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Remediation System Evaluation (RSE)

10th Street Superfund Site, OU2

Columbus, Nebraska

REMEDIATION SYSTEM EVALUATION

10TH STREET SUPERFUND SITE, OU2
COLUMBUS, NEBRASKA

Report of the Remediation System Evaluation
Site Visit Conducted at the 10th Street Superfund Site
May 12, 2009

Final Report
February 16, 2010

NOTICE

Work described herein was performed by GeoTrans, Inc. (GeoTrans) for the U.S. Environmental Protection Agency (U.S. E.P.A). Work conducted by GeoTrans, including preparation of this report, was performed under Work Assignment #48 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared part of a pilot project conducted by the United States Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (U.S. EPA OSRTI). The objective of this pilot project is to conduct independent, expert reviews of soil and ground water remedies with public funding with the purpose of optimizing the remedy for protectiveness, cost-effectiveness, and sustainability. The project contacts are as follows:

Organization	Key Contact	Contact Information
U.S. EPA Office of Superfund Remediation and Technology Innovation (OSRTI)	Jennifer Hovis	USEPA Headquarters – Potomac Yard 2777 Crystal Drive Arlington, VA 22202 phone: 703-603-8888 hovis.jennifer@epa.gov
Tetra Tech EM, Inc. (Contractor to EPA)	Elizabeth Powell	Tetra Tech EM Inc. 1881 Campus Commons Drive, Suite 200 Reston, VA 20191 phone: 703-390-0616 Elizabeth.Powell@ttemi.com
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1.0 INTRODUCTION

1.1 PURPOSE

During fiscal years 2000 and 2001 independent reviews called Remediation System Evaluations (RSEs) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (i.e., those sites with P&T systems funded and managed by Superfund and the States). Due to the opportunities for system optimization that arose from those RSEs, EPA OSRTI has incorporated RSEs into a larger post-construction complete strategy for Fund-lead remedies as documented in *OSWER Directive No. 9283.1-25, Action Plan for Ground Water Remedy Optimization*. A strong interest in sustainability has also developed in the private sector and within Federal, State, and Municipal governments. Consistent with this interest, OSRTI has developed a Green Remediation Primer (http://cluin.org/greenremediation/) and as a pilot effort now considers green remediation during independent evaluations.

The RSE process involves a team of expert hydrogeologists and engineers that are independent of the site, conducting a third-party evaluation of the operating remedy. It is a broad evaluation that considers the goals of the remedy, site conceptual model, available site data, performance considerations, protectiveness, cost-effectiveness, closure strategy, and sustainability. The evaluation includes reviewing site documents, potentially visiting the site for one day, and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Sustainability

The recommendations are intended to help the site team identify opportunities for improvements. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the evaluation team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders.

The 10th Street Superfund Site was selected by EPA OSRTI based on a nomination from EPA Region 7. The site is located in Columbus, Nebraska. Ground water contamination consists of VOCs, primarily PCE, TCE and cis-1,2-Dichloroethene (cis-1,2-DCE). Elevated levels of arsenic also have been detected in some ground water samples, but arsenic is believed to be naturally occurring in soils at the site and is not addressed by the remedial actions. There are three active components of the ground water remedy: 1) a ground water extraction and treatment (GET) system located in the southern (i.e., downgradient) part of the site; 2) an air sparge/soil vapor extraction (AS/SVE) system located at the One Hour Martinizing (OHM) source area in the northern (i.e., upgradient) part of the site; and (3) in situ chemical oxidation (ISCO) treatment at the OHM source area and also at locations between the OHM source area and the GET system.

The RSE provides an opportunity for an independent third-party review of these remediation efforts.

1.2 Team Composition

The RSE team consisted of the following individuals:

Name	Affiliation	Phone	Email
Doug Sutton	GeoTrans, Inc.	732-409-0344	dsutton@geotransinc.com
Rob Greenwald	GeoTrans, Inc.	732-409-0344	rgreenwald@geotransinc.com

In addition, the following individuals from EPA Headquarters participated in the RSE site visit.

- Jennifer Hovis
- Jennifer Edwards

1.3 Documents Reviewed

The following documents were reviewed. The reader is directed to these documents for additional site information that is not provided in this report.

- 2008 GET System Annual Performance Summary Report – HGL and CDM, April 2009
- 2008 AS/SVE Annual System Performance Summary Report – HGL and CDM, April 2009
- January 2009 GET System Quarterly Report – HGL, April 8, 2009
- October 2008 GET System Quarterly Report – HGL, January 26, 2009
- January 2009 Quarterly Sample Results for the One Hour Martinizing Source Area Air Sparging/Soil Vapor Extraction System – HGL, April 21, 2009
- October 2008 Quarterly Sample Results for the One Hour Martinizing Source Area Air Sparging/Soil Vapor Extraction System – January 26, 2009
- Operations and Maintenance Manual, GET System, Revision 2 – Arrowhead, August 2004
- Operations and Maintenance Manual for the OHM Source Area AS/SVE and ART Well Systems, Revision 2 – HGL and CDM, July 2008
- ISCO Injection Completion Report, Option Year 1 Round 1 – Lee and Ryan, August 11, 2008

- ISCO Injection Completion Report, Base Year Round 1 – Lee and Ryan (no date provided)

- ISCO Injection Completion Report, Contingent Round, One Hour Martinizing Area – Lee and Ryan, November 20, 2007

- Post-Injection Monitoring Report for Chemical Oxidant Injection, Round 1 – HGL, September 19, 2007

- Report on Final Chemical Oxidation Treatability Study Sampling Results for In Situ Chemical Oxidation Remedial Design – HGL, December 27, 2006

- Removal Assessment, Phase 3 Report – Ecology and Environment, June 2000

- Removal Assessment, Phase 2 Report – Ecology and Environment, September 1999

- Interim Remedial Action Report – EPA Region VII, June 13, 2007

- Revised Remedial Process Optimization Report Air Sparging/Soil Vapor Extraction System, One Hour Martinizing Source Area – HGL, November 3, 2006

- Draft Treatability Study Report for In Situ Chemical Oxidation Remedial Design – HGL, August 4, 2006

- Chemox Costs – Word File provided by RPM prior to RSE site Visit

- 10th Street Cost Analysis – PDF file provided by RPM after RSE site visit

- Electric Bills for AS/SVE System – Various months for 2008

- City of Columbus Costs for GET System, 2005-2009 – City of Columbus (Binder)

1.4 PERSONS CONTACTED

The following individuals associated with the site were present for the visit:

Name	Affiliation	Phone	Email
Nancy Swyers (RPM)	U.S. EPA Region 7	913-551-7703	Swyers.nancy@epa.gov
Charlene Sundermann	NDEQ		
Laura Splichal	CDM		
Marc Schlebusch	CDM		
Bill Mehnert	Hydrogeologic		
Bob Kloke	City of Columbus		
Chuck Thomerson	City of Columbus		

Hydrogeologic Inc. (HGL) is contracted to EPA. CDM Federal Programs Corporation (CDM) is a subcontractor to HGL. The GET system is currently being operated by the City of Columbus through a cooperative agreement with EPA, and both HGL and CDM provide engineering support to the City as needed.

1.5 BASIC SITE INFORMATION AND SCOPE OF REVIEW

1.5.1 LOCATION

The 10th Street Site is located in the City of Columbus in Platte County, Nebraska (see Figure 1.1 from the 2008 GET Annual Report, included in Attachment A of this report). The 10th Street Site is composed of two operable units (OUs) illustrated on that figure:

- OU1 is located in the southern part of the site including the southern municipal well field where ground water contamination was originally detected. Initially it was thought that the ground water contamination detected in this portion of the site originated at two dry cleaning locations (Liberty Cleaners and Jackson Services) located south of the railroad tracks (see Figure 1.2 from the 2008 GET Annual Report, included in Attachment A of this report).

- OU2 is a larger area that is the focus of the combined remedial measures currently conducted at the site. Ground water sampling conducted after the initial contamination was detected indicated an extended area of contamination to the north (i.e., upgradient) of the original investigation. OU2 extends northward to the OHM dry cleaning property.

