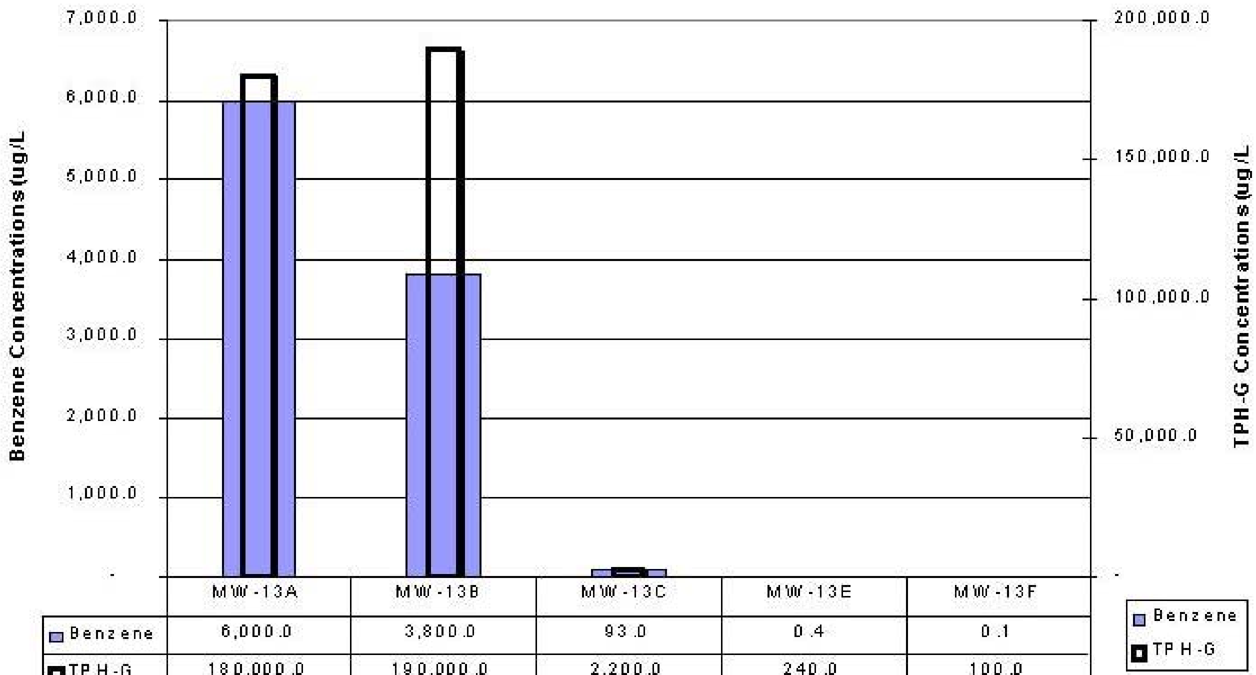
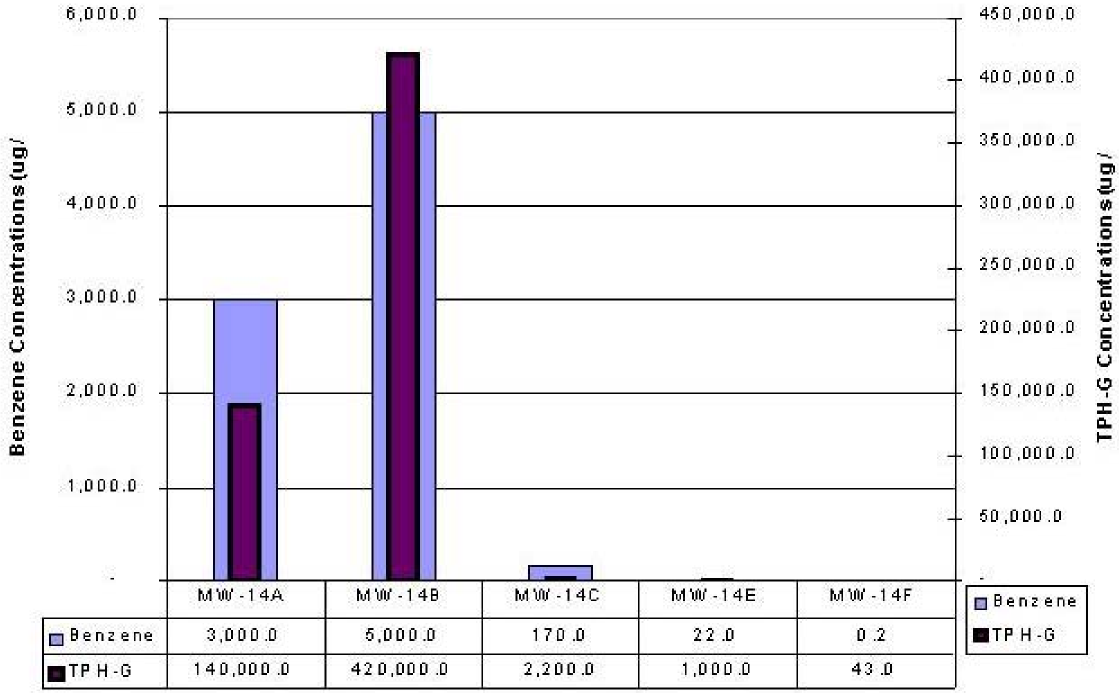


Figure 3. Bubblex^{SM} System Detail: A, B, C, E, and F show the water sample locations where stripping test samples were collected.



