FINAL

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ADDENDUM #2 TO SAMPLING AND ANALYSIS PLAN

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for

Corrective Action Plan-Part A and B Investigation for Former Underground Storage Tanks at Hunter Army Airfield, Georgia

Prepared for

U.S. ARMY CORPS OF ENGINEERS
SAVANNAH DISTRICT

Contract No. DACA21-95-D-0022
Delivery Order 0041

April 1999

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SAIC®

DOCUMENT 6

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TO
SAMPLING AND ANALYSIS PLAN
FOR THE
CORRECTIVE ACTION PLAN-PART A AND B INVESTIGATIONS FOR FORMER UNDERGROUND STORAGE TANKS
AT
HUNTER ARMY AIRFIELD, GEORGIA

Prepared for

U.S. Army Corps of Engineers
Savannah District
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Delivery Order 0041

Prepared by

Science Applications International Corporation
800 Oak Ridge Turnpike
Oak Ridge, Tennessee 37830

April 1999

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APPROVALS

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TO
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FOR THE
CORRECTIVE ACTION PLAN-PART A AND B INVESTIGATIONS FOR
FORMER UNDERGROUND STORAGE TANKS
HUNTER ARMY AIRFIELD, GEORGIA

Bruce King, Deputy Program Manager — 29 Apr 99
Date

Patricia A. Stoll, Project Manager — 4/29/99
Date

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1.0 INTRODUCTION

Past practices at two former petroleum dispensing facilities (former Building 133 and former Building 728) have resulted in petroleum contamination of the surrounding soils and groundwater. Free product has been measured (< 1 foot.) in one or more monitoring wells at each site. Both sites have been characterized and are presently in the Long-term Monitoring Program. The Corrective Action Plan-Part B report for former Building 728 proposed free product recovery, air sparging, and soil vapor extraction (SVE) to remediate the soil and groundwater contamination. The activities covered in this addendum will assist in designing an effective remediation system with an optimal life cycle cost.

This addendum supplements the Sampling and Analysis Plan for the Corrective Action Plan-Part A and B Investigations for Former Underground Storage Tanks at Hunter Army Airfield, Georgia (SAIC 1998). It addresses the additional field activities for performing free product delineation, enhanced biodegradation oxygen-injection, in situ respiration, and radius-of-influence tests. It presents changes and additions to the Work Plan (SAIC 1998a) and the specific sampling requirements for the performance of these studies and pilot tests.

The goal of the free product delineation at both sites is to determine the total recoverable amount of free product at each site and to optimize the location of product recovery wells. The goal of a free product recovery system is to reduce free product at a site to less than 1/8 of an inch (IAW GA EPD Guidance). The goals of the oxygen-injection pilot study are to determine its ability to remediate petroleum hydrocarbons in the soil and groundwater to below concentrations that pose a potential threat to human health and the environment. The goals of the in situ soil respiration test are to determine the activity of the aerobic organisms in the soil and to determine the rate and extent to which they can biodegrade the contaminants at the site. The radius-of-influence test will determine the effectiveness of an SVE system at this site. These tests and pilot studies will provide the data necessary to design a full-scale treatment system.

Free product delineation and determination of the total recoverable petroleum hydrocarbons at the site will be conducted at both the former Building 133 site and the former Building 728 site. At the former Building 728 site, the enhanced biodegradation oxygen-injection pilot test, in situ respiration test, and radius-of-influence test will be conducted.

2.0 PROJECT ORGANIZATION

The existing health and safety plan for Hunter Army Airfield (HAAF), Health and Safety Plan for the Sampling and Analysis Plan for the Corrective Action Plan Part A and B Investigations for Former Underground Storage Tanks at Hunter Army Airfield, Georgia (SAIC 1998b) and Addendum #1 (SAIC 1999) to this health and safety plan will be used for this project. The health and safety officer for this project is Patricia Stoll. The organizational chart for this addendum is presented in Figure 1.

3.0 FIELD ACTIVITIES

This section describes the additional field activities not covered in the Work Plan and the sampling associated with the pilot tests. The site-specific investigative activities for the sites are presented in Table 1. Table 2 presents the sample numbering system that will be used for these investigations.

3.1 FREE PRODUCT ACTIVITIES

3.1.1 Free Product Delineation

The extent and amount of free product must be determined at each site. At the former Building 133 site, 10 product delineation points will be installed (seven primary and three secondary) and at the former Building 728 site, 25 (21 primary and four secondary) product delineation points will be installed (Appendix A, Figure A.1 and A.2). These product delineation points will be temporary piezometers installed in soil borings. The delineation points at the Former Building 133 site will be used to determine the presence of free product, the water table elevation, gradient, and flow direction; no samples will be collected from them. At the former Building 728 site, one soil sample will be collected from each boring for pre-pilot study screening. Fifteen of these soil samples will be analyzed for benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbons (TPH). The field manager will select 15 samples, based on field photoionization detector (PID) readings, field conditions, and amount of free product in the piezometer. The temporary piezometers will be ¾-inch polyvinyl chloride (PVC) with 10 feet of 10 slot screen installed to bracket the water table to determine the presence of free product, the water table elevation, gradient, and flow direction over time. Temporary surface completions will be installed to protect the piezometers throughout the pilot/remediation period.

Following the determination of the extent of free product at the two sites, up to three additional free product recovery wells will be installed at the former Building 728 site. These wells will be installed using hollow-stem augers. No soil samples will be collected during the installation of these wells, and no development will be performed.

Product recovery systems will be installed at the former Building 133 site (SAIC 1999) and at the former Building 728 site. After the wells have been installed, three Ferret™ recovery systems will be installed at the former Building 728 site and one at the former Building 133 site. The product recovery system at the former Building 133 site is discussed in SAIC 1999. Addendum #1 to Work Plan for Long-term Monitoring at Six Sites (Former Buildings 133, 710, 728; Building 1310; the PDO Yard; and the Former Fire Training Area) at Hunter Army Airfield, Savannah, Georgia, (SAIC 1999). The Ferret™ recovery systems will be installed following the manufacturers instructions (Appendix B). Piping from the recovery systems to the AST will be above ground. The existing belt skimmer at the former Building 728 site will be relocated, if necessary, to maximize its recovery potential. All systems will be connected to aboveground storage tanks (ASTs) with overfill shutoffs and containment. The Ferret™ systems are passive recovery systems manufactured by QED Environmental Systems, Inc. They consist of a product-only pump, tubing, and an air compressor and are equipped with an automatic shutoff. A float with an inlet located in the product layer actively draws the product into the pump. When the pump is full, the compressed air enters the pump, pushing the product to the surface. When the pump empties, the air valve is shut off, allowing the pump to begin the next fill cycle.

- Atlas Copco GA-5 rotary screw air compressor with air dryer, vertical tank with auto drain, and low sound enclosure, rated for 25 ACFM @ 125 PSIG & 7.5 HP TEFC motor, three-phase/60 Hz/230 volts.
- static-phase converter to allow system to be used with single-phase/230 volt power;
- mainifold for 12 injection points to include individual pressure gauge (PSI) and variable area flow meter (scfh);
- adjustable timers (per set of six points) and solenoid valve to control oxygen flow for pulse injection;
- main electrical panel with breakers for easy connection to power supply; and
- fully integrated remediation system with all plumbing, electrical, and mechanical components installed.

Startup of the system will be performed by Matrix Environmental technicians and will include the following:

- placement of trailer on the site and connection to available power supply;
- connection of 12 injection points to the trailer manifold using ¾-inch polyethylene tubing;
- baseline groundwater dissolved oxygen, pH, and oxidation-reduction potential (ORP) readings;
- startup of the system and fine tuning of system settings such as flow rate and pulse cycle time;
- groundwater dissolved oxygen and ORP measurements from injection points one day after system startup; and
- training of Science Applications International Corporation (SAIC) personnel on operation and maintenance the Matrix Environmental System.

During the pilot test, up to six trips will be made, originally bi-weekly, then monthly, for the collection of groundwater samples and groundwater parameters and system parameters. Groundwater collected from the observation points will be analyzed in the field for pH, dissolved oxygen (DO), ORP, conductivity, and temperature and sent to the laboratory for BTEX analysis. BTEX will be the only laboratory parameter monitored during the pilot study; all other laboratory parameters will be compared as pre- and post-test results. The system parameters to be observed include the oxygen flow rate and the pressure at each injection point.

The oxygen generator is designed to fill the oxygen receiver tank on demand. The system is always powered up but oxygen is only produced when the receiver tank is depleted to approximately 20 PSI. The system is never shut down.

A total of 24 injection points will be installed. This was determined by estimating the rate of oxygen dispersion in the contaminated zone. The system is configured with two timer-controlled sets of six flow meters. Therefore, 12 injection points will be active at any given time. The injection points in the source area will operate first. The flow rate of oxygen to each injection point and the pulse interval will be determined in the field based on groundwater dissolved oxygen data. The initial settings will be 30 scfh per point at a cycle interval of 10 minutes on and 50 minutes off.

The purpose of the oxygen injection system is to increase groundwater dissolved oxygen levels from background to the solubility limit of approximately 40 mg/L. Oxygen consumption by bacteria will be the greatest during the first several months of operation when bacteria are in the growth phase. Oxygen consumption will stabilize once the biomass is acclimated and shifts to a stationary or maintenance phase. Oxygen consumption will begin to decrease as hydrocarbons are depleted. This will be reflected by a steady increase in groundwater dissolved oxygen in piezometers and monitoring the extracted gas are measured every 10 minutes for the first hour and then once per hour to determine when the soil oxygen content has increased to a concentration that is sufficient to begin the respiration test. Once the purging is complete and the oxygen content has increased, the in situ respiration tests are initiated.

When the purging is completed, the concentration of oxygen in the soil gas at the test well is periodically monitored throughout a one-to-two day period. Monitoring will take place after 30 minutes, 1 hour, 1½ hours, 2 hours, 4 hours, 6 hours, 12 hours, and 24 hours. This monitoring tracks the decline in oxygen or the utilization of oxygen during the biodegradation of the contaminant, which results in a decreasing oxygen concentration over time. The landfill gas monitor is used to determine the oxygen at these same intervals throughout the one- to two-day period.

At the conclusion of the test, oxygen utilization rates are calculated as the slope of the plot of oxygen versus time. The oxygen utilization rates determined from the tests represent the oxygen consumption rate when oxygen is abundant and not limiting the microbial activity. Based on the oxygen utilization rates, the hydrocarbon biodegradation rate is then estimated using the physical properties of the soil and the chemical properties of the contaminants. The physical properties to be used will include air fill porosity and water fill porosity and will be determined from a Shelby tube sample collected above the water table during well installation.

3.3.3 Soil Vapor Extraction Pilot Test

The monitoring well and the piezometers installed for the in situ respiration test will be used to conduct the SVE test. A short-term pilot test will be completed at the test well VW-01. The test will primarily involve extracting soil gas from well VW-01 at four different rates of vacuum and monitoring the induced subsurface vacuum at the monitoring piezometers and wells (MW 56 and MW 57), the extraction flow rate from well VW-01, and the concentration of volatile organic carbons (VOCs) in the extracted soil gas. Each of the four vacuum steps will be conducted for a minimum of 1 hour.

A 3-horsepower regenerative blower with a explosion-proof motor will be used to apply four different rates of vacuum on the test well during the pilot test. The four applied vacuum rates will be determined in the field as a percentage of the maximum vacuum obtainable on the wellhead with a minimum volume of water extracted. After the maximum vacuum attainable is determined, the test will begin with a 25-percent vacuum being applied, then move to 50 percent, from there to 75 percent, and finally 100 percent. An atmospheric intake valve located ahead of the blower intake will be used to adjust the applied vacuum on the wellhead. An EG&G Roton model DR606 regenerative blower capable of extracting 200 standard cubic feet per minute (scfm) of soil gas at a vacuum of 0 inches of WC or 40 scfm at 80 inches of WC (water column) will be used.

A Pitot tube will be attached to a section of extraction piping located between the wellhead and the blower's atmospheric intake valve. The Pitot tube, in conjunction with a magnehelic gauge and temperature gauge, will be used to determine the extraction flow rate. The flow rate will be determined at 15-minute intervals during each vacuum step of the pilot test.

The wellheads and the piezometer wellheads will each be equipped with magnehelic gauges to monitor the applied or induced vacuum values. The applied and induced vacuum values will be recorded at 15-minute intervals during each vacuum step.

- In cases in which contamination is detected by field headspace gas analysis in one or more of the borehole intervals, the 2.0-foot interval exhibiting the highest detected organic vapor concentration will be selected.

3.4.4 Groundwater Sampling during Soil Borings

Groundwater samples will be collected through the use of temporary piezometers installed using direct-push sampling techniques. These techniques will provide in situ groundwater samples without the generation of soil cuttings. Field measurements performed during the investigations will include pH, specific conductance, DO, ORP, and temperature. Procedures and equipment for measurement of pH, specific conductance, DO, ORP, and temperature are presented in the Sampling and Analysis Plan, Section 4.1.5 (SAIC 1998a).

The groundwater samples will be sent to an off-site analytical laboratory and analyzed for BTEX and polycyclic aromatic hydrocarbons. A summary of the number of groundwater samples and quality control sites is presented in Table 3.

3.5 MONITORING WELL INSTALLATION

A total of four monitoring wells may be installed; three free product recovery wells whose location will be determined from the free product delineation points and one soil vapor test well (VW-1). The monitoring wells, composed of 2-inch PVC, will be installed using the hollow-stem auger drilling method. The procedures and methodology for hollow-stem auger drilling are presented in the Sampling and Analysis Plan, Section 4.1.2.2 (SAIC 1998a). The proposed locations of the monitoring wells are presented in Appendix A, Figures A.1, A.2, A.3, and A.4.

Soil samples will not be collected in the free product recovery wells.

3.6 WATER LEVEL MEASUREMENTS

Prior to pilot testing, a complete set of water level measurements will be collected from all the wells and temporary monitoring points at the site. Procedures and equipment for water level measurements are presented in the Sampling and Analysis Plan, Section 4.1.2.7 (SAIC 1998a).

3.7 SITE PREPARATION

Prior to the initiation of field activities, the existing fencing at former Building 728 will be removed and the open former piping vaults will be backfilled. Subcontracted fencing services will be supplied by Savannah Fence and Entry Systems. Backfilling of the former piping vaults will be handled by Hunter Army Airfield, DPW, Roads and Grounds. Following the installation of all piezometers and monitoring wells, new fencing will be installed at the former Building 728 and 133 areas. The new fencing will enclose the newly installed points at each site. It is estimated that the fencing at the former Building 133 area will be 100 feet by 100 feet and the new fencing at the former Building 728 area will be 270 feet by 180 feet.