The site is an area consisting of both commercial and residential land use. The Loup River is located approximately one-half mile south of the site. The ground water extraction wells and treatment building associated with the GET system are located in the southern portion of OU2. Several components of the remedy, including AS/SVE and ISCO injections, are conducted at the OHM property, which is bordered by 23rd Street to the north, an alley to the south, a fast-food restaurant to the west, and 25th Avenue to the east.

1.5.2 SITE HISTORY, POTENTIAL SOURCES, AND RSE SCOPE

According to the 2008 GET System Annual Report (April 2009), VOCs were detected in 1983 during a routine sampling event of the City's municipal wells. Follow-up analysis of the municipal wells also detected elevated TCE concentrations. In April 1987, the site was referred to EPA for investigation. The 10th Street Site was proposed for the NPL in October 1989 to provide emergency response, as well as long-term cleanup. The site was placed on the NPL in August 1990.

Initial investigations focused on the vicinity of the southern municipal well field, and a ROD was signed for the site in February 1995 consisting of sampling of municipal and monitoring wells plus institutional controls, plus a contingency for extraction of contaminated ground water with treated water discharge to the Loup River. Subsequent ground water monitoring by EPA in 1997 to 1998 indicated higher concentrations of PCE and TCE in the northern portion of the existing monitor well network, and further investigation of soil and ground water to the north revealed that significant VOC contamination appeared to originate from the OHM dry cleaning business. In September 1999 EPA installed additional monitoring wells upgradient of the initial study area. Through a Fund-Lead removal action, EPA implemented an AS/SVE system at the OHM property in October 2000, and this system continues to operate (a dry cleaning business also continues to operate at the OHM site). The AS/SVE system was declared operational and functional by EPA and NDEQ in 2004.

EPA issued an interim action ROD for OU2 of the 10th Street Site in September 2001 to protect the southern municipal well field, and it included the following interim remedy elements:

- Extraction of contaminated ground water at municipal well W-1
- Additional extraction of contaminated ground water upgradient of the southern municipal well field
- Treatment (if necessary) of extracted ground water, with the following discharge options: the City storm sewer system; the City municipal water treatment system; or potential re-use
- Continued operation of the AS/SVE system at the OHM source area

The GET system was designed so that effluent would meet the influent requirements for the City's water treatment plant, so that the water can then be included in the City water supply. If the City has too much potable water such that storage capacity is exceeded, the treated water from the GET system can be discharged to surface water via the City storm sewer system. The location of well EW-03 was modified from the original design so that it would not capture ground water contamination from a former manufactured gas plant (FMGP) site located in the vicinity. Construction of the GET system began in September 2003 and was completed in March 2004. The system began full-scale operation and discharge to the City storm sewer system in April 2004 (with discharge of backwashed water after acid treatments made to the City sanitary sewer), and the system began providing treated water to the City's south water treatment plant in May 2005. EPA installed an additional extraction well (EW-04) in July 2005 to extend the capture area of the GET system to the east. The GET system was declared Operational and Functional (O&F) on January 11, 2006.

EPA issued a final ROD in September 2005 to address site-wide ground water contamination, which included the following active remedy components:

- Continued operation of the AS/SVE system at the OHM source area
- Continued operation of the GET system
- ISCO upgradient of the GET system to supplement site-wide ground water remediation

In 2006 a treatability study of ISCO was conducted using potassium permanganate ($KMnO_4$) injections, and subsequently a design package for ISCO injections was developed. Lee & Ryan Environmental Consulting, Inc. was awarded a contract and had conducted three rounds of ISCO injections by the end of 2008 at a variety of locations (Liberty Cleaners, "mid-plume", and at the OHM parking lot). At the time of the RSE visit a fourth round of ISCO was occurring (at Liberty Cleaners and "mid-plume"), and there were plans to complete the ISCO contract work with 120 additional injections to be started later in 2009 (some of which would likely occur at the OHM facility).

This RSE includes a holistic third-party review of overall site remedy.

1.5.3 HYDROGEOLOGIC SETTING

Site reports refer to the following three aquifer horizons:

Aquifer Designation	**Well Designation**	**Description**
shallow aquifer – upper portion	"A" level	~ 15-20 ft bgs (near water table)
shallow aquifer – lower portion	"B" level	~ 50-60 ft bgs
middle aquifer	"C" level	~ 95-105 ft bgs

"bgs" = below ground surface

Depth to water is typically on the order of 10 to 15 ft bgs. A clay layer located approximately 65 feet bgs is continuous beneath a portion of the site. The clay varies in thickness depending on location but is considered a confining layer that separates the shallow and middle aquifers. The "C" level wells are finished in the middle aquifer just below this clay layer. Site reports indicate that the middle aquifer consists of sand and gravel units down to bedrock. Note that VOC impacts are found in all three aquifer horizons.

The most recent potentiometric surface maps provided to the RSE team are from January 2009. However, the October 2008 event is a more comprehensive event, and potentiometric surface maps from the October 2008 GET Quarterly Report are included in Attachment A of this report (for A, B and C level wells). Background flow appears to be to the south towards the Loup River in all three aquifer horizons. However, the flow system is clearly modified by the extraction wells. Based on the shape of the plume (discussed later) as well as water level maps from before the GET system implementation, it appears that background flow is generally to the southeast, but historical pumping at the southern municipal well field (at rates that existed prior to the remedy) caused the plume to migrate more to the southwest as it approached the railroad tracks.

Based on the water level maps from October 2008, there appears to be very little vertical head difference between the A level wells and B level wells, except in the immediate vicinity of extraction wells. The same appears to be the case between the B and C wells in locations away from the extraction wells, but there is a significant downward vertical head difference (on the order of 5 ft) between the B and C wells in the vicinity of EW-02C. Based on site reports provided to the RSE team the extraction wells are screened as follows:

Extraction Well	Screen Interval (ft bgs)	Aquifer Horizons Screened
EW-01R	53-73	B
EW-02C	100-120	C
EW-03	52.5-82.5	B
EW-04	50.5-70.5	B
W-1	34-59, 79-109, 119-124	B, C

The following parameter value information was estimated from pump tests, according to reports provided to the RSE team:

- Shallow aquifer pump test at EW-01R
  - T = 17,763 ft2/d
  - K = 295 ft/d (appears to assume saturated thickness of 60 ft)
  - S = 0.16 (indicative of unconfined conditions)

- Middle aquifer pump test at EW-02C
  - T = 5,399 ft2/d
  - K = 77 ft/d (appears to assume saturated thickness of 70 ft)
  - S = 0.0018 (indicative of semi-confined to confined conditions)

The RSE team provides the following calculation of ground water velocity in the shallow aquifer, using approximate values of 0.0015 for hydraulic gradient (based on water level maps) and 0.2 for porosity (estimate for sand):

$$V = ki/n = 295 \text{ ft/d} * 0.0015 / 0.2 = 2.2 \text{ ft/d} * 365 \text{ d/yr} = \sim 800 \text{ ft/yr}$$

The OHM facility is on the order of 5,000 ft from the southern extent of the plume. Thus, the calculated ground water flow velocity is consistent with a release at the OHM facility serving as the source of the VOC plume in the shallow aquifer that extends to the City well field.

1.5.4 Potential Receptors

The City of Columbus southern municipal well field is partially located in the southern portion of the site. The southern municipal well field consists of seven wells located near the City's south water treatment plant on 10th Street (W-1, W-2, W-4, W-8, W-11, W-12, and W-13). VOCs have historically been detected in at least five of the seven municipal wells of the southern municipal well field. W-1 pumps as part of the GET remedy, and the others continue to pump for water supply purposes, though at a lower combined rate than existed prior to the remedy due to additional wells in other parts of the City that also provide water for public distribution.

Impacted water that is extracted and treated by the GET system is generally discharged into the City's water treatment plant for subsequent use as water supply within the City's water distribution system (the treated water from the GET system can optionally be discharged to surface water via the City storm sewer). The City has one additional area from which it can draw ground water, municipal well W-15. W-15 is located 2.2 miles east of the City.