	MW-13A	MW-13B	MW-13C	MW-13E	MW-13F
Benzene	6,000.0	3,800.0	93.0	0.4	0.1
TPH-G	180,000.0	190,000.0	2,200.0	240.0	100.0

Figure 4 Stripping test results (MW-13): The concentrations of Benzene and TPH-G were reduced over 95% from the water table to the wellhead (from B to C) due to stripping in the Bubblex^{SM} extraction pipe. Additional 95 to 98 % stripping occurred in the pipe between the wellhead and AC unit (from C to E).



	MW-14A	MW-14B	MW-14C	MW-14E	MW-14F
Benzene	3,000.0	5,000.0	170.0	22.0	0.2
TPH-G	140,000.0	420,000.0	2,200.0	1,000.0	43.0

Figure 5 Stripping test results (MW-14): The concentrations of Benzene and TPH-G were reduced over 95% from the water table to the wellhead (from B to C) due to stripping in the Bubblex^{SM} extraction pipe. Additional 95 to 98 % stripping occurred in the pipe between the wellhead and AC unit (from C to E).

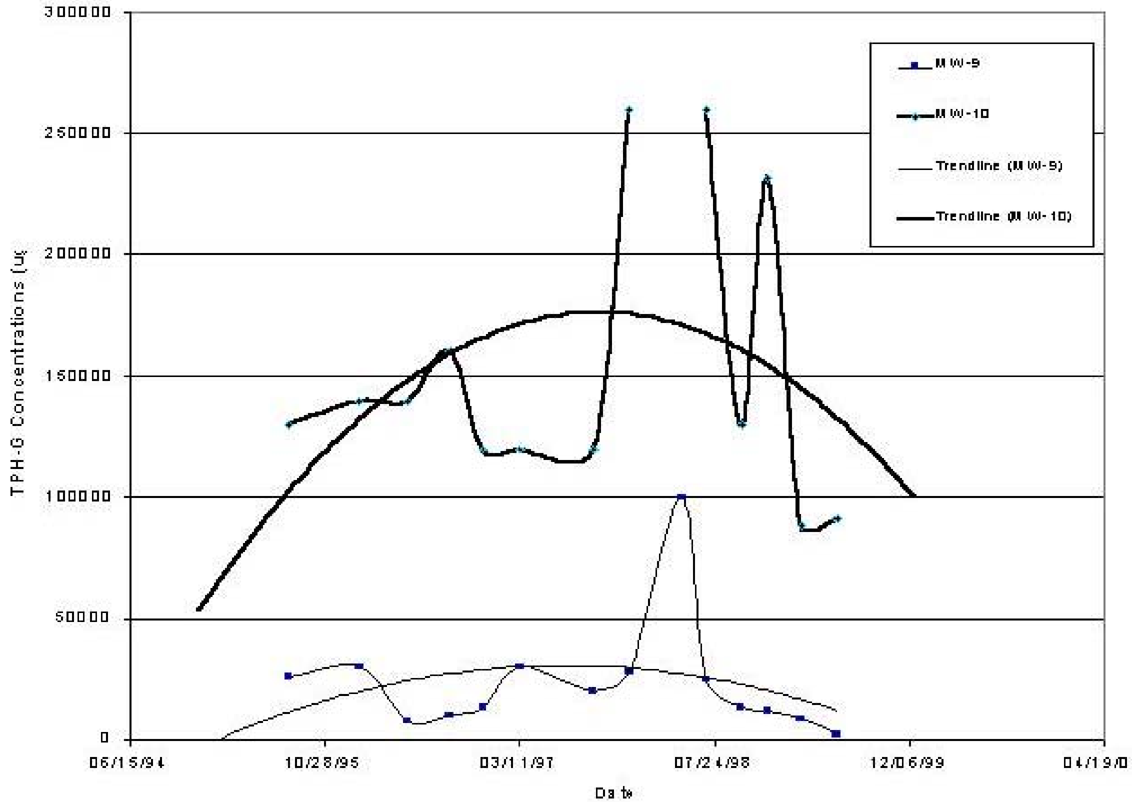


Figure 6. TPH-G Concentrations in MW-9 and MW-10: The increasing trend in concentrations is reversed after the system startup in April 1998.