A field trailer will be installed and set-up at the site as depicted on Figure A.1. In addition a map showing directions to the former Building 728 site from the Main Gate and from the Montgomery

Table 1. Proposed Drilling for the Pilot Study

Site	Facility ID	Type of Tank	Delineation Points	Observation Points	Injection Points	Wells
Former Building 133	9-00653	Gas/diesel/waste oil	10	NR	NR	NR
Former Building 728 (Oxygen Injection Test)	9-02535 and 9-025049	Aviation fuel/waste oil/alcohol-water mixture/JP-4/oil-water separators	25	5	24	3
Former Building 728 (Respiration & SVE Tests)	9-02535 and 9-025049	Aviation fuel/waste oil/alcohol-water mixture/JP-4/oil-water separators	NR	2	NR	1

NR = Not required.

Table 3. Summary of Soil, Groundwater, and Gas Samples to be Collected during the Pilot Study

Investigation	Matrix	Analysis	Analytical Procedures	No. Field Smpls	QC Dups[a]	Field Rnsts[b]	QC Trip Blnks	Total Smpls	Holding Time	Preservation Requirements	Sample Containers
Former Building 728	Groundwater	BTEX	EPA 8260B	90	12	6	8	116	14 days	Cool 4°C HCl pH<2	2, 40 mL GSV
		TPH	EPA 418.1	30	3	2	0	35	28 days	Cool 4°C H_2SO_4 to pH<2	1,1L AG
		Nitrate	EPA 353.3	30	3	0	0	33	28 days	Cool 4°C H_2SO_4 to pH<2	250 mL poly bottle
		Sulfate	EPA 300.0	30	3	0	0	33	28 days	Cool 4°C	250 mL poly bottle
		Sulfide	EPA 376.2	30	3	0	0	33	7 days	Cool 4°C zinc acetate plus NaOH to pH>9	500 mL poly bottle
		Iron (Total & Dissolved)	EPA 6010B	30	3	0	0	33	180 days	Cool 4°C HNO_3 to pH<2	500 mL poly bottle
		Methane	EPA 8000	30	3	0	2	35	14 days	Cool 4°C	2, 40 mL GVS
		CO_2	SM 4500	30	3	0	2	35	14 days	Cool 4°C	1, 250 mL poly bottle
Former Building 728	Soil	BTEX	EPA 5035/8260B	33	3	2	0	38	48 hours	Cool 0°C	Encore
		TPH	EPA 418.1 Mod.	33	3	2	0	38	28 days	Cool 4°C	1, 8 oz. CWM
		TOC	EPA 9060	5	0	0	0	5	28 days	Cool 4°C	None[e]
		Lead	EPA 6010B/7000	2	0	0	0	2	180 days	Cool 4°C	None[e]
		Geotechnical	Various	5	0	0	0	5	N/A	Wax Seal	Shelby tube
Former Building 728	Gas	VOC	GC Screen	2	0	0	0	2	ASAP	None	1, 1 L gas-tight plastic bag

AG = amber glass.
ASAP = as soon as possible.
CWM = clear, widemouth glass jar.
GSV = glass septa vial.
MOGAS = motor gasoline
NA = not applicable.
NR = not required.
QA = quality control.
(This table is in conformance with EM200-1-3).

[a] The number of quality control duplicate samples represents a 10-percent distribution between the different types of investigations to be conducted. However, the actual number of duplicates collected for each investigation type might vary slightly from the distribution presented.
[b] The number of quality control rinsate blank samples represents a 5-percent distribution between the different types of investigations to be conducted. However, the actual number of blanks collected for each investigation type might vary slightly from the distribution presented.
[c] Sample containers will be filled so that no headspace is present.
[d] Analysis will be performed on matrix placed into the BTEX sample container.
[e] Analysis will be performed on matrix placed into the TPH sample container.

APPENDIX A

PROPOSED SAMPLING LOCATIONS FOR THE PILOT STUDY

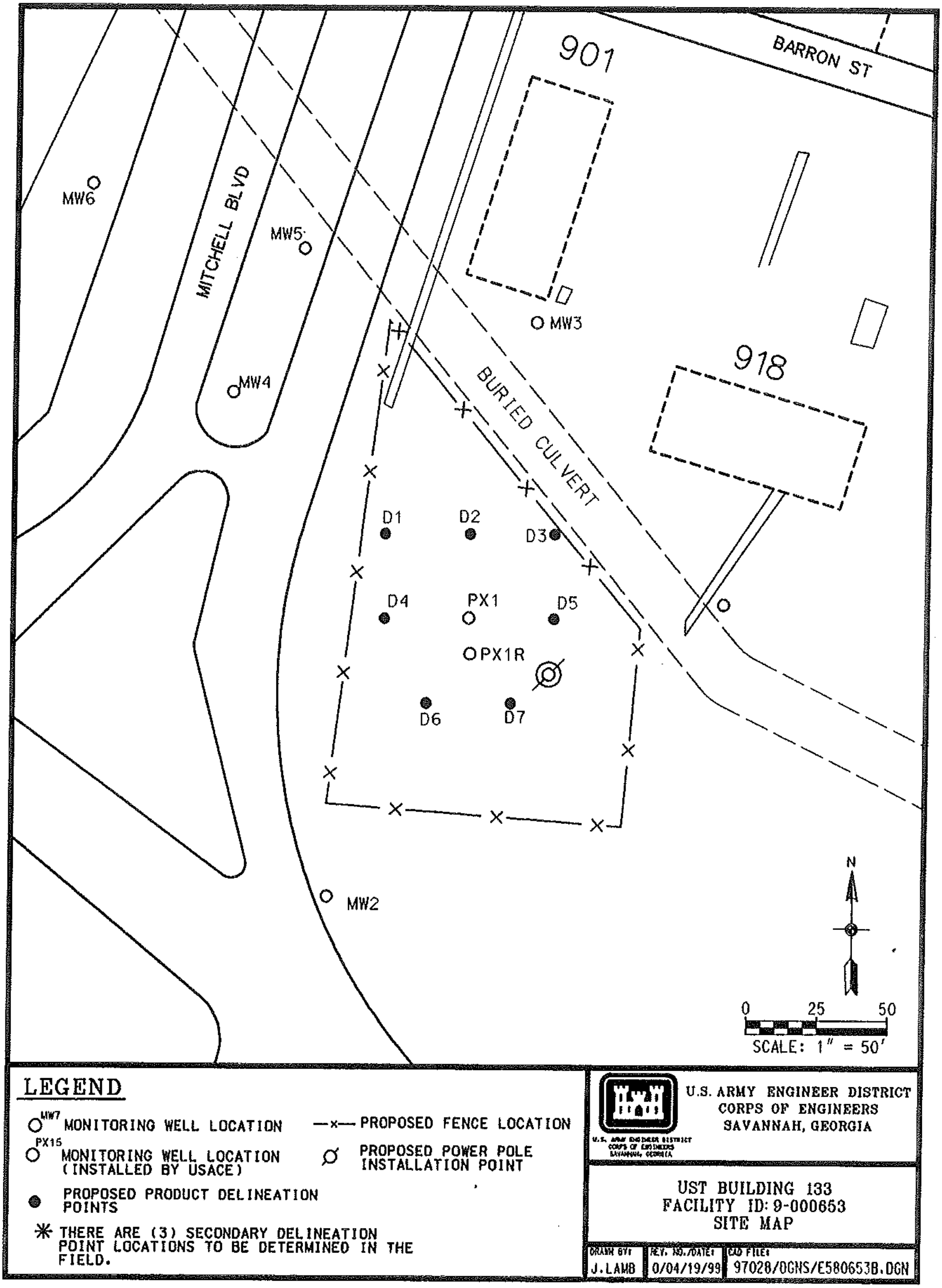


Figure A.1. Locations of Product Delineation Points for Former Building 133 Site

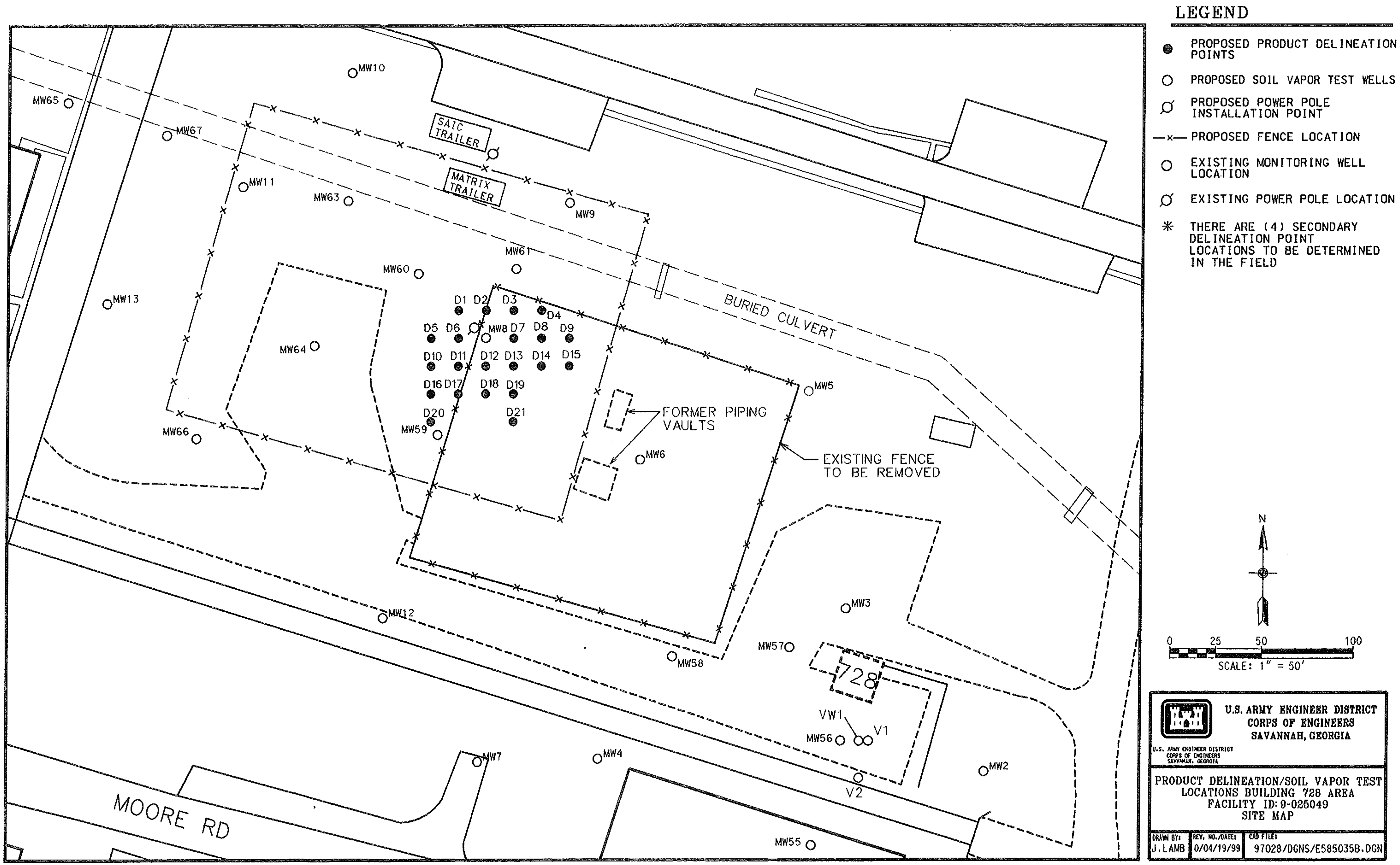


Figure A.2. Locations of Product Delineation Points for Former Building 728 Site

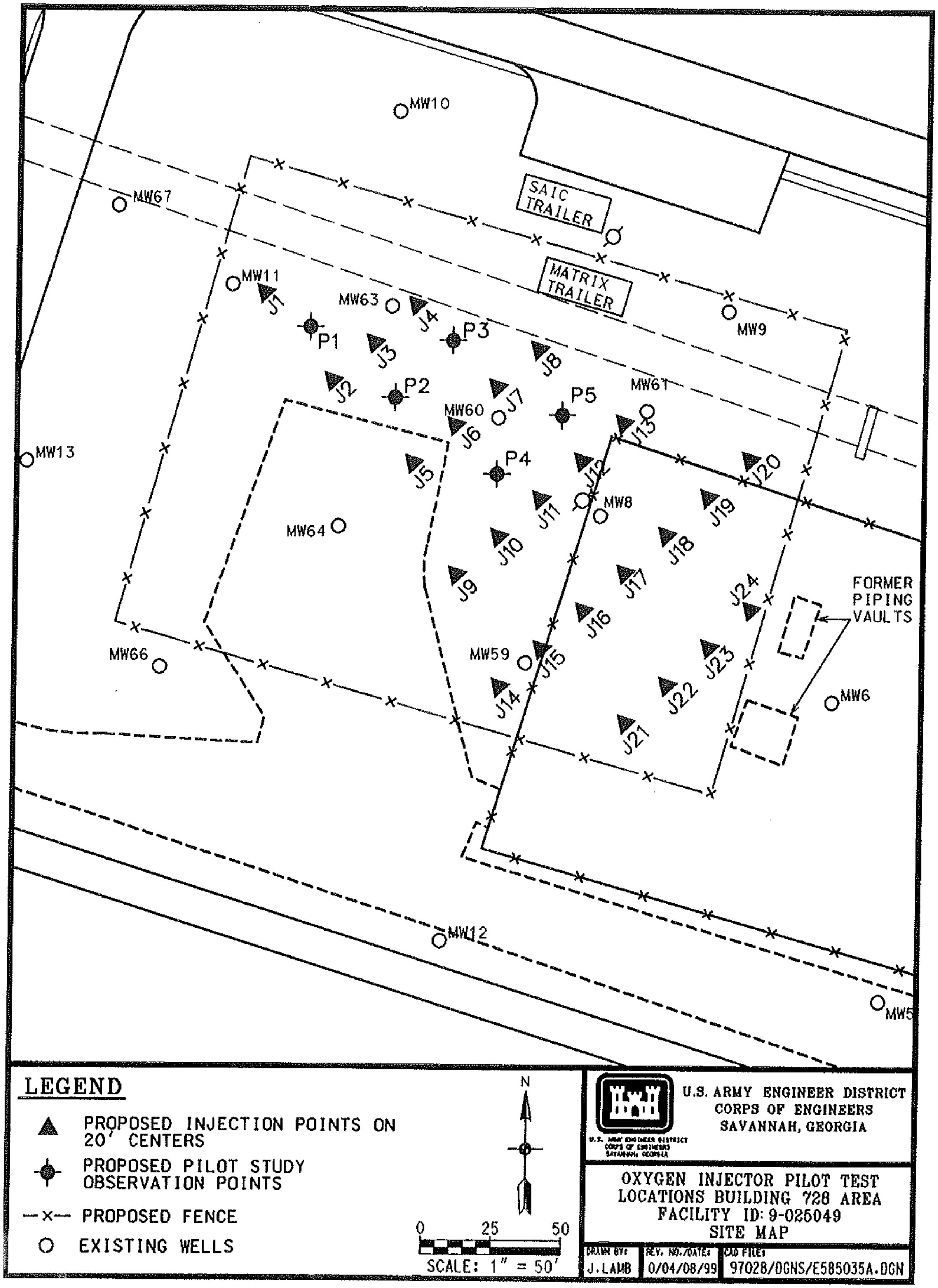


Figure A.3. Proposed Locations of Injection and Observation Points for Former Building 728 Site