According to the 2008 GET Annual Report, the Columbus Institutional Control Area (CICA) was established by the City in 2003 to provide for institutional controls. The CICA is bounded by Mahood Drive/24th Street on the north, the Loup River on the south, 33rd Avenue on the west, and 16th Avenue on the east. This ordinance allows existing private wells within CICA to remain in place if reasonable safeguards are implemented so that there is no unreasonable likelihood of human contact with the contaminants in the ground water. In addition, this ordinance prohibits the installation of new water wells within the CICA.

1.5.5 DESCRIPTION OF GROUND WATER PLUME

The most recent plume maps provided to the RSE team are from January 2009. However, the October 2008 event is a more comprehensive event, and combined plume extent maps from the October 2008 GET Quarterly Report are included in Attachment A of this report (for A, B and C level wells). These maps illustrate the extent of TCE, PCE, and cis-1-2-DCE above ground water standards in each of the three aquifer horizons. Site reports for the GET system also present more detailed maps with values posted for each of the three constituents in each of the three aquifers (9 maps), and AS/SVE reports similarly present maps focused on the vicinity of the OHM facility for each of these three constituents for multiple depth horizons. All of those maps are not included in this report, but key observations are noted below:

- At the OHM facility there are PCE concentrations exceeding 1,000 ug/L in multiple locations and at all depth intervals sampled (17-20 ft bgs, 30 ft bgs, and 50 ft bgs). At the OHM facility the TCE and cis-1,2-DCE concentrations are much lower than the PCE concentrations.

- In the A wells PCE concentrations above standards extend approximately 1000 ft downgradient of the OHM facility, but TCE and cis-1,2-DCE concentrations above standards persist much further to south/southeast suggesting that PCE is degrading to TCE and subsequently cis-1,2-DCE with distance from the OHM facility. Vinyl chloride is generally not detectable in ground water, suggesting that the cis-1,2-DCE is not further degrading to vinyl chloride.

- There is PCE contamination just north of extraction well EW-03 in the B zone at well MW-18B (~150 to 300 ug/L) and in the C zone at wells MW-31B (~150 to 300 ug/L) and MW-18C (~50 to 200 ug/L). In this area the PCE concentrations are somewhat higher than concentrations of TCE and cis-1,2-DCE (such as at the OHM source area). However, since there does not appear to be a source in this area, the RSE team assumes the PCE in this area is due to historical transport of VOCs from the OHM facility, and the gap in PCE currently observed between the OHM source area and this other area further downgradient is likely due to remedial measures such as the AS/SVE system, and/or due to Leaky Underground Storage Tank sites present in the northern portion of the site (particularly at the Emerson School) that have likely provided a carbon source that has contributed to the degradation of PCE in this area.

- The plume shape as it approaches the railroad tracks (and further south) likely reflects the historical impact on flow directions from pre-remedy pumping at the City wells. Since much of the City well field pumping has now been replaced by pumping at the GET extraction wells and other supply wells, the flow directions have changed relative to those that existed when the plume originally migrated to the City wells. An example of a pre-remedy water level map is included in Attachment A.

2.0 SYSTEM DESCRIPTION

There are three active components of the ground water remedy:

- The GET system located in the southern (i.e., downgradient) part of the site
- The AS/SVE system located at the One Hour Martinizing (OHM) source area located in the northern (i.e., upgradient) part of the site
- ISCO treatment at the OHM source area and also at locations between the OHM source area and the GET system

Details regarding these components of the remedy are provided below.

2.1 GROUND WATER EXTRACTION SYSTEM

The ground water extraction system consists of the following wells (locations are illustrated on Figure 1.2 from the 2008 GET Annual Report, included in Attachment A of this report):

- EW-01R (10 HP pump)
- EW-02C (30 HP pump)
- EW-03 (10 HP pump)
- EW-04 (added in July 2005, 10 HP pump)
- municipal well W-1 (50 HP pump)

These wells were designed to pump a combined 1,400 gpm (with a design maximum rate of 1,820 gpm). The well vaults for the EW wells are designed to extend significantly above ground surface (approximately five feet) per Nebraska Department of Human Health System (NDHHS) regulation. The pumps are constant speed pumps that are controlled by throttling back a gate valve in the well vault. Pumping rates are monitored via magnetic signal flow meters (paddle wheel). There is a float valve in the control vault that will trigger a high-level alarm at the treatment plant (via fiber optic cable). HDPE piping brings the water to the treatment plant.

2.2 GROUND WATER TREATMENT SYSTEM

A simple process flow diagram of the treatment system (from the 2008 GET Annual Report) is included in Attachment A of this report. The treatment plant consists of the following components:

- A phosphate-type dispersant (AQ-5010 was the name provided during the RSE site visit) is added to water entering the treatment plant (via chemical metering pump CMP-1). This is intended to prevent iron and manganese fouling of the air stripper. The water then enters a 12,000 gallon influent tank.

- Water is transferred to the air stripper via a feed pump (50 HP) controlled with a variable frequency drive (VFD) set at a frequency of 54 Hz. The system originally included bag filters before the air stripper, but after the initial startup period the turbidity levels decreased to the point that the bag filters were not needed, and they were subsequently taken off-line. There is a magnetic flowmeter (paddle wheel) prior to the air stripper.

- The air stripper is a packed column design (Jaeger 3.5-inch tripack). It utilizes a 20 HP blower.

- Acid washing of the air stripper utilizes a 15 HP pump, and occurs approximately every 3 months (requires approximately 3 days).

- Treated water is discharged to either the City's south water treatment plant (across the street from the GET plant) via a pump (50 HP) controlled with a VFD (set at a frequency of 36 Hz) through a 12-inch line, or to the City storm sewer system via gravity flow if potable demand is exceeded. Water that is discharged to the City's south water treatment plant is blended with other water pumped from the southern municipal well field, which is then treated by the City by adding fluoride, chlorination, and a sequestering agent for copper. That water is then used for public water supply. There are plans for a new City water treatment plant to replace the south water treatment plant, to be constructed next to the GET treatment plant.

- Controls include an Allen-Bradley PLC connected to a computer, which connects via Ethernet to the GET system building control panel and via fiber optic cable to the extraction well control panel. The PLC also has a connection to the City's SCADA system.

2.3 OTHER REMEDY COMPONENTS

2.3.1 AS/SVE SYSTEM

The AS/SVE system is located at the OHM source area. A pilot-scale system was installed in April 2000 and operated in May 2000. The full-scale system was installed in July through September 2000. Figures from the 2008 AS/SVE Annual Report are included in Attachment A that illustrate the process flow diagram for the AS/SVE system, the locations of the wells, and a cross-section illustrating the shallow clay and underlying sand (and typical screen interval of the various types of wells).

The intent of the AS/SVE system is to inject air into the saturated zone, which should strip VOCs from the ground water as the air percolates upward to the unsaturated zone, where the vapors are removed and treated. This system consists of the following wells for injection and extraction of air:

- 46 vertical clay vapor extraction (CVE) wells (screened approximately 2-7 ft bgs) combined with the 3 horizontal extraction wells (approximately 5-10 ft bgs) intended to remove VOCs from the shallow clay layer.

- 9 vertical sand vapor extraction (SVE) wells (screen approximately 7-20 ft bgs) intended to contain the injected air from sparge wells, and to remove VOCs from the sand underlying the clay (as well as from the water table). Because the SVE wells are screened across the ground water table, they are also used to measure ground water levels and concentrations.

- 26 air sparging wells with 5-ft screens (generally screened from 65 to 70 ft bgs).

- 7 combined injection and extraction well clusters (PCIX and CIX). The PCIX-1 and PCIX-2 well clusters each consist of one sparging well screened at 70 feet bgs, one SVE well screened at 18 feet bgs, and two monitoring points at 30 feet bgs and 50 feet bgs. The PCIX-5 well cluster consists of one sparging well screened at 70 feet bgs and three monitoring points (18 feet bgs, 30 feet bgs, and 50 feet bgs). PCIX-3 and PCIX-4 consist of four monitoring points only with no sparging or SVE. The two CIX wells each have four screened intervals, with the deepest (70 ft bgs) used for air sparging.

- The Accelerated Remediation Technology (ART) well was pilot tested at the OHM source area as a remediation well to enhance the effectiveness of the AS/SVE system. The ART system is a proprietary in-well remediation system that combines in-situ air stripping, sparging, and water circulation (water comes in the bottom and out the top). It also promotes recirculation of permanganate as a side-benefit, but this was not the primary purpose. The ART well was installed at a depth of approximately 65.5 feet bgs with a screened interval from 12-65 ft bgs.

The treatment building adjacent to the OHM facility includes the following equipment:

- Two compressors (50 HP each) for the air sparging system (for the sparge, PCIX, CIX, and ART wells). Only one compressor operates at a time. Air flows through an air dryer system before entering the sparge piping. An oil water separator collects a mixture of oil and water from this compressor air stream. The separated oil is collected for disposal, and the water is discharged to the City of Columbus sanitary sewer system.

- Blowers consisting of high vacuum system (for the CVE wells and the ART well) and a low vacuum system (for the SVE, PCIX, and CIX wells).

    - The high vacuum system consists of a liquid/vapor separator (knockout tank), blower, and a heat exchanger. The blower is 75 HP. An AMT pump transfers the water from the separator to the liquid phase carbon system.

    - The low vacuum system consists of a liquid/vapor separator (knockout tank) and two regenerative blowers. Each of the two blowers is 10 HP, and only one blower operates at a time. An AMT pump transfers the water from the separator to the liquid phase carbon system. The low vacuum system is used for wells screened in the more permeable sand, and the low vacuum also reduces water entrainment because the SVE wells are screened across the water table.

- Liquid-phase GAC to treat condensate from the two knockout tanks (two 200-pound vessels in series), which is then discharged through the City sanitary sewer system.

- Vapor-phase GAC with three 5,000-pound vapor-phase GAC vessels (two in series to treat the air stream from the high vacuum system, and one vessel to treats the air stream from the low vacuum system).

The AS/SVE has operated inconsistently for the last few years for a variety of reasons (discussed in Section 4 of this report).

2.3.2 ISCO Injections

The locations of the ISCO injections completed prior to the RSE site visit are summarized below:

- Mid-Plume Injections
    - The first round (January to May 2007) was on 20th Street between 22nd Avenue and 24th Avenue. It included 68 locations (10 ft spacing) with potassium permanganate continuously injected into three intervals (65-49 ft bgs, 48-32 ft bgs, and 31-15 ft bgs). Approximately 275 pounds of potassium permanganate was injected per location.
    - The second round (August to September 2007) was on 16th Street between 20th Avenue and 22nd Avenue. It included 59 locations (10 ft spacing) with potassium permanganate injected into two intervals (65-40 ft bgs and 40-15 ft bgs). Approximately 275 pounds of potassium permanganate was injected per location.
    - The third round (September to October 2008) included 70 injections (10 ft spacing) with potassium permanganate injected in two intervals (65-40 ft bgs and 40-15 ft bgs) in the following areas: Liberty Cleaners parking lot on 10th Street (20 points), and the intersection of 20th Street and 22nd Avenue (22 points). Approximately 275 pounds of potassium permanganate was injected per location.
- OHM Facility Injections
    - The first round (September to October 2007) included 50 locations with potassium permanganate continuously injected into three intervals (65-50 ft bgs, 50-35 ft bgs, and 35-15 ft bgs). Approximately 19,250 pounds of potassium permanganate were injected.
    - The second round (May to July 2008) included 72 locations with potassium permanganate continuously injected into two intervals (65-40 ft bgs and 40-15 ft bgs). Approximately 19,800 pounds of potassium permanganate were injected.
    - The third round (September to October 2008) included 28 locations with potassium permanganate continuously injected in two intervals (65-40 ft bgs and 40-15 ft bgs). Approximately 7,700 pounds of potassium permanganate were injected.

At the time of the RSE visit a fourth round of ISCO was occurring (20 injections at Liberty Cleaners south of the GET extraction wells and 52 "mid-plume" injections on 20^{th} street), and there were plans to complete the ISCO contract work with 120 additional injections to be started later in 2009 (locations to be determined, though it was stated during the RSE site visit that some of these locations would be at the OHM facility).

2.4 Monitoring Program

Monitoring at the site includes the following:

- There are 91 site-wide monitoring wells that are sampled annually, along with 11 Former Manufactured Gasification Plant (FMGP) wells, and two treatability study (TS) wells that are sampled to provide additional data in the vicinity of the Columbus FMGP. All of the FMGP wells and TS study wells are sampled quarterly, along with approximately 50 of the site-wide monitoring wells. There are an additional 25 wells at the OHM facility that are sampled quarterly. The OHM well list is the same regardless of whether it is an annual or quarterly event. Thus, the total number of wells sampled annually is 129. The approximate number of wells sampled during the other three quarters is 88 per quarter. Wells sampled annually are sampled in October, so results for October events represent the most comprehensive ground water sampling. Analysis is for VOCs. Results for many wells are reported in the GET system reports, but results for some of the wells located near the OHM site are reported in the AS/SVE reports.

- For GET system "process monitoring", quarterly sampling of water is performed at the 14 locations with analysis for VOCs:

    - 5 GET extraction wells (including City well W-1)
    - 6 additional City wells
    - GET influent
    - GET effluent
    - City water distribution sample

- For the AS/SVE system, "process monitoring" includes quarterly air sampling for VOCs collected from the influent and effluent vapor-phase GAC adsorption treatment vessels via summa canisters, for the low vacuum and high vacuum systems (i.e., 4 samples per quarter, plus a field blank), and also includes one liquid carbon effluent sample each quarter to monitor discharge to the City sanitary sewer system and determine when liquid-phase carbon change out is required.

- For the ISCO injections, "process monitoring" for the early injection rounds included some ground water samples from direct push borings analyzed for VOCs. However, current monitoring of the ISCO effectiveness is performed with the site-wide ground water monitoring program.

Passive diffusion bags (PDB) have been implemented at some of the ground water monitoring locations where there is no dedicated pump. Additional monitoring has been performed to compare results of the PDB samples to results using pumps. The comparison has been favorable in most cases but not favorable in a few cases.

3.0 SYSTEM OBJECTIVES, PERFORMANCE, AND CLOSURE CRITERIA

3.1 CURRENT SYSTEM OBJECTIVES AND CLOSURE CRITERIA

The goals of the selected remedy in the 2005 ROD include the following:

- Prevent human exposure to contaminated ground water and soil
- Ensure protection of the City's southern municipal well field
- Further reduce contaminant concentrations at the OHM source area
- Reduce the highest ground water contaminant concentrations using a treatment that does not require intensive operation and maintenance

The remedial action objectives (RAOs) for OU2 are to:

- Control migration of soil contaminants into ground water
- Reduce risks associated with PCE and TCE in soil at source areas
- Reduce concentrations of PCE and TCE in ground water at the source areas and the core contamination of the ground water plume north of the GET system extraction wells
- Intercept and control the migration of the ground water contaminant plume
- Prevent domestic exposures to private drinking water wells within the ground water contaminant plume
- Prevent the development and use of the three source properties for residential housing, schools, child care facilities, and playgrounds
- Restrict the construction or installation of any new water wells on the three source properties to ground water monitoring wells or remediation wells
- Prevent the excavation of soils on OHM property except by prior written approval from EPA and NDEQ and ensure that any excavations are conducted in accordance with appropriate worker protection and soil disposal requirements

According to the 2008 GET annual report, EPA has adopted the following remediation goals:

- 60 micrograms per kilogram (ug/kg) for PCE in soil at the OHM source area
- 60 ug/kg for TCE in soil at the OHM source area

- 5 ug/L for PCE in ground water
- 5 ug/L for TCE in ground water
- 70 ug/L for cis-1,2-dichloroethene (cis-1,2-DCE) in ground water

The ground water criteria are consistent with federal MCLs, which are the cleanup goals stated in the ROD.