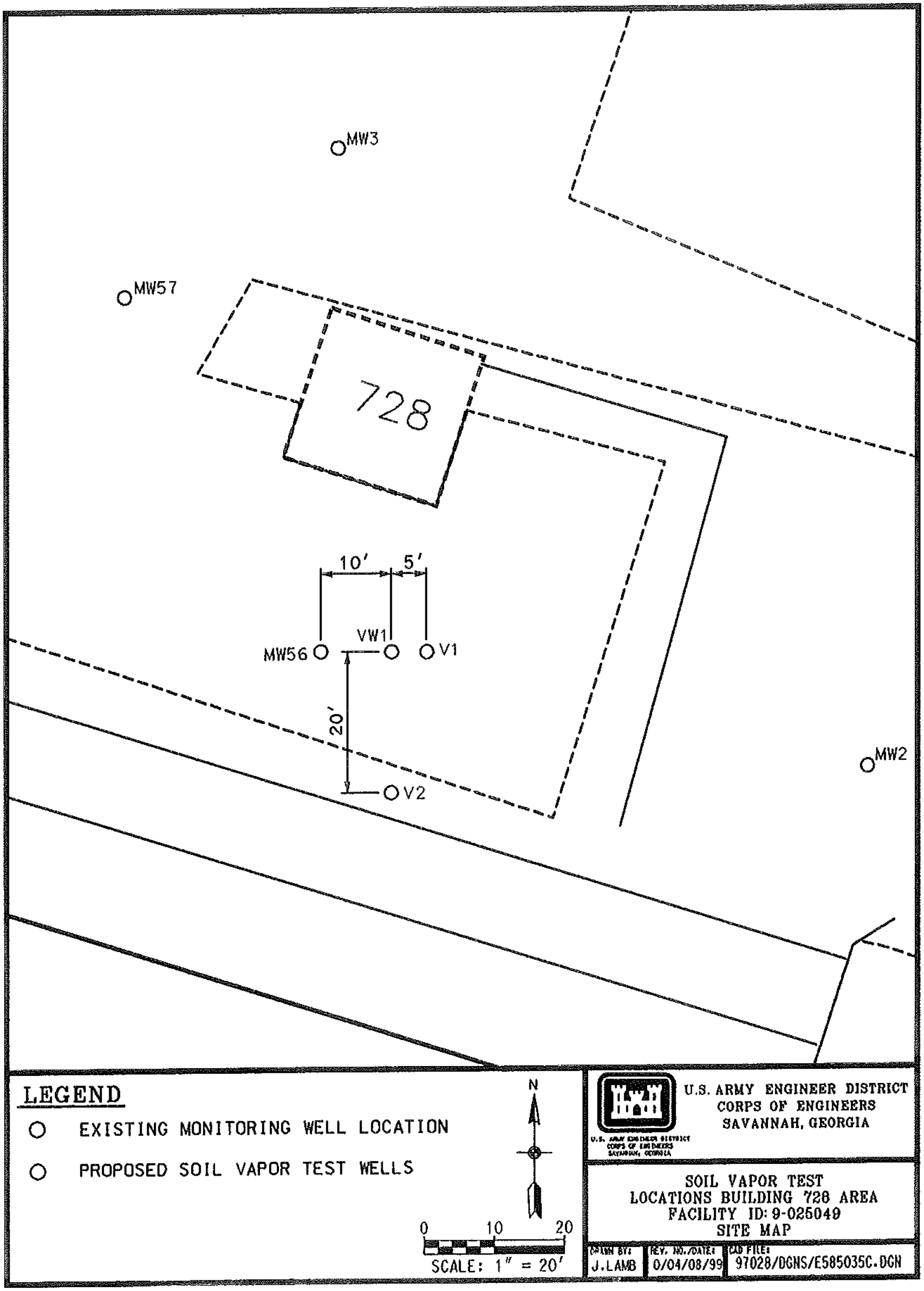


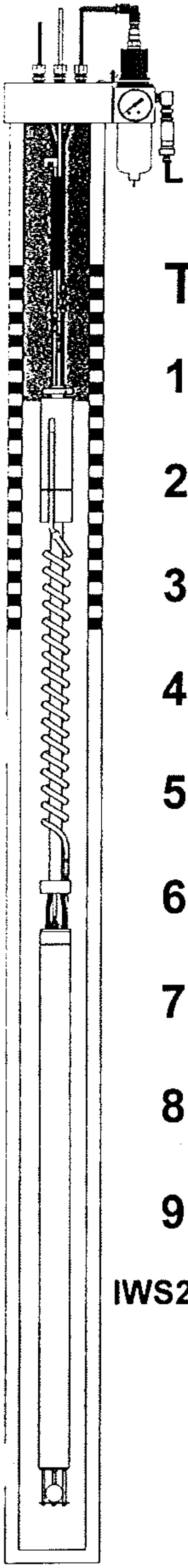
Figure A.4. Proposed Locations of Soil Vapor Test Wells for Former Building 728 Site

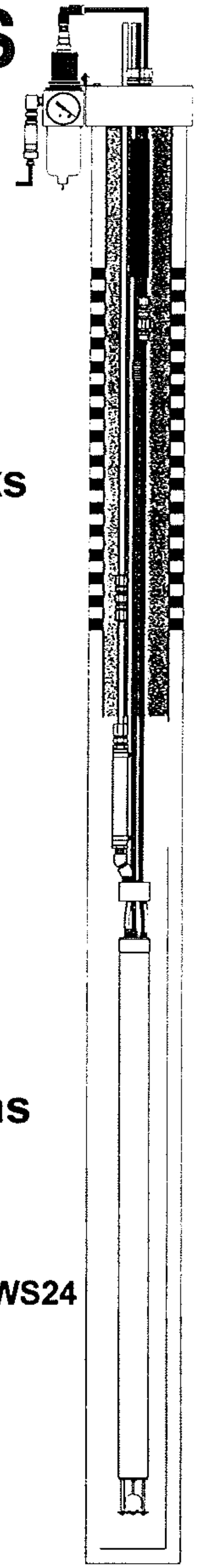
APPENDIX B

FERRET™ INSTALLATION INSTRUCTIONS

IN-WELL SEPARATORS

Models No. IWS26 & SIWS24





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IWS26

SIWS24

QED *Environmental Systems, Inc.*

The GroundWater Specialists

P.O. Box 3726. Ann Arbor, Michigan 48106

734-995-2547 800-624-2026 Fax: 734-995-1170

E-Mail: info@qedenv.com Website: http://www.qedenv.com

P/N 95124 Rev. #8 12-30-98

IF PRODUCT LAYER IS OVER 1/4" THICK

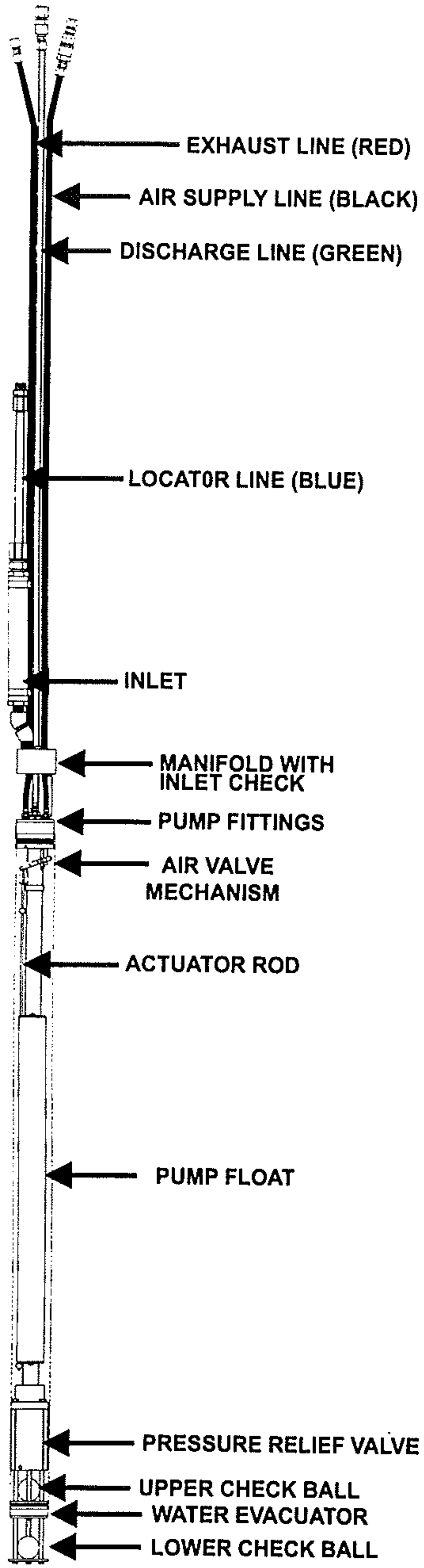
Liquid enters the Ferret by way of a floating inlet. If the product layer is over a 1/4" thick, only product will enter the pump. As the pump fills with product, the pump float rises up triggering the drive mechanism causing air to enter the pump, forcing the product into the discharge tube and up to the surface.

As the product is forced out of the pump the float drops, sliding the actuator rod downward, shutting off the air supply and allowing the compressed air in the pump to vent. This allows the pump to refill. The float rises back to the top position and the cycle is repeated.

IF PRODUCT LAYER IS LESS THAN 1/4" THICK

As the product is removed from the well and the layer is reduced to less than 1\4" thick, the inlet will become positioned just below the interface, allowing both product and water to enter the pump. The upper and lower check balls are made of a material which floats in water, but sinks in product.
As both water and product enter the pump, the water being the heavier of the two liquids separates to the bottom causing the upper check ball to float. The lower check being outside of the Ferret is always submerged in water, floats up sealing off the bottom, not allowing water to enter through the opening in the bottom of the water evacuator.

Once the pump is full of liquid, and the pump float turns the air on, the water is pushed out the water evacuator, past the floating upper check ball and lower check ball, until the product reaches the upper check ball sinking it into the water evacuator seat. This forces the product into the discharge tube and up to the surface. The cycle then repeats.



IF PRODUCT LAYER IS AT THE INLET

Liquid enters the Ferret through the inlet. If the product layer is over the inlet, only product will enter the pump. As the pump fills with product, the pump float rises up triggering the drive mechanism causing air to enter the pump, forcing the product into the discharge tube and up to the surface.

As the product is forced out of the pump the float drops, sliding the actuator rod downward, shutting off the air supply and allowing the compressed air in the pump to vent. This allows the pump to refill. The float rises back to the top position and the cycle is repeated.

IF WATER IS AT THE INLET

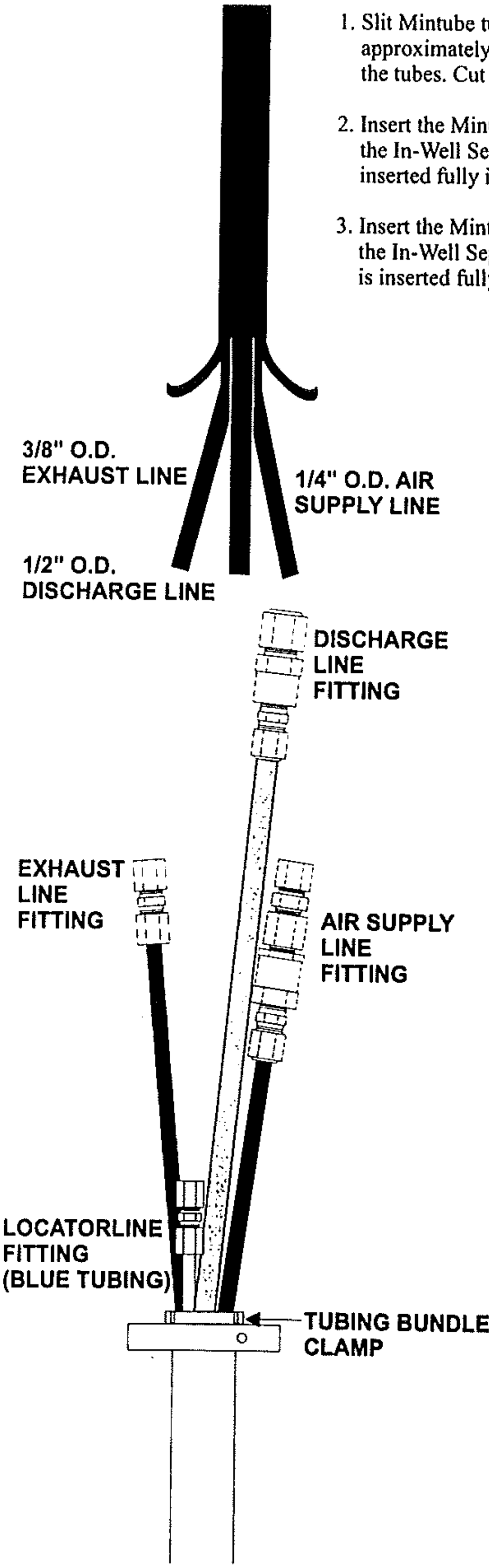
As the product is removed from the well and the layer is reduced, the inlet will be just below the interface, allowing water to enter the pump. The upper and lower check balls are both made from a material which floats in water, but sinks in product. As the water enters the pump, the water being heavier than the product causes the upper check ball to float. The lower check being outside of the Ferret is always submerged in water, floats up sealing off the bottom, not allowing water to enter through the opening in the bottom of the water evacuator.

Once the pump is full of liquid, and the pump float turns the air on, the water is pushed out the water evacuator, past the floating upper check ball and lower check ball. As the water is forced out of the pump the float drops, sliding the actuator rod downward shutting off the air supply to the pump. The cycle then repeats.

1. Slit Mintube tubing sheath (being careful not to cut the tubes) approximately 1' up tubing bundle. Peel back sheath exposing the tubes. Cut off excess sheathing.

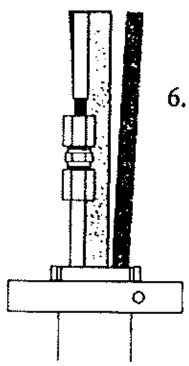
2. Insert the Mintube's exhaust tube into the compression fitting of the In-Well Separator's exhaust line (red). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.

3. Insert the Mintube's air supply tube into the compression fitting of the In-Well Separator's air supply line (black). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.



4. Cut the Mintube discharge tubing so that the tube fits fully into the In-Well Separator's discharge line compression fitting without bowing the tubing (and so that the In-Well Separator Hangs evenly from the tubing).

5. Insert the Mintube's discharge tube into the compression fitting of the In-Well Separator's discharge line (green). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.



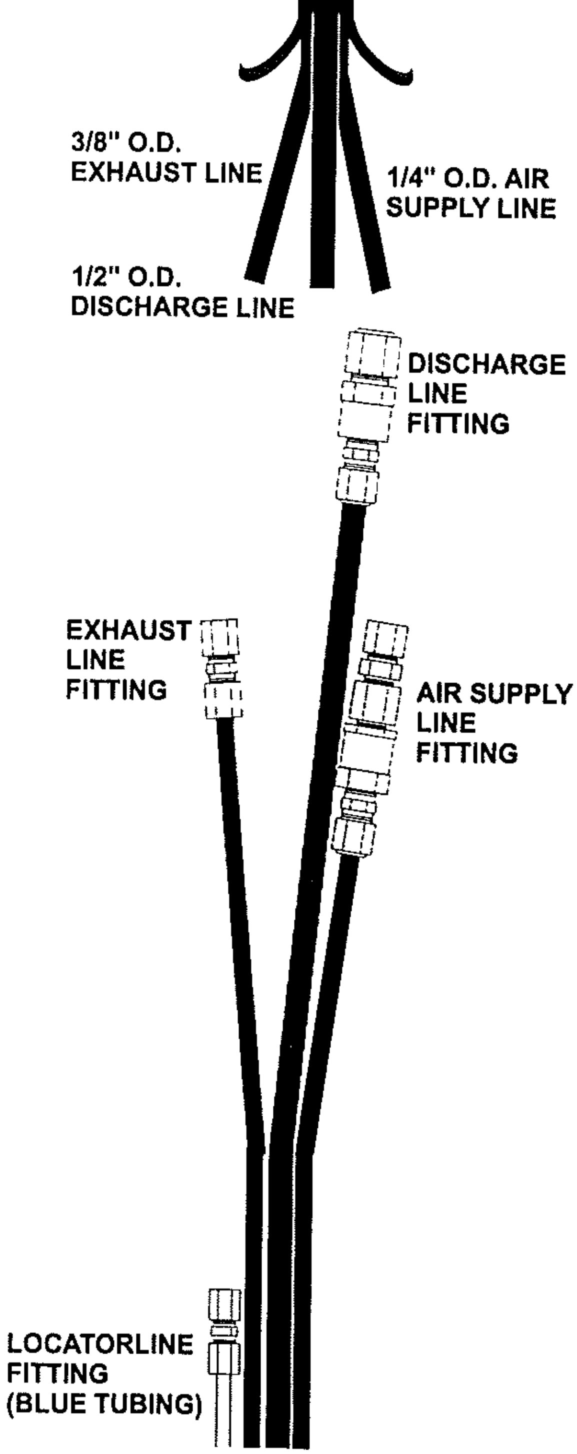
6. Insert locator tube into the compression fitting of the In-Well Separator's locator line (blue). Make Sure the tube is inserted fully into the fitting. Tighten fitting securely.

3

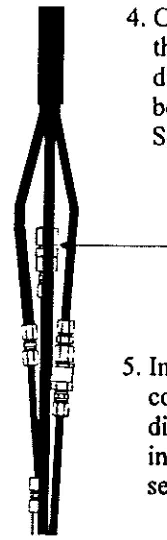
1. Slit Mintube tubing sheath (being careful not to cut the tubes) approximately 1' up tubing bundle. Peel back sheath exposing the tubes. Cut off excess sheathing.

2. Insert the Mintube's exhaust tube into the compression fitting of the In-Well Separator's exhaust line (red). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.

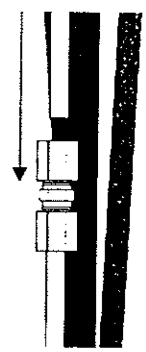
3. Insert the Mintube's air supply tube into the compression fitting of the In-Well Separator's air supply line (black). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.



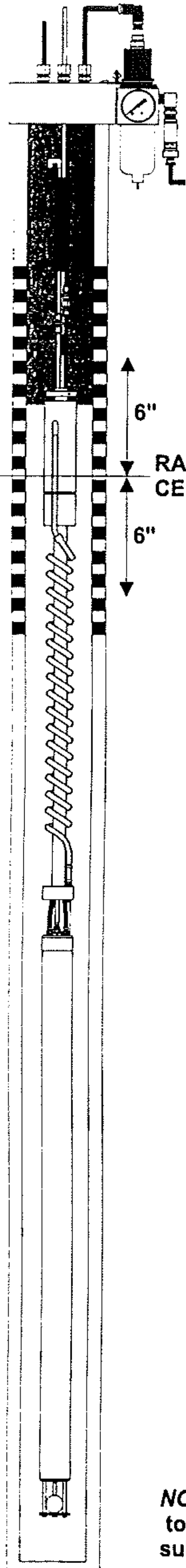
4. Cut the Mintube discharge tubing so that the tube fits fully into the In-Well Separator's discharge line compression fitting without bowing the tubing (and so that the In-Well Separator Hangs evenly from the tubing).

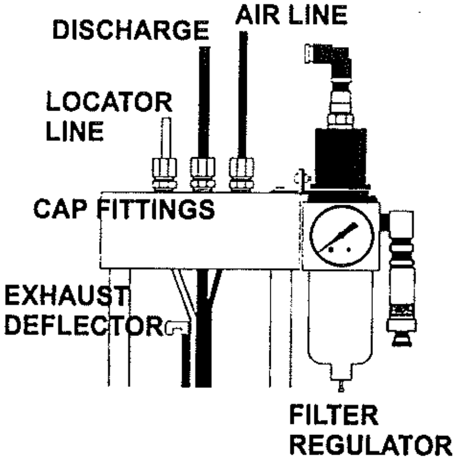


5. Insert the Mintube's discharge tube into the compression fitting of the In-Well Separator's discharge line (green). Make sure the tube is inserted fully into the fitting. Tighten fitting securely.

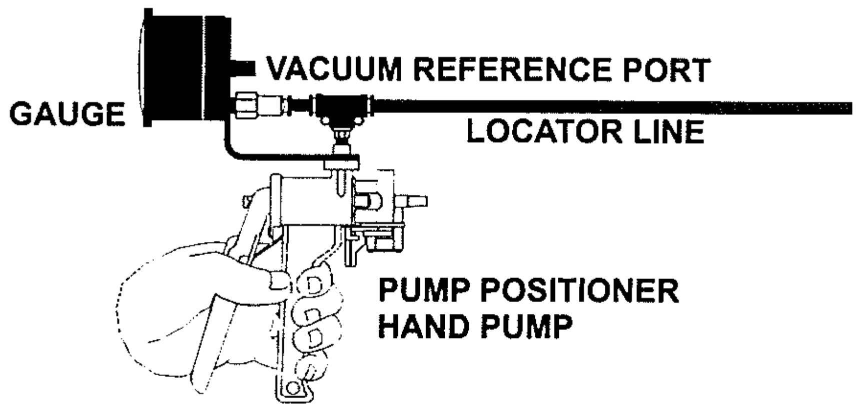


6. Insert locator tube into the compression fitting of the In-Well Separator's locator line (blue). Make Sure the tube is inserted fully into the fitting. Tighten fitting securely.

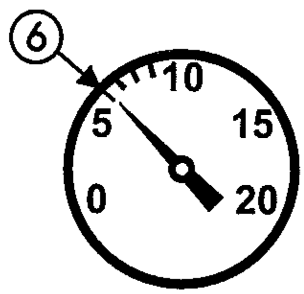




Attach tubing to Ferret In-Well Separator and insert Separator down well to approximate desired depth. Cut and peel off the tubing bundle sheath (being careful not to cut the tubing itself) so that approximately 2' of the tubing is exposed. Locate the exhaust tube and cut it at a point just below the well cap. Attach supplied exhaust deflector (simply slides on). Loosen well cap's bore through roving fittings so the separator's tubing will pass through them easily. Slide the Separator lines through the cap fittings. Do not tighten fittings until the pump has been properly positioned in the well (see below). While holding the Separator's tubing (above the cap) locate the Separator's Locator Line

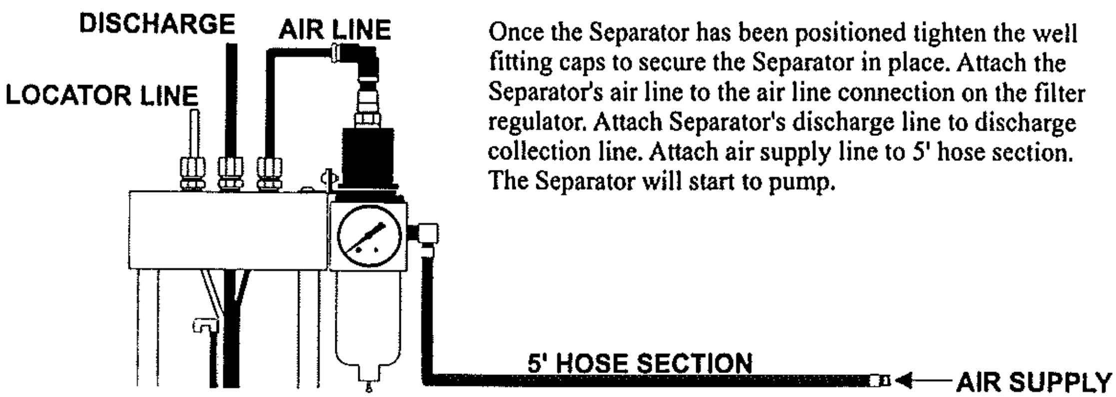


Attach locator Line to connector located on the hand positioner pump, (simply push end of tube into the fitting). To remove tube push back on black fitting lock ring to release grip on the tubing.



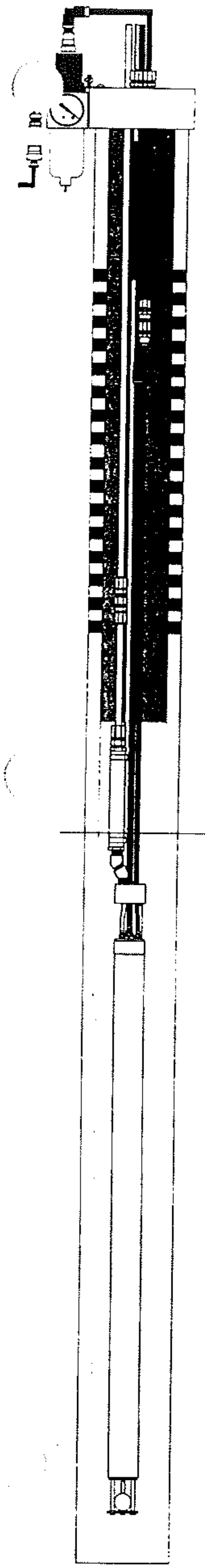
Squeeze hand pump until gauge needle reads same depth consistently. Raise or lower the Separator by its tubing to desired inlet setting. Typical application setting would be at 6". This centralizes the Separator's inlet range.

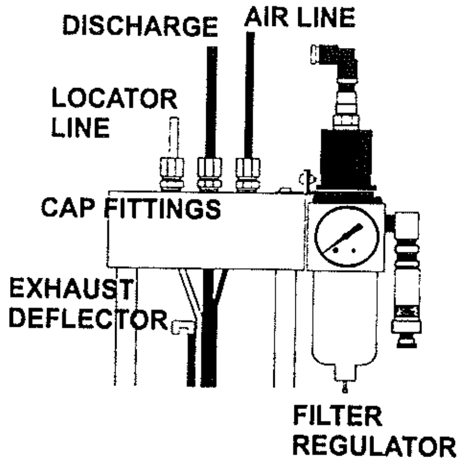
***NOTE:* THIS DEVICE ONLY LOCATES THE INLET IN FLUID. IT DOES NOT DETERMINE THE THICKNESS OF THE PRODUCT LAYER.**



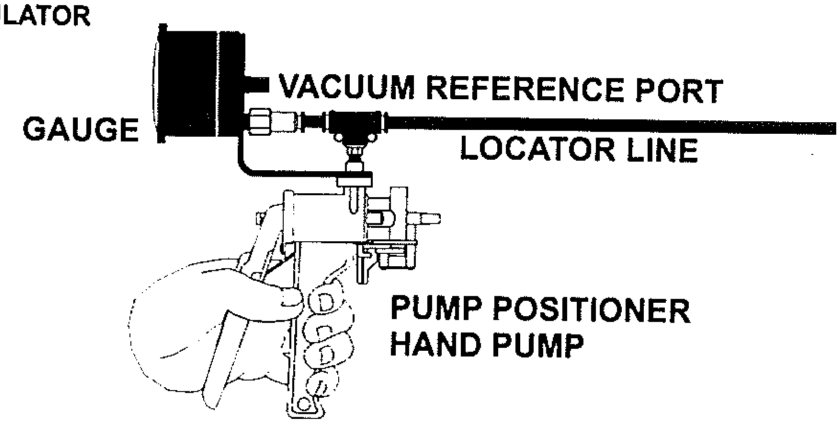
Once the Separator has been positioned tighten the well fitting caps to secure the Separator in place. Attach the Separator's air line to the air line connection on the filter regulator. Attach Separator's discharge line to discharge collection line. Attach air supply line to 5' hose section. The Separator will start to pump.