3.2 Treatment Plant Operation Standards

For the GET system, the Nebraska drinking water standards are the basis for the effluent limits (these standards are located in a table of Title 118, Chapter 4, Narrative and Numerical Standards). The pertinent limits are:

- 5 ug/L for PCE
- 5 ug/L for TCE
- 70 ug/L for cis-1,2-DCE
- 100 ug/L for trans-1,2-DCE
- 2 ug/L for vinyl chloride

There is also a limit for maximum pH of 9 for the effluent from the GET system.

For the AS/SVE system, the influent and effluent from the vapor carbon units is monitored and provides data for calculating mass removal. However, the RSE team has not seen reference to standards or permit values for the effluent air in the site reports it has reviewed.

4.0 FINDINGS

4.1 GENERAL FINDINGS

The observations provided below are not intended to imply a deficiency in the work of the system designers, system operators, or site managers but are offered as constructive suggestions in the best interest of the EPA and the public. These observations have the benefit of being formulated based upon operational data unavailable to the original designers. Furthermore, it is likely that site conditions and general knowledge of ground water remediation have changed over time.

4.2 SUBSURFACE PERFORMANCE AND RESPONSE

4.2.1 PLUME CAPTURE

The RSE team reviewed several different types of capture zone evaluations provided in site documents:

- The 2008 GET Annual Report discusses hydraulic containment based on results of previous simulation modeling, and also presents a summary of a recent modeling update.

- The GET quarterly reports discuss hydraulic containment with regard to head difference pairs that were selected based on previous modeling efforts, and they conclude that many of these paired locations show that inward flow predicted by modeling is not actually achieved in the A and B zones based on observed water levels.

The RSE team has serious reservations regarding the effectiveness of the present system to achieve hydraulic containment in the A and B zones, and also has serious reservations about the predictive capability of the current model. Some of these concerns were raised in the latest site modeling report (Appendix D of the 2008 GET System Annual Performance Report, April 2009) which identified that full capture is not occurring in the area between EW-03 and EW-04, and that contaminant migration continues between these wells to the southeast. That modeling report further identified that pumping rate increases at EW-03 and EW-04, or installation of an additional well is needed to address this issue, and that current pumping rates are maintained to prevent drawing in nonstrippable ground water contaminants associated with the Columbus FMGP and Deyke and Pollard Oil sites.

Specific observations by the RSE team regarding plume capture include the following:

- The analyses of head differences presented in the quarterly reports clearly illustrate that the observed conditions do not match the simulated conditions. This suggests the modeling results are not accurate. This model limitation was also identified in the April 2009 modeling report.

- This potential lack of model accuracy is further confirmed by comparing the potentiometric surface maps for the A and B zones (e.g., for October 2008 presented in Attachment A of this report) with the particle tracking results presented in Appendix D of the 2008 GET Annual Report (one example of particle tracking is provided in Attachment A). The predicted particle tracks from the modeling suggest flow patterns that do not match the observed conditions.

Examples include the following:

- The modeling suggests that flow south of W-1 is from the Loup River north towards W-1, whereas the actual potentiometric surface maps indicate flow in that area is to the southeast away from W-1. The modeling report also indicated some issues with the flow model calibration in this area.

- The modeling suggests that water flowing through a gap in capture between EW-03 and EW-04 generally then flows west towards EW-01R, whereas the actual potentiometric surface maps suggest flow through this gap will then be to the south or southeast away from EW-01R.

- The model calibration hydrographs presented as part of Appendix D in the 2008 GET annual report clearly illustrate that the model predicts water levels that are too low at most of the observation wells after 2006 (one example is presented in Attachment A). Also, at critical locations near extraction wells the simulated versus observed head differences do not match well, suggesting the predictions of drawdown due to pumping may not be accurate (examples include MW-18B to MW-15B and MW-32A to MW-37A). The match of simulated versus observed conditions is generally better in the initial time period close to the system startup (i.e., 2004 to 2006).

As discussed later in Section 4.2.2, increasing VOC concentrations have been observed at the MW-202 and MW-203 clusters, located in the gap between EW-03 and EW-04. The particle traces from the modeling suggest that this could occur, but also suggest that much of this water will ultimately be captured to the west by EW-01R. However, observed flow patterns from actual water level measurements illustrated on site potentiometric surface maps suggest that water flowing through a gap between EW-03 and EW-04 will continue flowing to the south or southeast and will not be captured.

The site team indicated during the RSE site visit that a gap in capture between EW-03 and EW-04 was planned from the outset because of a desire not to pull in ground water impacted by the Dykes and Pollard oil sites that are located between these extraction wells. Ground water impacts from those sites include BTEX compounds and PAH compounds, and there is concern that these compounds (particularly the PAHs) could impact the GET treatment operations. Nevertheless, EW-04 seems to be poorly located. The plume maps presented in Attachment A of this report indicate that EW-04 pumps water that is not very impacted, and in fact all VOCs have been below criteria at EW-04 since April 2008. The RSE team believes that, had EW-04 been located a few blocks north of the Dykes and Pollard oil sites (rather than a few blocks east), it would have provided much more effective capture. Unfortunately, the current location of EW-04 provides little benefit, and may actually make it more likely that impacted water flows beyond the capture zone of EW-03.

With respect to the potentiometric surfaces presented in site reports, the RSE team notes that there are some locations where no cone of depression is indicated near an extraction well where one likely exists (e.g., near EW-03 in the A and B zones and near EW-04 in the B zone). This is due to lack of measurement points in the vicinity of the extraction wells (the site team correctly does not use water levels measured at the extraction wells). As per “A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems” (EPA 600/R-08/003, January 2008) EPA recommends installation of water level measurement points near extraction wells to address this issue (these points need not also be monitored for water quality).

4.2.2 GROUND WATER CONTAMINANT CONCENTRATIONS

Evaluating concentration trends over time at this site is complex due to a variety of factors:

- There are multiple aquifer zones, with varying degree of connection in different locations (i.e., the C zone appears to be in poor connection with the overlying A and B zones near EW-02C and to the south, but appears to be better connected to the north as evidenced by ground water impacts observed in the C zone between the OHM facility and the railroad tracks).

- Multiple remediation technologies have been employed in different locations and at different times (AS/SVE, GET, ISCO)

- There appears to have been a significant change in ground water flow direction over time that is related to change in pumping patterns at the City's southern municipal well field. Previous site reports illustrate that before the year 2000 the southern municipal well field caused flow near the railroad tracks to bend to the west towards the southern municipal well field, rather than follow the natural flow direction that is to the southeast. This explained the shape of the contaminant plume. However, when pumping at the City well field was cut back, flow directions shifted to a more southeasterly direction, as illustrated on more recent potentiometric surface maps.

The RSE team provides the following observations regarding concentration trends:

- There continue to be ground water impacts emanating from the OHM facility, but these impacts are greatly reduced compared to pre-remedy impacts. For instance, PCE concentrations up to 49,000 ug/L and TCE concentrations up to 6,400 ug/L were detected at MW-26A (immediately downgradient of the OHM facility) in 1999-2001, compared to more recent concentrations that are close to 20 ug/L for PCE and 10 ug/L for TCE. This suggests that remediation efforts at the OHM facility have provided improvements in water quality. However, concentrations of PCE in ground water above 1,000 ug/L continue to be found sporadically at all three elevations where data are collected (17-20 ft bgs, 30 ft bgs, 50 ft bgs) at the OHM facility, and sometimes very high concentrations are detected (such as 75,000 ug/L of PCE at PCX-1D in April 2007 or 10,000 ug/L at PCX-5B in April 2008). This suggests there is sufficient source strength remaining at the OHM facility to impact ground water with VOC concentrations above standards for many years if it is not more fully remediated or contained, and it is possible that VOC concentrations immediately downgradient of the OHM facility could increase above current levels in the future, especially if source area remediation is not continued.