***NOTE:* Upon initial installation it could take up to several minutes to begin to deliver free product to the surface. The length of time is dependent upon product viscosity, well depth and inlet submergence.**

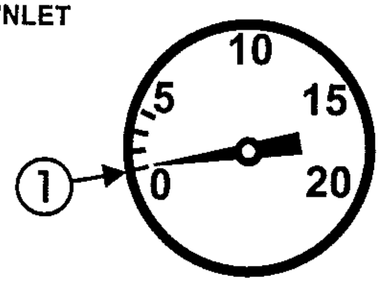




Attach tubing to Ferret In-Well Separator and insert Separator down well to approximate desired depth. Cut and peel off the tubing bundle sheath (being careful not to cut the tubing itself) so that approximately 2' of the tubing is exposed. Locate the exhaust tube and cut it at a point just below the well cap. Attach supplied exhaust deflector (simply slides on). Loosen well cap's bore through roving fittings so the separator's tubing will pass through them easily. Slide the Separator lines through the cap fittings. Do not tighten fittings until the pump has been properly positioned in the well (see below). While holding the Separator's tubing (above the cap) locate the Separator's Locator Line



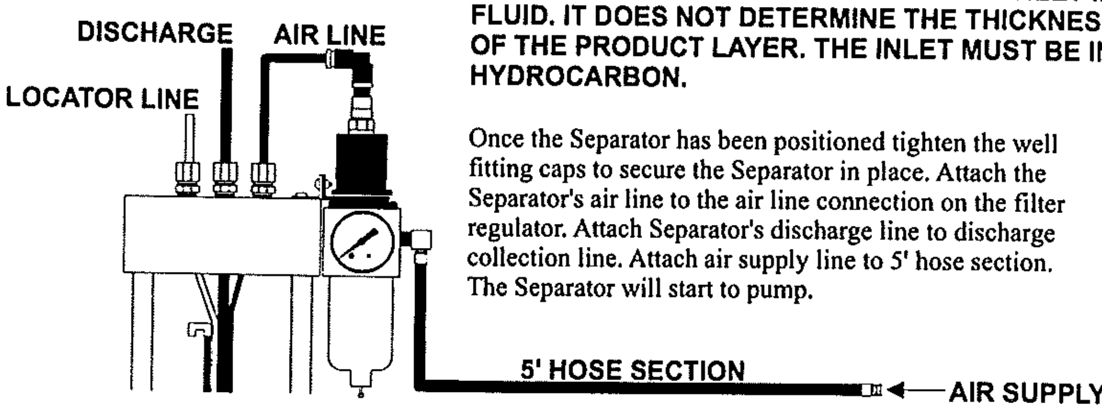
Attach Locator Line to connector located on the hand positioner pump, (simply push end of tube into the fitting). To remove tube push back on black fitting lock ring to release grip on the tubing.



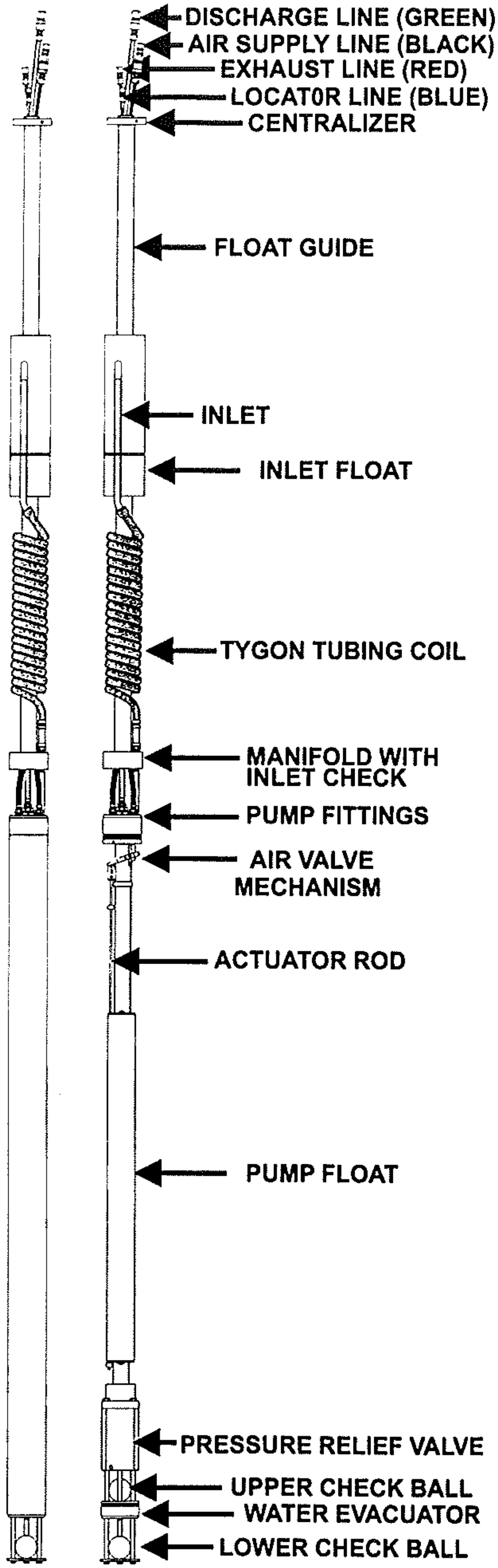
Squeeze hand pump until gauge needle reads same depth consistently. Raise or lower the Separator by its tubing to desired inlet setting. The gauge reads the height of liquid above the pump inlet. The thinner the product layer, the closer you will want to position the inlet to the top of the liquid in the well, to be sure that the inlet is in product. A gauge reading "1" means the inlet is 1" below the top of the liquid.

***NOTE:* THIS DEVICE ONLY LOCATES THE INLET IN FLUID. IT DOES NOT DETERMINE THE THICKNESS OF THE PRODUCT LAYER. THE INLET MUST BE IN HYDROCARBON.**

Once the Separator has been positioned tighten the well fitting caps to secure the Separator in place. Attach the Separator's air line to the air line connection on the filter regulator. Attach Separator's discharge line to discharge collection line. Attach air supply line to 5' hose section. The Separator will start to pump.



***NOTE:* Upon initial installation it could take up to several minutes to begin to deliver free product to the surface. The length of time is dependent upon product viscosity, well depth and inlet submergence. This pump has a fixed inlet, if the water table changes moving the interface up or down, the pump may need to be repositioned.**



Separator Type: Positive Air Displacement

Dimensions:

O.D.:	1.75" (45mm)
Length:	72" (183cm)
Weight:	5.75 lbs.
Minimum Well Diameter:	2" (50mm) or larger
Inlet Port:	60" (152 cm) above bottom of device
Inlet Range:	12" (31 cm)

Materials: Stainless Steel, Brass, Delrin, Polypropylene, and Epoxy with Viton O-rings and Tygon Tubing.

Fittings:

Type:	Brass Compression
Discharge Size:	1/2" O.D.(13 mm)
Air Supply Size:	1/4" O.D. (6 mm)
Exhaust Size:	3/8" O.D. (9 mm)
Level Gauge:	1/4" O.D. (6 mm)

Separator Performance:

Operating Pressure Range:	50-100 P.S.I. (350-700 kPa)
Maximum Lift:	150 FEET (45 m)
Estimated Air Flow:	0.5-1.0 S.C.F.M. at 50 P.S.I. (350 kPa)

Separator Flow Rates:

Up to 60 G.P.D. (227 L.P.D.) possible with 6" (15 cm) or more of product submergence over inlet. Rate will vary depending on conditions.

Discharge Amount:

Maximum product volume per cycle 0-.07 gal. (250 ml),varies depending upon amount of water that enters and is expelled by the separator. THE IN-WELL SEPARATOR WILL ONLY DISCHARGE PRODUCT TO THE SURFACE.

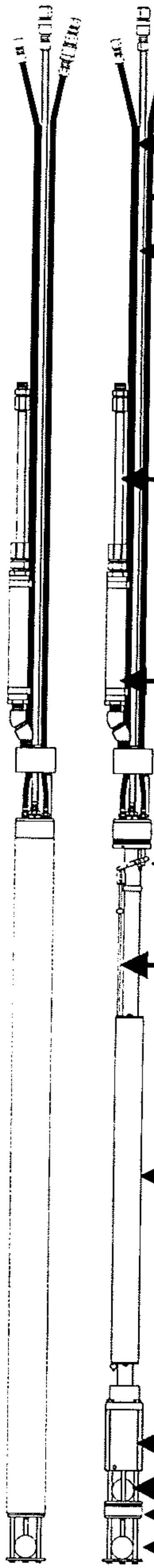
Product Pumped Density: 0.7-0.90 g/cc

Viscosity Range:

The In-Well Separator is recommended for liquids with kinematic viscosities ≤ 4 centistokes. Suitable liquids that may meet the viscosity recommendations are gasoline, JP4, JP5, Kerosene, Diesel Fuel, #2 Fuel Oil. Incompatible liquids include #3 (and above) Fuel Oil, SAE 10 (and above) Motor Oil, and Hydraulic Fluids.

Solvent Compatibility:

The Tygon tubing in the In-Well Separator is compatible with most hydrocarbon fuels, but may be attacked by high concentrations of MEK, Acetone, other Ketones, and some Alcohols- consult QED for guidance.



Separator Type:

Positive Air Displacement

Dimensions:

O.D.:	1.75" (45mm)
Length:	50" (127cm)
Weight:	5.75 lbs.
Minimum Well Diameter:	2" (50mm) or larger
Inlet Port:	45" (114 cm) above bottom of device

Materials:

Stainless Steel, Brass, Delrin, Polypropylene, Epoxy and Viton O-rings.

Fittings:

Type:	Brass Compression
Discharge Size:	1/2" O.D.(13 mm)
Air Supply Size:	1/4" O.D. (6 mm)
Exhaust Size:	3/8" O.D. (9 mm)
Level Gauge:	1/4" O.D. (6 mm)

Separator Performance:

Operating Pressure Range:	50-100 P.S.I. (350-700 kPa)
Maximum Lift:	150 FEET (45 m)
Estimated Air Flow:	0.5-1.0 S.C.F.M. at 50 P.S.I. (350 kPa)

Separator Flow Rates:

Up to 200 G.P.D. (757 L.P.D.) possible with 6" (15 cm) or more of product submergence over inlet. Rate will vary depending on conditions.

Discharge Amount:

Maximum product volume per cycle 0-.07 gal. (250 ml),varies depending upon amount of water that enters and is expelled by the separator. THE IN-WELL SEPARATOR WILL ONLY DISCHARGE PRODUCT TO THE SURFACE.

Product Pumped Density:

0.7-0.90 g/cc

Viscosity Range:

The short In-Well Separator is recommended for liquids with kinematic viscosities ≤ 40 centistokes. Suitable liquids that may meet the viscosity recommendations are gasoline, JP4, JP5, Kerosene, Diesel Fuel, #2 Fuel Oil and #3 Fuel Oil. Incompatible liquids include #5 (and above) Fuel Oil, SAE 10 (and above) Motor Oil, and Hydraulic Fluids.

IN-WELL SEPARATORS

Models No. IWS26 & SIWS24

QED Environmental Systems, Inc. (QED) warrants to the original purchaser of its products that, subject to limitations and conditions provided below, the products, materials and/or workmanship shall reasonably conform to descriptions of the products and shall be free of defects in materials and workmanship. Any failure of the products to conform to this warranty will be remedied by QED in the manner provided herein.

This warranty shall be limited to the duration and the conditions set forth below. All warranty durations are calculated from the original date of purchase.

1. Liquid contacting equipment (including pumps), tubing, liquid contacting supplies and flow totalization equipment are warranted for 1 year.

2. Control devices, control device mounting, and surface air supply hose are warranted for 1 year.

3. Separately sold parts and spare parts kits are warranted for ninety (90) days.

4. Repairs performed by QED are warranted for ninety (90) days from date of repair or for the full term of the original warranty, whichever is longer.

Buyer's exclusive remedy for breach of said warranty shall be as follows: if, and only if, QED is notified in writing within the applicable warranty period of the existence of any such defects in the said products, and QED upon examination of any such defects, shall find the same to be within the term of and covered by the warranty running from QED to buyer, QED will, at its option, as soon as reasonably possible, replace or repair any such product, without charge to Buyer. If QED for any reason, cannot repair a product covered hereby within four (4) weeks after receipt of the original Purchaser's /Buyer's notification of a warranty claim, then QED's sole responsibility shall be, at its option, either to replace the defective product with a comparable new unit at no charge to the Buyer, or to refund the full purchase price. In no event shall such allegedly defective products be returned to QED without its consent, and QED's obligations of repair, replacement or refund are conditioned upon the Buyer's return of the defective product to QED.

IN NO EVENT SHALL QED ENVIRONMENTAL SYSTEMS INC. BE LIABLE FOR CONSEQUENTIAL OR INCIDENTAL DAMAGES FOR BREACH OF SAID WARRANTY.

The foregoing warranty does not apply to major subassemblies and other equipment, accessories, and other parts manufactured by others, and such other parts, accessories, and equipment are subject only to the warranties, if any, supplied by their respective manufacturers. QED makes no warranty concerning products or accessories not manufactured by QED. In the event of failure of any such product or accessory, QED will give reasonable assistance to Buyer in obtaining from the respective manufacturer whatever adjustment is reasonable in light of the manufacturer's own warranty.

THE FOREGOING WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED OR STATUTORY (INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE), WHICH OTHER WARRANTIES ARE EXPRESSLY EXCLUDED HEREBY, and of any other obligations or liabilities on the part of QED, and QED neither assumes nor authorizes any person to assume for it any other obligation or liability in connection with said products, materials and/or workmanship.

It is understood and agreed that QED shall in no event be liable for incedental or consequential damages, nor for improper selection of any product described or referred to for a particular application.

This warranty will be void in the event of unauthorized disassembly of component assemblies. Defects in any equipment that result from abuse, operation in any manner outside the recommended procedures, use and applications other than for intended use, or exposure to chemical or physical environment beyond the designated limits of materials and construction will also void this warranty.

Chemical attack to liquid contacting equipment and supplies shall not be covered by this warranty. A range of materials is available from QED and it is the Buyer's responsibility to select materials to fit the Buyer's application. QED will only warrant that the supplied liquid contacting materials will conform to published QED specifications and generally accepted standards for that particular material.

QED shall be released from all obligations under all warranties if any product covered hereby is repaired or modified by persons other than QED's service personnel unless such repair by others is made with the written consent of QED. If any product covered hereby is actually defective within the terms of this warranty, Purchaser must contact QED for determination of warranty coverage. If the return of a component is determined to be necessary, QED will authorize the return of the component, at owner's expense. If the product proves not to be defective within the terms of this warranty, then all costs and expenses in connection with the processing of the Purchaser's claim and all costs for repair, parts and labor as authorized by owner hereunder shall be borne by the Purchaser.

The original Purchaser's sole responsibility in the instance of a warranty claim shall be to notify QED of the defect, malfunction, or other manner in which the terms of this warranty are believed to be violated. You may secure performance of obligations hereunder by contacting the Customer Service Department of QED and:

1. Identify the product involved (by model or serial number or other sufficient description that will allow QED to determine which product is defective).

2. Specifying where, when, and from whom the product was purchased.

3. Describing the nature of the defect or malfunction covered by this warranty.

4. Sending the malfunctioning component, after authorization by QED to:

QED Environmental Systems, Inc.
6155 Jackson Rd.. Ann Arbor, Michigan 48103

FERRET™ IN.WELL SEPARATOR

QED Environmental Systems, Inc.
P.O. Box 3726, Ann Arbor, Michigan 48106
734-995-2547 800-624-2026 Fax: 734-995-1170
E-Mail: info@qedenv.com Website: http://www.qedenv.com

APPENDIX C

MATRIX ENVIRONMENTAL OXYGEN INJECTION SYSTEM

November 30, 1998

MATRIX
Environmental Technologies
5835 Ellis Road
P.O. Box 427
Orchard Park, N.Y. 14127-0427
(716) 662-0745
(716) 662-0946 (Fax)

Mr. Jeff Longacker
SAIC Engineering Inc.
P.O. Box 2502
800 Oak Ridge Turnpike
Oak Ridge, TN. 37831-2502

RE: Proposal for Matrix Trailer Mounted Oxygen Injection System
Hunter Army Airfield
Savannah, Georgia
Proposal #BIO98-334

Dear Mr. Longacker:

Matrix Biotechnologies (Matrix) is pleased to provide this proposal for the construction, installation and start-up of a Matrix Trailer Mounted Oxygen Injection System at the site referenced above. The information used in preparing this proposal included subsurface boring logs and analytical data provided by you.

The injection of pure oxygen into groundwater using oxygen generators is a patented remediation process develop by Matrix. It is a proven remediation technique for sites with conditions that are difficult to remediate including shallow groundwater, steep groundwater gradient, and fractured bedrock. There is no need for vapor extraction and absolutely no generation of hazardous vapors. It has also resulted in the biodegradation of MTBE, a fuel additive which is very difficult to extract from the subsurface or degrade using industry standard remediation methods. Oxygen injection rapidly enhances the biodegradation of organics which are biodegradable under aerobic conditions including petroleum hydrocarbons and chlorinated solvents. The system is operated to take full advantage of oxygen transport via advection and dispersion. This process actually uses the same transport mechanisms which resulted in contaminant migration.

To oxygenate the plume and stimulate aerobic biodegradation, ten injection points are recommended as shown on the site map. The points on site should be placed on fifteen foot centers and to a depth of approximately ten feet below the groundwater table. The points can be installed with a rotary drill rig or direct push rig and consist of ¾-inch diameter PVC riser with a one-foot slotted bottom section, sandpack and bentonite/grout seal. Header piping from each point to the location of the trailer should be installed below ground and consist of ¾-inch polyethylene tubing. Each injection point should be finished with a limited access curb box for groundwater sampling.

Scope of Work

Construction of a Matrix Trailer Mounted Oxygen Injection System including the following components:

- Six foot by ten foot cargo trailer.
- Electric heater and power roof ventilator with thermostat for year round operation.
- AirSep Model AS-80 oxygen generator with a 120 gallon surge tank and regulator. The generator produces 80 SCFH of oxygen at 90-95% purity. Single phase/60 Hz/110 volts.
- Atlas Copco GA-5 rotary screw air compressor with air dryer, vertical tank with autodrain, and low sound enclosure. Rated for 25 ACFM @ 125 PSIG. 7.5 HP TEFC motor, three phase/60 Hz/230 volts.
- Static phase converter to allow system to be used with single phase/230 volt power.
- Manifold for ten injection points (standard) to include individual pressure gauge (PSI), and variable area flow meter (SCFH).
- Two adjustable timers (per set of five points) and solenoid valve to control oxygen flow for pulse injection.
- Main electrical panel with breakers for easy connection to power supply.
- Fully integrated remediation system with all plumbing, electrical, and mechanical components installed.

Startup of the system will be performed by Matrix Technicians and will include the following:

- Placement of trailer on the site and connection to available power supply.
- Connection of ten (10) injection points to the trailer manifold using ¾-inch polyethylene tubing.
- Baseline groundwater dissolved oxygen, pH and oxidation-reduction potential (ORP) readings.

- Start-up of the system and fine tuning of system settings such as flow rate and pulse cycle time. Settings will be set to maximize system efficiency for site specific conditions.

- Groundwater dissolved oxygen and ORP measurements from injection points one day after system startup.

Assumptions

The following tasks will be assumed to be performed by others when Matrix is preparing to install this system.

- All necessary parties (i.e. property owner, manager) have been notified of the installation schedule and permission has been granted to perform the work on the property.

- All necessary permits have been applied for and obtained prior to the start of installation.

- Adequate electrical service is available on the site in close proximity to the trailer location (100 amp., single phase, 230 volt).

A suggested monitoring program includes the following:

- Bi-weekly measurement of flow and pressure from the oxygen manifold located in the trailer.

- Bi-weekly reading of AirSep and Atlas Copco gauges.

- Weekly measurement of groundwater dissolved oxygen and ORP levels and groundwater elevation gauging from select monitoring wells during the first month of operation, reducing to monthly measurements thereafter.

- Quarterly sampling of groundwater for laboratory analysis for petroleum hydrocarbons or as required by regulatory agency.

Matrix Biotechnologies, a division of Matrix Environmental Technologies Inc., is an innovative team of scientists and engineers who are focused on developing new technologies and advancing the field of environmental remediation. Environmental remediation using biotechnologies, in controlled systems or in the subsurface, requires an in depth understanding of natural systems and how they function in the environment. The application of this knowledge with practical design of mechanical and electrical systems produces innovative products. Matrix Biotechnologies was built on this philosophy and with the technical experience of Matrix Environmental Technologies Inc., we offer true innovation and outstanding field support from our regional offices.

All Matrix' professional, exploration, and remediation personnel participate in a yearly baseline medical monitoring program, have been trained in the use and maintenance of Level D, Level C, and Level B personal protective equipment, and have received safety training for work at hazardous waste sites pursuant to OSHA CFR 1910.120. Site specific decontamination and health and safety programs are developed, implemented, and administered by in-house personnel using equipment and facilities owned by Matrix.

Matrix' work on this project will be performed in a competitive, competent, and professional manner in compliance with all federal, state, and local regulations. Payment terms are net 30.

If you have any questions or require additional information, please contact me.

Sincerely,
Matrix Biotechnologies

Sean R. Carter
Senior Biological Engineer

Enclosures

MATRIX

Environmental Technologies

80 AND 12 SCFH OXYGEN INJECTION TRAILER MOUNTED SYSTEMS

MATRIX offers trailer mounted oxygen injection systems to be used in a variety of applications including short term 'hot spot" cleanups, pilot testing, and full scale remediation. The injection of pure oxygen into groundwater using oxygen generators is a patent pending remediation process developed by *MATRIX*. It is a proven remediation technique for sites with conditions that are difficult to remediate: shallow groundwater, steep groundwater gradient, and fractured bedrock.

Oxygen injection rapidly enhances the biodegradation of organics which are biodegradable under aerobic conditions; from petroleum hydrocarbons to chlorinated solvents. There is no need for vapor extraction and absolutely no generation of hazardous vapors. It has also resulted in the biodegradation of MTBE.

The 80 SCFH system is a full scale remediation system which consumes far less power than a comparable air sparging system and is often used on a short term basis to complete an on-going remediation project.

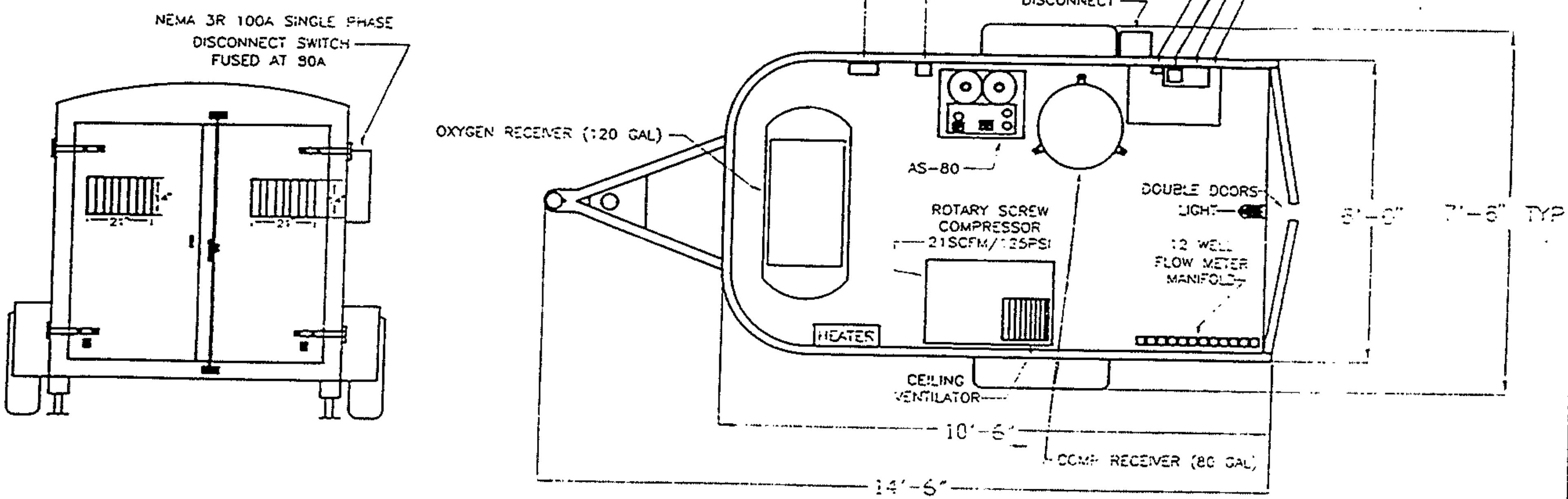
The 12 SCFH system is solar powered and designed for oxygen injection into one injection point. The system is ideal for sites with a confined zone of contamination (i.e. only one contaminated monitoring well) which must be reduced for site closure.

The 80 SCFH Trailer Mounted Oxygen Injection System includes the following components:

- Six foot by ten foot insulated cargo trailer.
- Electric heater and root ventilator with thermostat for year round operation.
- Oxygen generator with a 60 gallon surge tank and regulator. The generator produces 80 SCFH of oxygen at 90-95% purity. 1 phase/60Hz/120 volts.
- Air compressor with air dryer, and vertical tank. Rated for 25 ACFM @ 125 PSIG. 7.5 HP TEFC motor, 3 phase/60 Hz/230-460 volts.
- Static phase converter standard on all systems.
- Manifold for six injection points to include individual variable area flowmeters and pressure gauges.
- Adjustable timer and solenoid valve to control oxygen flow for pulse injection.
- Main electrical panel for easy connection to power supply.
- Fully integrated remediation system with all plumbing, electrical, and mechanical components installed.

The 12 SCFH Trailer Mounted Oxygen Injection System includes the following components:

- Four foot by six foot insulated cargo trailer.
- Solar powered roof ventilator with thermostat for year round operation.
- Oxygen generator with a 30 gallon surge tank and regulator. The generator produces 12 SCFH of oxygen at 90-95% purity. 1 phase/60Hz/120 volts.
- Built in air compressor.
- Variable area flowmeter with needle control valve and pressure gauge.
- Adjustable timer and solenoid valve to control oxygen flow for pulse injection.
- Three roof mounted photo voltaic modules with internal storage rack for transport, and 360 watt power output array.



MATRIX
Biotechnologies
5835 Ellis R... Orchard Park 716-662-0745

TRAILER MOUNTED OXYGEN INJECTION SYSTEM
FOR SINGLE PHASE EXTERNAL POWER SOURCE

ENHANCED BIODEGRADATION OF MTBE AND BTEX USING PURE OXYGEN INJECTION

Sean R. Carter, J. Michael Bullock and William R. Morse

ABSTRACT: A novel approach to groundwater remediation at a petroleum release site is presented. The technique involves the injection of pure oxygen into groundwater via multiple injection points at flow rates substantially lower than traditional air sparging. The remediation system consists of an AirSep AS80 pressure swing adsorption oxygen generator which produces oxygen at a rate of 80 standard cubic feet per hour (scfh). The oxygen is stored in a 60-gallon receiver tank and pulse sparged to seven (7) injection points at a rate of approximately 7 scfh per point. The injection points are located directly downgradient of the source area and spaced to sufficiently increase dissolved oxygen levels throughout the site. The surficial geology consists of alluvial sands underlain by a low-permeability clay. Depth to groundwater is approximately 4 feet in the source area and drops to greater than 10 feet off site. Due to the steep groundwater gradient, oxygen transport was considered sufficient for off-site remediation.

After 6 weeks of operation, groundwater dissolved oxygen levels increased from a background level of 0 parts per million (ppm) to 6 to 10 ppm in both on-site and off-site monitoring wells. Dissolved oxygen remained at high levels as long as the system was operational. Concentrations of both MTBE and BTEX decreased with increasing dissolved oxygen levels. Four months after system startup, MTBE and BTEX had decreased by an order of magnitude in both on-site and off-site monitoring wells. A 48-hour endpoint assay using soils obtained from the goundwater interface zone confirmed the biodegradation of MTBE by *Pseudomonas fluorescens* type G.

The relatively low oxygen injection rate per point and high transfer efficiency into groundwater negates the need for vapor control via vadose zone extraction. This eliminates costly air treatment, provides a high degree of certainty for plume control, is suitable for shallow groundwater, and results in the rapid biodegradation of MTBE and BTEX.

In Situ and On-Site Bioremediaton: Volume 4

Fourth International
In Situ and On-Site
Bioremediation Symposium

Brief Review of Remediation Sites Using the Patent Pending Oxygen Injection System by Matrix Biotechnologies

Petroleum Marketing Company - Clifton Park, NY

Injection of oxygen at 80 SCFH into seven injection points for the treatment of groundwater contaminated with low levels of BTEX (2 ppm or less) and MTBE (0.5 to 2 ppm). The subsurface is characterized by a highly permeable saturated zone of 5 to 7 feet underlain by clay. The groundwater elevation is very shallow, from surface to 3 feet bgs, and the gradient is steep. Oxygen is injected near the former source area and transported via groundwater flow. **Dissolved oxygen levels increased immediately following system startup. Over a 14 month period BTEX was completely removed and MTBE decreased by two orders of magnitude.**

Petroleum Marketing Company - Campbell, NY

Injection of oxygen at 20 SCFH into two injection points for the source treatment of petroleum hydrocarbons. Total hydrocarbon concentrations less than 2 ppm in groundwater. Highly porous sand and gravel lithology and shallow groundwater (2-5 feet bgs). **Biodegradation of hydrocarbons at the source was very effective in slowing the off-site migration of contaminants. Over a two year period the source area was remediated to closure levels.**

Petroleum Marketing Company - Buffalo, NY

Injection of oxygen at 80 SCFH into six injection points for the treatment of weathered gasoline in groundwater. Shallow fractured bedrock and shallow groundwater (2-4 feet bgs). The goal is to highly oxygenate the groundwater and realize transport into bedrock fractures. The site has been under remediation with vacuum extraction for 6 years with little progress made. **Groundwater dissolved oxygen levels increased to over 20 ppm within one week of operation. Groundwater color, which is also impacted by organics from a leaking sewer main, improved in clarity during the first month of operation.**

Petroleum Marketing Company - West Chester, PA

Injection of oxygen at 80 SCFH into six injection points for the removal of benzene (less than 1 ppm) in groundwater. Shallow groundwater (4-10 feet bgs) and steep groundwater gradient. The goal is to highly oxygenate the groundwater at the upgradient source location and achieve transport via groundwater flow. The site has been under remediation with air sparging, vacuum extraction and groundwater recovery for 10 years. Current remediation technologies have not affected the low levels of residual benzene for several years. Oxygen injection to begin in May 1997. Results not yet quantified.