- A slug of higher VOC concentrations appears to be migrating to the south towards the gap in capture between EW-03 and EW-04. At MW-31A, TCE concentrations greater than 500 ug/L were observed in 2004 but have decreased substantially since to less than 50 ug/L (with a related increase in cis-1,2-DCE). This declining trend pre-dates ISCO injections, and likely results from positive impacts of the AS/SVE system and resulting reduction in source strength emanating from the OHM facility. With that conceptual model, one would expect subsequent concentration declines at MW-18 (further downgradient), and in fact TCE concentration at MW-18A has declined significantly since 2006 (from 510 ug/L in April 2006 to ~10 ug/L recently). Over that same period, TCE concentration at MW-15B (further downgradient) has been increasing from approximately 20 ug/L in 2004 to more than 150 ug/L recently. These trends support the concept of a slug of VOC impacts migrating to the south. Note that MW-15B is located downgradient of EW-03, but it is not clear if it is located inside or outside the capture zone of EW-03.

- At the next downgradient sampling locations from MW-15B (i.e., MW-202 and MW-203 clusters) the TCE concentrations have noticeably increased during the last several quarterly sampling events. These two monitoring well clusters are located in the gap in capture between EW-03 and EW-04 discussed earlier. At MW-203B the most recent TCE concentration (January 2009) was up to 27 ug/L. It is quite possible that higher VOC concentrations exist east of the MW-202 and MW-203 clusters. There is the potential that concentrations of VOCs may continue to increase at the MW-202 and MW-203 clusters (and/or east of those clusters) over the next several years, and that VOC impacts may spread further to the southeast into an area where there are no current monitoring wells or institutional controls (which end at 16th Avenue).

- As noted in site reports, vinyl chloride is detected at only two locations in the October 2008 sampling: MW-32A (0.98 ug/L) and MW-37A (5.5 ug/L). These monitoring wells are located in the area downgradient of the Deyke and Pollard oil sites, and BTEX compounds are also detected at these wells. It appears likely that the contamination from the Deyke and Pollard oil sites enhances bioremediation of PCE/TCE beyond cis-1,2-DCE to vinyl chloride in this area.

- VOC concentrations at many wells close to the southern municipal well field have declined significantly over time. Examples include MW-9A/9B, MW-13A/13B/13C/13D, and MW-8A. This is perhaps due to effectiveness of the GET system, but may also be due to the changing flow patterns associated with reduced pumping at the southern municipal well field over the last decade discussed in Section 4.2.1 (i.e., the well field no longer pulls contamination that far to the west, unlike historical pumping conditions that led to the well field being impacted).

4.3 COMPONENT PERFORMANCE

4.3.1 GROUND WATER EXTRACTION SYSTEM

Design rates and actual rates achieved in 2008 are summarized below:

	Design Rate (gpm)	Design Max Rate (gpm)	Avg Flow 2008 (gpm)
EW-01R	200	240	209
EW-02C	500	600	457
EW-03	150	200	143
EW-04	150	180	127
W-1	400	600	591
Total	1,400	1,820	1,528

*from Table 1-2 of 2008 GET annual report

The site team indicated during the RSE site visit that the specific capacity of the pumping wells is not calculated or tracked over time. No major issues have been reported with well fouling during the RSE site visit, but the operators did mention iron build-up on one of the extraction wells.

During RSE visit it was mentioned that the pumps at the extraction wells are throttled with valves, not VFDs.

4.3.2 GET Treatment System

The GET treatment system has relatively low influent concentrations, and meeting the effluent standards has not been an issue. Recent influent and effluent concentrations are indicated below:

		Influent Conc (ug/L)	Effluent Conc (ug/L)
PCE	Oct-07	0.76	0.5 U
	Jan-08	0.87	0.5 U
Standard: 5 ug/L	Apr-08	0.5 U	0.5 U
	Aug-08	0.5 U	0.5 U
	Oct-08	0.5 U	0.5 U
TCE	Oct-07	32	0.5 U
	Jan-08	17	0.5 U
Standard: 5 ug/L	Apr-08	8.2	0.5 U
	Aug-08	0.5 U	0.5 U
	Oct-08	9.10	0.5 U
Cis-1,2-DCE	Oct-07	24	0.5 U
	Jan-08	24	0.5
Standard: 70 ug/L	Apr-08	7.7	0.74
	Aug-08	0.5 U	0.5 U
	Oct-08	22	1.2
Trans-1,2-DCE	Oct-07	0.5 U	0.5 U
	Jan-08	2.3	0.5 U
Standard: 100 ug/L	Apr-08	0.93	0.5 U
	Aug-08	0.5 U	0.5 U
	Oct-08	1.7	0.5 U
Vinyl Chloride	Oct-07		
	Jan-08	0.5 U	0.5 U
Standard: 2 ug/L	Apr-08	0.5 U	0.5 U
	Aug-08	0.5 U	0.5 U
	Oct-08	0.5 U	0.5 U

The treatment system is clean and well-maintained. Historic problems with manganese fouling have generally been addressed by modifying the chemical addition, acid washing the air stripper packing on a quarterly basis (a 3-day event each quarter), and cleaning the paddle flow meters approximately three times per year.

The City generally uses all of the treated water (approximately 735 million gallons per year) for water supply except the water that is used during the acid wash events. The water from the acid washing events (approximately 12,000 gallons total for all four acid wash events) is neutralized and discharged to the City sanitary sewer system. This appears to be an efficient use of resources.

4.3.3 AS/SVE System

The AS/SVE and the source area ISCO injections (see below) have been relatively effective at reducing VOC mass in the source area. However, AS/SVE system operation has been intermittent over the past few years, and continued operation of the AS/SVE in its current configuration would likely have marginal effectiveness in remediating the source area to standards. Between August 2007 and December 2008, the

AS system operated approximately 50% of the time, the low vacuum SVE system operated approximately 37% of the time, and the high vacuum system operated approximately 49% of the time. The following limitations to system performance are noted:

- Approximately the first 10 ft of the subsurface is clay, and when the water table rises as high or higher than the bottom of this clay, it becomes impractical for the SVE system to extract vapors derived from the air sparging. As a result, the AS/SVE system is not operated during periods with a high water table. The small diameter SVE wells may also complicate vapor extraction during periods of high water. Approximately 50% of the recent low vacuum SVE system down time is attributed to shutdowns during periods with a high water table.

- To prevent mounding and surfacing of potassium permanganate during source area ISCO injections at the OHM facility, operation of the AS/SVE system is discontinued during and immediately following ISCO events at the OHM facility. Approximately 35% of the recent down time is attributed to ISCO injections. The ART well continued to operate during the ISCO events.

- Air sparge points and SVE wells in the source area have been focused in the open areas on the property, primarily the parking lot, sidewalks, and surrounding alleys. Significant source material is likely located beneath the facility, and thus has not and cannot be addressed with the current system configuration.

- The air sparge points and SVE wells are each configured into common distribution headers, which makes it difficult to target specific areas that may historically receive inadequate flow.

- A number of leaks have been identified in the AS and both SVE systems, reducing air delivery and air extraction, and possibly biasing sampled vapor concentrations with atmospheric air. The November 2006 Revised Remedial Process Optimization Report and the 2008 AS/SVE Annual report discuss many of the operational problems. Mass removal has reportedly decreased (as would be expected as mass is removed); however, given the various issues described in these documents, it is unclear if the mass removal rate has decreased due to leaks (i.e., reduced air delivery via the sparge system and reduced air recovery and/or dilution of the SVE systems).