Brief Review of Remediation Sites Using the Patent Pending Oxygen Injection System by Matrix Biotechnologies

Petroleum Marketing Company - Westford, MA

Injection of oxygen at 80 SCFH into five injection points for the removal of TPH (less than 1 ppm) in groundwater. The lithology is silty sand and groundwater depth exceeds 20 feet. The site has been under remediation with air sparging and groundwater recovery for several years, but these remediation technologies have not been able to bring groundwater contaminant levels to closure. **The system started in April of 1997 and dissolved oxygen concentrations in groundwater immediately increased from less than 1 ppm to over 14 ppm. Dissolved concentrations of aromatic and aliphatic hydrocarbons decreased by 1 to 2 orders of magnitude after one month of operation.**

Petroleum Marketing Company - Acton, MA

Injection of oxygen into groundwater at 80 SCFH at the estimated stagnation point of a groundwater recovery system. The system was installed to prevent the migration of MTBE into a nearby municipal well field. **MTBE migration was successfully controlled with this "biobarrier" approach and BTEX removal has been enhanced.**

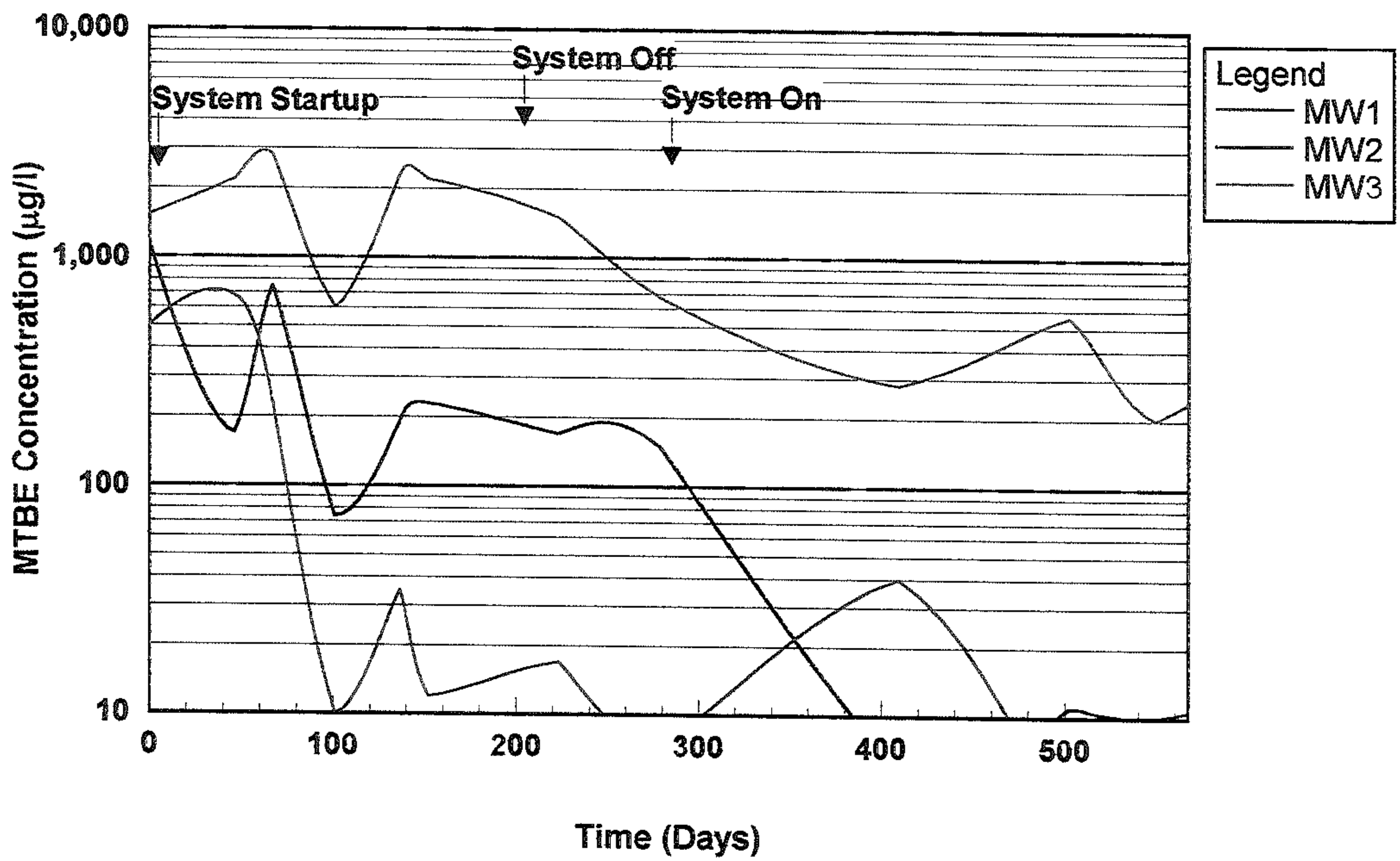
Petroleum Marketing Company - Middletown, CT

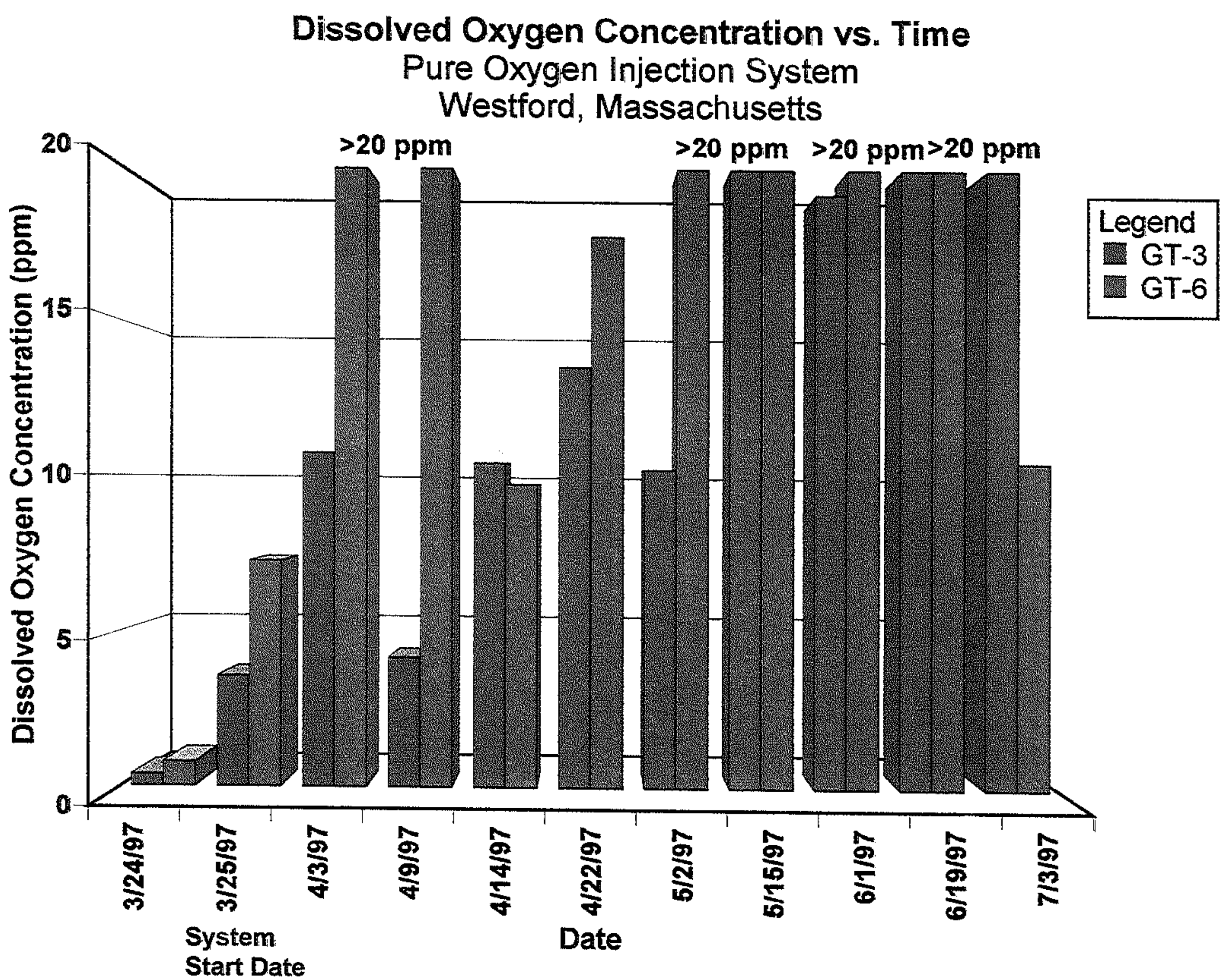
Injection of oxygen into groundwater at 80 SCFH to protect a wetland from BTEX impact from an upgradient plume. The system is used in conjunction with an air sparging and vapor extraction system treating the highly contaminated plume. Results not yet quantified.

Petroleum Marketing Company - Albany, NY

Injection of oxygen into groundwater at 80 SCFH at a property boundary to control the off-site migration of MTBE and BTEX. The logistics of the site prevent installing a remedial system beyond the property boundary. Oxygen transport via groundwater flow is the primary transport mechanism. Results not yet quantified.

MTBE Concentration vs. Time
Pure Oxygen Injection System
Clifton Park, New York




Dissolved Oxygen Concentration vs. Time
Pure Oxygen Injection System
Westford, Massachusetts
>20 ppm
>20 ppm
>20 ppm
>20 ppm
Dissolved Oxygen Concentration (ppm)
20
15
10
5
0
3/24/97
3/25/97
4/3/97
4/9/97
4/14/97
4/22/97
5/2/97
5/15/97
6/1/97
6/19/97
7/3/97
System
Start Date
Date
Legend
GT-3
GT-6

Matrix: Biofiltration and O_2 Injection

Matrix Environmental Technologies (Orchard Park, NY) reports that two of its areas of biotechnology focus, biofiltration and pure oxygen injection, are increasingly being used at sites in the U.S.

Biofiltration

In a presentation at the 69th Annual New York Water Environment Association, Inc. Conference in January of this year, Matrix presented information on the control of volatile organic compounds and odor-causing agents from air streams. As Matrix reported, remediation of petroleum retail, transfer, and bulk storage facility sites can produce a contaminated air stream. Air discharge limits for benzene and other aromatic hydrocarbons leads to utilization of air treatment. Additionally, anoxic conditions in the subsurface can mean the accumulation of mercaptans, sulfides, and other odor-causing agents to be controlled. Matrix stated that biofiltration results in contaminant destruction, rather than phase transfer, and is cost-effective as compared to such techniques or other methods, such as catalytic oxidation and incineration technologies (see figure for cost comparison of Matrix biofilter operation vs. reactivated carbon).

Biofilters can be operated at VOC removal rates from 30% to 95% depending on the level of treatment needed. It is the only air treatment technology currently that operates over a wide range of removal efficiencies and is controllable. A modular biofiltration system was designed by Matrix to reduce the concentration of petroleum hydrocarbons and odor-causing agents from the air discharge of soil vapor extraction systems (SVE) and air strippers. Concentrations of VOCs up to 3,000 ppm at air flows greater than 300 scfm have been treated. Control of mercaptans and other odor-causing agents is achieved at air retention times in the media of less than 30 seconds. Retention times of 1 to 2 minutes are needed for VOC removal of greater than 80%.

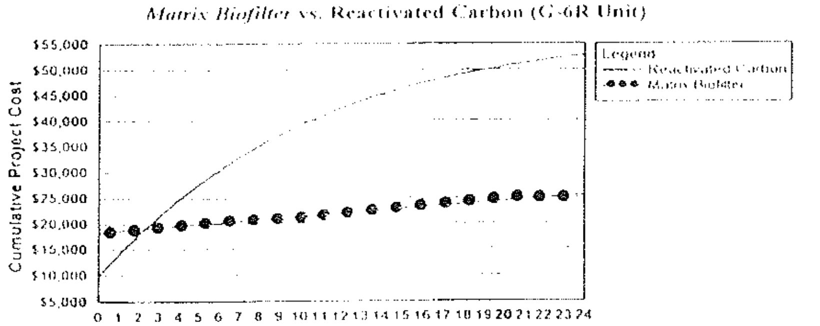
Pure oxygen injection

A patent-pending system for oxygen delivery to the subsurface entails the injection of pure oxygen into groundwater via multiple injection points at flow rates that are significantly below that of traditional air sparging. The system used consists of an AirSep AS80 pressure swing adsorption oxygen generator (*see Biotreatment News, Vol. 7, No. 7, p. 12*). The oxygen is pulse sparged into several injection points that are directly downgradient of the source area and spaced to increase dissolved oxygen levels. At one site in Clifton Park, NY, after 6 weeks of operation, groundwater-dissolved oxygen levels increased from a background level of 0 parts per million (ppm) to 6-10 ppm in both on-site and off-site monitoring wells. Dissolved oxygen remained at high levels as long as the system was operational. Both methyl tert-butyl ether (MTBE) and benzene, toluene, ethylene and xylene (BTEX) concentrations decreased with increasing dissolved oxygen levels from 2 ppm or less and 0.5-2 ppm, respectively. Four months after start-up, MTBE and BTEX had decreased by an order of magnitude in both on-site and off-site monitoring wells. A 48-hour endpoint assay using soils from the groundwater interface zone confirmed the degradation of MTBE by *Pseudomonas fluorescens* Type G. Over a 14-month period, BTEX was completely removed and MTBE decreased by two orders of magnitude.

Other sites where the oxygen injection system has been used include the following. In Campbell, NY, biodegradation of hydrocarbons at the source was effective in slowing the off-site migration of contaminants and within a two-year period, the source area was remediated to closure levels. A Buffalo, NY site had been under vacuum extraction for 6 years, with the goal being to highly oxygenate the groundwater and realize transport into bedrock fractures. Dissolved oxygen levels at the site increased to over 20 ppm within one week of oxygen injection operation. In Westford, MA, where a site that has been under air sparing and groundwater recovery for several years has not met contaminant closure levels, dissolved concentrations of aromatic and aliphatic hydrocarbons decreased by 1 to 2 orders of magnitude after one month of operation. An Acton, MA site with migration of MTBE was successfully controlled with this "biobarrier" approach.

Contact: Matrix Environmental Technologies 5835 Ellis Rd., P. O. box 427, Orchard Park, NY 14127-0427; (716) 662-0745; fax (716) 662-0946.

Cost Comparison
Matrix Biofilter vs. Reactivated Carbon (G-6R Unit)



Source: Matrix Environmental Technologies

MATRIX
Environmental Technologies

Process increases pure oxygen to aid in biodegradation of MTBE

By Sean R. Carter

A patent pending process using a pressure-swing adsorption (PSA) oxygen generator has been developed to cost-effectively and safely produce high purity oxygen gas for injection into groundwater. The process was used at a petroleum underground storage tank (UST) remediation site in Clifton Park, N.Y. to oxygenate groundwater contaminated with BTEX and MTBE. The results from this site suggest that MTBE biodegrades in oxygen-enhanced groundwater once BTEX is depleted or is present in very low concentrations.

The oxygen injection process

A turnkey oxygen injection system using a PSA oxygen generator was designed for installation in cargo trailers or on steel skids for use at groundwater remediation sites. The PSA process separates oxygen from compressed air using a synthetic zeolite which adsorbs nitrogen at high pressure and desorbs it at low pressure.

AirSep Corp., Buffalo, N.Y., manufactures PSA systems which generate high purity oxygen at 95 percent using two adsorbers for a continuous flow of oxygen. The oxygen generator produces oxygen at a low pressure of 3.2 kg/cm^2. The compressed air supply to the oxygen generator is provided by a rotary screw compressor. The compressor includes a refrigerated air dryer to produce a moisture-free air supply to the oxygen generator. Oxygen gas is stored in a low pressure tank and metered to injection points installed below the water table using variable area flowmeters.

The solubility of oxygen in groundwater is substantially higher with pure oxygen up to 40 mg/L as opposed to air with a typical 10-12 mg/L. Nitrogen, a major component of air, has a higher partial pressure than oxygen which effects the solubility of oxygen in water. Injecting air into groundwater is a very effective technique for removing hydrocarbons through volatilization. It also provides the secondary benefit of increasing dissolved oxygen.

However, dissolved oxygen concentrations for air injection are often not sufficient to completely oxygenate the contaminated area and can result in little or no diffusion of oxygen into small soil pores which tend to adsorb BTEX. Injecting pure oxygen results in higher dissolved oxygen concentrations and transport through the contaminated area through advection and dispersion.

Field data indicate that higher concentrations of dissolved oxygen from pure oxygen injection results in oxygen diffusion and biodegradation of BTEX adsorbed to soil where it typically does not biodegrade due to a lack of oxygen. This is suggested by a lack of BTEX rebound when the oxygen supply to groundwater is terminated. BTEX rebound is often observed using other remediation techniques, such as air injection, which are diffusion limited.

The biodegradability of aromatic hydrocarbons such as BTEX is well documented. However, the biodegradation of MTBE has only recently been identified in laboratory studies and in the field. Competitive inhibition may explain the persistence of MTBE in groundwater contaminated by petroleum products. Hydrocarbons may repress the biodegradation of MTBE due to enzyme competition. However, the absence of hydrocarbons and the presence of MTBE degrading organisms in groundwater provides conditions which may be oxygen enhanced for MTBE biodegradation.

Clifton Park remediation site

The Clifton Park site, located near Albany, N.Y., is an active gasoline retail store with three USTs and two sets of product dispensers. A subsurface investigation was performed in 1995 before a facility upgrade which included replacing the product dispensers and underground piping. The investigation revealed BTEX in groundwater at low concentrations of 1 to 806 µg/L and MTBE at higher concentrations of 300 to 5,100 µg/L. The cause of the release was likely surface spills and/or a piping leak.

The site geology consists of 1.5 to 2.5 meters of alluvial sands underlain by a low permeability clay which extends to bedrock. Depth to groundwater is

Sean Carter is president of Matrix Environmental Technologies, Orchard Park, N.Y.

0.6 to 1.2 meters below grade in the sand layer and flows across the site at a gradient of about 0.027 m/m. Downgradient of the site the upper surface of the clay slopes downward and the groundwater gradient changes to about 0.11m/m. Groundwater from a monitoring well installed about 15 meters downgradient of the site tested clean for BTEX and MTBE. The steep gradient of the thin saturated zone away from the site and the conservative nature of MTBE in groundwater were risk factors for off-site contamination.

During the subsurface investigation, two soil samples were collected onsite from the saturated zone for microbial analyses. The total heterotrophic plate counts were 4.69×10^4 and 5.30×10^4 colony forming units per gram. Different strain types identified from the samples included *Bacillus cereus*, *Bacillus licheniformans*, *Bacillus pumilus*, *Pseudomonas flourenscens* type G, *Brevibacterium acetylicum* and *Bacillus sphaericus* subgroup I.

A 48 hour endpoint assay was conducted on the 10 identified strains with gasoline and MTBE. Four of the 10 strains — *Bacillus pumilus*, *Pseudomonas flourenscens*, *Brevibacterium acetylicum* and *Bacillus sphaericus* — showed growth on MTBE but not on gasoline. The highest growth was by *Pseudomonas flourenscens*; the growth of *Bacillus sphaericus* was minimal. Additional endpoint testing was performed with the three strains showing the highest growth on MTBE. Hydrogen peroxide, nitrate, phosphate and a nutrient mix were independently added with MTBE. Growth on MTBE was not observed under any of these conditions.

The results of the microbial analyses and the low concentrations or absence of BTEX in groundwater sampled from monitoring wells indicated the potential to enhance the biodegradation of MTBE with the addition of oxygen to groundwater. This approach was chosen over air sparging and groundwater pumping due to their ineffectiveness with MTBE and the site geological conditions of thin saturated zone and steep gradient.

Oxygen injection system design and operation

The oxygen injection system used at the site had an oxygen production capacity of 2.3 standard cubic meters per hour (SCMH) and storage capacity of 0.9 cubic meters. This system produced up to 2.7 kg of pure oxygen per hour. Oxygen in the storage tank was metered to seven injection points at a cycle rate of 10 minutes on and 20 minutes off resulting in an average flow rate of 0.20 SCMH per point.

The flow rate of oxygen and cycle time is site specific and is set to optimize the dissolution of oxygen to groundwater resulting in maximum dissolved oxygen concentrations and transport throughout the contaminated zone. The flow rate of oxygen is not determined by the oxygen demand or contaminant mass of the site. The mass of oxygen injected can exceed the total site oxygen demand in days or weeks of operation.

The injection pressure was sufficient to displace water in the injection point and initiate oxygen flow into the sandpack and surrounding formation without causing pressure buildup, groundwater displacement or vapor production. With a saturated thickness of 1.2 to 1.5 meters the injection pressure was about 0.14 kg/cm^2 per point.

Five injection points were installed downgradient of the product dispensers at a spacing of about 9 meters and two points were installed downgradient of the USTs near the west product dispensers. The 2.5 cm diameter PVC injection points were screened in the saturated zone just above the clay layer. Injection points were not installed between the dispensers and USTs due to underground utilities and the 123 metric tons of contaminated soil that was removed from the area during the facility upgrade.

Results of the remediation

The oxygen injection system operated over a 19 month period and groundwater was monitored for one year after shutdown. Before system startup, groundwater was sampled from all monitoring wells

Continues on page 24

MTBE, from page 23

except MW4, which was dry at the time, and analyzed for dissolved oxygen in the field and for MTBE and BTEX in the lab. Background dissolved oxygen levels were below detection limits in all monitoring wells.

After 46 days of operation, the average dissolved oxygen concentration from the sampled wells was 8.5 mg/L and after 67 days was 7.4 mg/L. Over the next 85 days of operation, dissolved oxygen decreased in all wells but was still above the background levels. This decrease was likely due to microbial utilization.

The system was shutdown from days 152 to 192 while the equipment was in use at another location. During this shutdown period, dissolved oxygen continued to decrease in all site monitoring wells. Dissolved oxygen in MW6, located downgradient of the site, had begun to increase before shutdown of the system and remained at higher concentrations than the on-site wells during the shutdown period. This is an example of downgradient oxygen transport through groundwater flow.

To confirm the dissolution of oxygen in the injection points, the oxygen flow was stopped and groundwater samples retrieved from the injection points. Dissolved oxygen measured greater than 20 mg/L, the upper limit of the meter, in these points. Recent data obtained from other oxygen injection sites with a higher upper limit meter indicate dissolved oxygen up to 40 mg/L in injection points. Due to improvements in the injection point design and spacing since the system was installed at Clifton Park, dissolved oxygen concentrations are kept about 5 mg/L in monitoring wells and consistently exceed 20 mg/L in wells within 6 meters of injection points.

Groundwater sampling before system startup, except from MW4, showed MTBE at concentrations ranging from 3.3 µg/L in MW5 to 1,540 µg/L in MW3. BTEX was detected in MW2 at 3.5 µg/L, in MW3 at 57 µg/L and in MW5 at 2.6 µg/L. After 101 days of oxygen injection, MTBE concentrations decreased from 503 to 10 µg/L in MW1 and from 1,140 to 74 µg/L in MW2. Over the next 806 days, MTBE concentrations fluctuated slightly but remained well below background levels and the New York State groundwater standard. With the removal of contaminated soil before the oxygen injection system was installed, it can be assumed that dilution was a factor in the MTBE decreases.

However, the decline in MTBE following the introduction of oxygen suggests that biodegradation was a significant factor. MW1 tested below detection limits for BTEX for 15 consecutive sampling events over three years and was only detected in MW2 before system startup. The absence of BTEX in groundwater and presence of MTBE degrading bacteria provided ideal conditions for MTBE to biodegrade.

The results observed in MW3, which had BTEX concentrations of more than 200 µg/L during most of the oxygen injection period, differed from MW1 and MW2. With the exception of the data collected on day 101, MTBE did not significantly decrease for 279 days at which time BTEX measure 159 µg/L. This implies that competitive inhibition suppressed the biodegradation of MTBE until the BTEX concentration had decreased to low levels. It also implies that dilution was not the only factor in the MTBE decreases in MW1 and MW2, otherwise, MTBE in MW3 would have declined at a similar rate.

Conclusions drawn from site

Pressure-swing adsorption is an effective method of generating pure oxygen for groundwater injection. The higher solubility of pure oxygen, compared to air, improves the transport and persistence of dissolved oxygen in groundwater. Biodegradation in small pore spaces may also result from the diffusion of oxygen at higher concentrations.

The groundwater data collected over three years from the Clifton Park site indicates competitive inhibition or the repression of MTBE degradation by BTEX. The data also suggest that MTBE is biodegraded in groundwater by naturally occurring microorganisms when oxygen is not limiting and BTEX is degraded or at very low concentrations.■

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APPENDIX D

MAP TO SITE

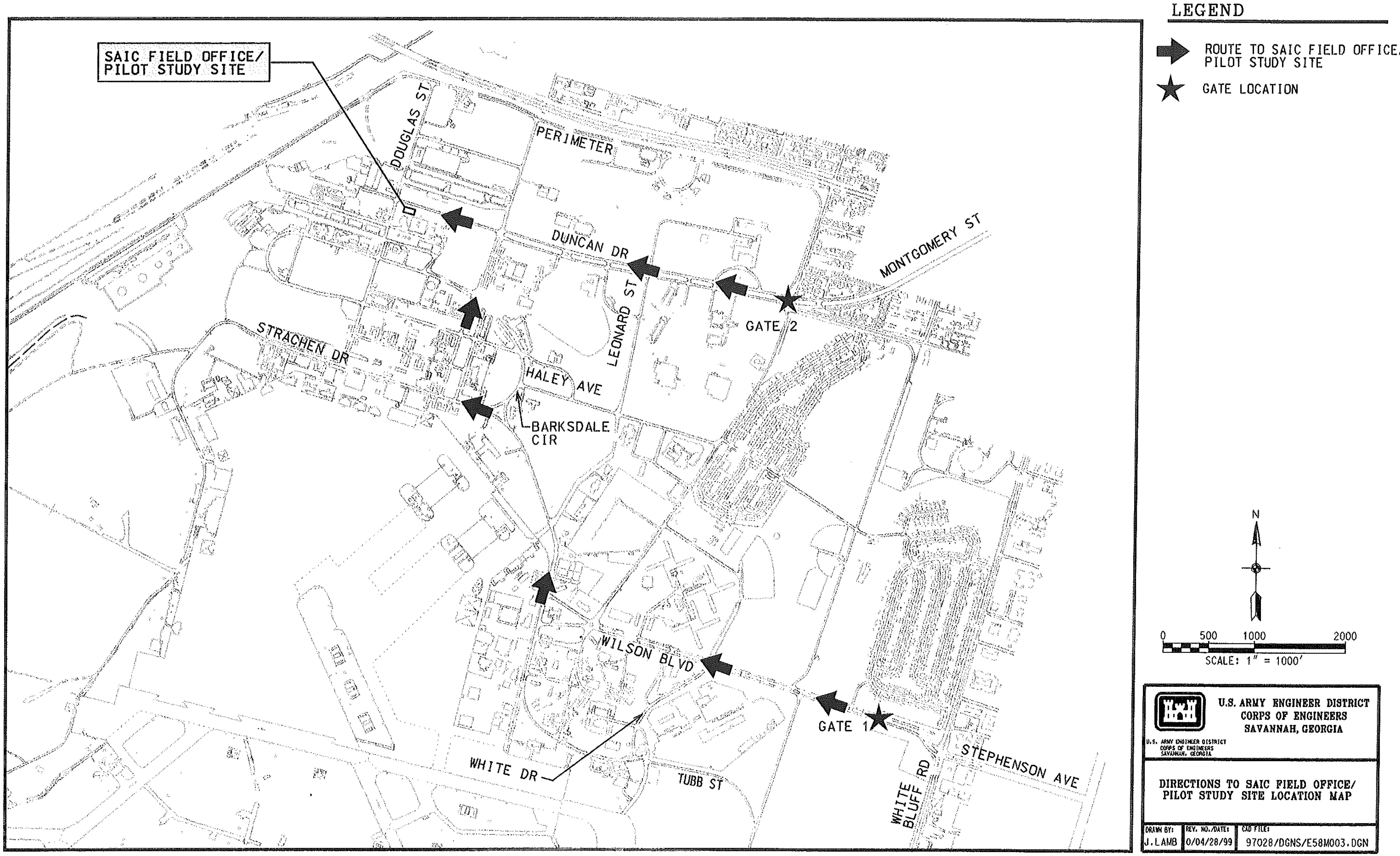

Figure D.1. Map Showing Directions to SAIC Field Office/Pilot Study Site