This system has made a significant contribution to limiting the amount of mass that migrates from the source area. However, given that ground water concentrations are still widely present above 1,000 ug/L (and even above 10,000 ug/L in some locations) after 8 years of system operation, it does not appear that cleanup levels will be reached in the near term using this approach. In the B and C monitoring well intervals, the plume appears to be detached from the source area (see figures in Attachment A), suggesting that significant contaminant mass has not migrated from the source area in these intervals for several years. In the A monitoring well interval, the plume is still attached to the source area but the concentrations in wells downgradient of the source area (e.g., MW-26A) are substantially lower than they were historically. For example, MW-26A had a PCE concentration of 41,000 ug/L in December 1999. The concentrations at MW-26A and other shallow monitoring wells downgradient of the source area have decreased substantially since AS/SVE system operation began. By January 2005, the PCE concentration at MW-26A was below 100 ug/L, and the concentration has been below 40 ug/L for eight consecutive quarters. However, given the sporadic high ground water concentrations that continue to be detected at the OHM facility, it appears reasonable to conclude that this system, as it currently operates, will not restore ground water to concentrations below cleanup levels. It is unclear how high concentrations in ground water downgradient of the AS/SVE system may increase, if system operation were discontinued.

4.3.4 ISCO INJECTIONS

During the RSE visit, it was stated that the ISCO was not expected to restore the aquifer to cleanup criteria. Rather, the goal of the ISCO was to reduce VOC concentrations in the source area(s) and mid-plume to an extent that operation of the GET system might be shortened.

OHM Injections

The results of the OHM ISCO injections are mixed and difficult to interpret given the intermittent operation of the AS/SVE system between ISCO injection events. The ground water monitoring results from the PCIX-1 and PCIX-2 wells indicate that concentrations generally decreased in the shallow zone (PCIX C and D intervals, which are 20 feet and 30 feet deep respectively) but increased substantially in the deep zone (PCIX B interval, which is approximately 50 feet deep). The October 2008 monitoring results had the highest TCE concentrations in PCIX-1B and PCIX-2B since 2004 or earlier. The TCE concentration at PCIX-1B was approximately 2,500 ug/L and the TCE concentration at PCIX-2B was approximately 10,000 ug/L. The ART well also experienced significant increases in TCE concentrations over the duration of the ISCO injection events. These results suggest that contamination may have been pushed and/or mobilized into the vicinities of these sampling locations rather than remediated by either the air sparging from PCIX-1 and PCIX-2 or the ISCO injections.

The results at the MW-44 cluster show the opposite result. The shallow TCE concentrations increased to approximately 500 ug/L, but the deeper TCE concentrations decreased from as high as 5,000 ug/L to under 20 ug/L.

Some locations showed notable improvement, such as SVE-3, in which concentrations decreased from 1,100 ug/L to under 50 ug/L over the course of the two 2008 injections. The MW-45 cluster (both shallow and deep) also showed positive results. TCE concentrations in the shallow zone decreased from 4,300 ug/L to under 20 ug/L.

The mixed results appear indicative of subsurface heterogeneity and the difficulty in evenly distributing the oxidant such that it contacts all of the contamination. The ISCO injections have been successful at reducing contaminant mass, but based on the current data do not seem to have made meaningful progress in restoring the source area.

Mid-Plume Injections

The mid-plume injections were originally intended to address the portion of the plume that would take the longest to migrate to and be extracted by the GET system. The injections appear to have provided little benefit to overall plume remediation as described below.

The first and third round of injections was conducted upgradient of the MW-23 and MW-41 clusters. A review of the data suggests that low level TCE and PCE concentrations were generally remediated in the vicinity of these wells by the ISCO injections; however, TCE concentrations in MW-23B were generally unaffected and concentrations in general were already declining due to source area remediation (AS/SVE). The cis-1,2-DCE concentrations in the vicinity of these wells did not appear to be significantly affected by the ISCO injection. PCE appears to continue to migrate at low levels from the source area, so recontamination of the area partially remediated by the first and third mid-plume ISCO events is a possibility.

There are no monitoring wells immediately downgradient of the second round of mid-plume ISCO injections. MW-18 is the closest monitoring well to this injection location and is located over 600 feet downgradient. There may have been a slight response in the TCE concentrations at MW-18A to the ISCO injection, but in general, there was no apparent benefit for any constituent at the MW-18B and MW-18C intervals. PCE concentrations remain above 200 ug/L at MW-18B as late as January 2009.

4.4 COMPONENTS OR PROCESSES THAT ACCOUNT FOR MAJORITY OF ANNUAL COSTS

The RSE team has estimated the approximate annual O&M costs based on information provided by CDM and the City of Columbus.

Item Description	**Approximate Annual Cost**
Routine project management (HGL + CDM)	$ 75,000 (GET + AS/SVE + ISCO)
Engineering Support (HGL + CDM)	$ 200,000 (GET + SVE+ISCO)
O&M Labor	$120,000 (GET)
	$ 40,000 (AS/SVE)
Electricity	$ 50,000 (GET)
	$ 25,000* (AS/SVE)
Supplies & routine maintenance	$ 105,000 (GET)
	$ 20,000 (AS/SVE)
Ground water sampling (129 wells annually, ~88 wells in other three quarters, for approximately 400 samples per year)	$185,000***
Quarterly and annual reporting for the GET and AS/SVE systems, ISCO injections, and all ground water monitoring	$185,000***
Lab Analysis**	$ 2,000 (GET)
Total Estimated Annual Cost	**$1,007,000**

*when all components operating
**most lab analysis is performed by contract lab and is not billed to the site.
*** based on the total of sampling/reporting of approximately $370,000 per year provided to the RSE team and using the RSE team's professional experience with costs for labor, equipment and travel associated with sampling

In addition, the expected total ISCO injections costs (2007 to 2009), including injections still to be performed after the RSE visit, is approximately $710,000.

Note that the system provides some avoided costs to the City of Columbus, which uses most of the water pumped and treated at the GET system for public water supply. For instance, wellhead maintenance and electricity costs for those wells are covered as part of the ground water remedy, such that those costs are not borne by the City. Thus, some additional benefit to the community is provided by this system.

4.4.1 UTILITIES

Electricity cost for the GET system is incurred by the City of Columbus and estimated to be approximately $4,000 per month ($48,000 per year), primarily for well pumps, treatment system blower, treatment system transfer pumps, and electric heaters in the GET building. Electricity cost for the AS/SVE system is incurred by CDM and is estimated to be approximately $2,000 per month when the system is operating as intended, primarily for the compressors and blowers. Based on the Loup Power District (electrical utility) rate schedules, the average cost per kWh is approximately $0.03 per kWh for the GET system and approximately $0.07 per kWh for the AS/SVE system. The difference is based on the different power consumptions of the two facilities. A number of other fees apply, including a demand charge for the GET system. Other utilities such as water and phone are very minor relative to the overall costs.

4.4.2 NON-UTILITY CONSUMABLES AND DISPOSAL COSTS

For the GET treatment system, the largest cost in this category is for chemicals, which appear to cost on the order of $75,000 per year. These chemicals include the polyphosphate-type chemical added to prevent fouling of the air stripper, as well as acid used for the acid washes of the air stripper. The polyphosphate is added to the public water supply prior to distribution regardless of the treatment for VOCs. Other costs in this category include equipment maintenance and supplies (approximately $30,000 per year).

For the AS/SVE system, the liquid phase GAC for the condensate from the knockout tanks is estimated to be replaced once per year, and the vapor phase GAC was reportedly changed out approximately 2 years ago. These changeout frequencies may be heavily influenced by system down time.

4.4.3 LABOR

There are multiple entities associated with the operation of the current remedy:

<u>Hydrogeologic (HGL)</u>

HGL is EPA's contractor and is responsible for the following with respect to routine O&M for the GET and AS/SVE systems:

- Overall project management
- Weekly O&M visits to the AS/SVE system (~ 1.5 hrs per visit for one person)
- Participation in quarterly long term monitoring (LTM) events (shared between HGL and CDM)
- Review reports generated by CDM

For special projects, HGL directly subcontracts for drillers and other contractors (rather than CDM) to avoid a double-markup.

It was indicated during the RSE site visit that the October monitoring event requires a four person crew for approximately 10 days, and the other events generally require a four person crew for 8 to 9 days. There has been a continuing evaluation of the use of PDBs at 13 wells without dedicated pumps. The PDB data have not matched low-flow results well at the OHM wells but have matched the low-flow data well at the 11 FMGP wells and two TS wells. The current plan is to use PDBs to sample the FMGP and TS wells, which will save about a day worth of labor for four samplers, but revert to low-flow sampling at OHM. No further comparisons of the PDB and low-flow datasets are planned.

CDM

CDM is a subcontractor to Hydrogeologic. CDM was the original design contractor for the GET system. CDM provides services for routine O&M including the following:

- Project management and reporting
- Engineering and technical support to the City
- Modeling updates
- Quarterly reports for the GET system
- Quarterly reports for the AS/SVE system and ISCO injections
- Participation in quarterly monitoring events (shared between HGL and CDM)

CDM also provides engineering design services for special projects associated with the remedy (e.g., pipeline relocation, and management and technical support of the ISCO injections), and CDM shared responsibility for engineering design services on the ART well design.

City of Columbus

The City of Columbus operates under a cooperative agreement with EPA and expenses associated with the remedy are funded through an EPA grant. The City is responsible for:

- Extraction well maintenance
- Operation of the GET system treatment plant operation

The operators reportedly spend approximately 2 hrs per day seven days a week for routine operation, plus 3 days per quarter for acid wash of the GET system.

4.4.4 CHEMICAL ANALYSIS

Chemical analysis is generally provided by the Contract Laboratory Program and is not billed to the site. If the costs were billed to the site, it is estimated that the analytical costs would be on the order of $10,000 annually for the current process monitoring program and on the order of $50,000 annually for long-term monitoring of ground water. The effluent from the GET system is sent to the State Lab and is billed to the project, and there is minor cost expended in field kits (e.g., Hach kits).

4.5 APPROXIMATE ENVIRONMENTAL FOOTPRINTS ASSOCIATED WITH REMEDY

4.5.1 ENERGY, AIR EMISSIONS, AND GREENHOUSE GASES

Based on the annual electricity cost of $48,000 and the schedule of fees and rates for the Loup Power District (electric utility), approximately 1.5 million kWh of electricity is used on an annual basis by the GET system. This usage compares closely to electricity usage estimated from motor sizes and VFD settings. The annual electrical usage from the AS/SVE system is more difficult to calculate due to the intermittent and unpredictable operation of the system. Based on a survey of 2008 electricity bills, the electrical usage for 2008 was approximately 278,000 kWh, which is significantly smaller than the usage that would occur if the system were operating at capacity for the whole year. If the system were operating at full capacity for a whole year, electricity usage would likely be three to four times higher. The electricity provided by the Loup Power District is generated from a hydroelectric facility that was constructed in the 1930s. As a result, the incremental environmental footprint of the electricity consumed by the GET and AS/SVE systems is minimal. Table 4-1 provides the estimated electrical usage at the site over a 10-year period and includes an emission factor of 0 for the hydroelectric power.

Other direct energy usage associated with the site is for gasoline and diesel. Gasoline is associated with transportation to and from the site for a variety of activities, and diesel is associated with freight of the ISCO to the site, equipment operation for the ISCO injections, and transportation of ISCO injection equipment to the site. Table 4-1 summarizes the gasoline and diesel usage for the site. The usages associated with the GET and AS/SVE systems are on an annual basis. The usage for the ISCO injections is for the life-cycle of the ISCO injection project.

Air emissions of greenhouse gases and other pollutants would result from manufacturing of the chemicals used at the site and from other services (e.g., laboratory analysis) associated with site activities. Estimates of emissions from these are provided in Table 4-1. Ground water monitoring, although it applies to all remedial activities, was included under the GET system footprint.

A review of Table 4-1 shows that the footprint of 10 years of operation of the GET and AS/SVE systems combined is approximately to the footprint for the entire ISCO project, and the ground water monitoring program comprises approximately 60% of the GET system footprint. This comparison highlights the environmental benefit of using renewable hydroelectric power for power-intensive remedies. Had the electricity been provided by fossil fuels, the annual footprint for the GET system would have been almost three times the footprint for the full ISCO project.

With respect to criteria pollutants (e.g., ozone, nitrogen oxides, sulfur dioxide, lead, particulate matter, and VOCs), Columbus is located in Platte County, and criteria pollutant air quality monitoring data for Platte County is not available from the EPA Air Data website. The data for nine Nebraska counties are included, and eight of the nine counties had Air Quality Indexes below 100 indicating good or moderate air quality. The remaining county is Douglas County, the most populous county in the State (where Omaha is located). Based on the results from these nine counties, it is presumed that Platte County has good to moderate air quality. It is further noted that most of the emissions associated with the remedy are not local to the site (i.e., they are for materials manufacturing or transportation). As a result, the emissions primarily occur at the locations of the chemical/material manufacturing or along the highways between the consultant/contractor offices and Columbus. As such, the criteria pollutants are not expected to have significant adverse affects on the local or regional environment. The primary emissions associated with the site are the VOCs emitted from the air stripper off-gas. As calculated and discussed in Section 5, the emission rate is very low compared to the requirements for a minor source of hazardous air pollutants (HAPs). This suggests that the air stripper off-gas would not significantly affect regional air quality. More local effects on Columbus residents have not been quantified.

4.5.2 WATER RESOURCES

Approximately 735 million gallons per year are extracted, treated, and provided to the City as potable water. Water for the acid washing (approximately 12,000 gallons per year) and water from the AS/SVE knockout tanks (difficult to quantify, but relatively low in volume) are treated and disposed of to the City sanitary sewer system. Water used for the make-up of the potassium permanganate solution for the ISCO injections is returned to the aquifer and therefore does not represent a net removal of water from the aquifer.

The polyphosphate chemicals that are added to the water prior to treatment by the air stripper and distribution to the public contribute to phosphorous loading to natural waters. It is unlikely that the current wastewater treatment facility effectively removes phosphorous, so it is expected that the phosphorous will enter the receiving water body. This could increase the potential for eutrophication in this receiving water body. The RSE team did not quantify the amount of phosphorous entering the system or the potential for eutrophication (which may be insignificant) because the chemicals are added to the water for public distribution and this RSE is not intended to be a review of the water supply and wastewater treatment provided by the City of Columbus.

4.5.3 Land and Ecosystems

The entire remedy is confined to the urban, commercial, and residential sections of the City of Columbus. The GET system occupies space immediately surrounding other water treatment infrastructure for the City, and the AS/SVE system was constructed in an attachment to the dry cleaning facility and is likely unnoticeable by the community. The ISCO injections are the aspect of the remedy that likely creates the most disturbance to the community. The injections involve running diesel equipment in commercial and residential areas, which results in incremental noise and exhaust. However, the site team and contractors have done a good job of planning and executing the ISCO injections to minimize inconvenience and nuisance to the community.

4.5.4 Materials Usage and Waste Disposal

Materials comprise one of the larger components of the remedy footprint, but waste disposal is fairly minimal. Primary materials usage includes GAC for treating the off-gas and knockout tank water from the AS/SVE system, potassium permanganate for the ISCO injections, and chemical additives for the GET system. The GAC is regenerated, which requires energy but fosters materials reuse and reduces waste disposal. The potassium permanganate is injected into the aquifer and generates relatively little waste on-site (typically buckets and personal protective equipment used during the injection process). Waste is likely generated during the manufacturing process and associated supply chain for the potassium permanganate but is not quantified or accounted for here due to lack of manufacturing-specific information. Similar to potassium permanganate, the chemical additives for the treatment plant do not generate any on-site waste but some waste (not quantified or characterized as part of this report) is likely generated in the manufacturing process and supply chain. However, the RSE team understands that some of this chemical usage introduced as part of the GET system reduces that amount of chemicals required for other water treatment provided by the City in order to provide water of suitable quality to the community.

4.6 Recurring Problems or Issues

There have been issues with shut-downs of extraction wells due to electrical storms and power failures. In 2008 a surge suppressor was installed on all extraction wells to protect the flow meters.

4.7 Regulatory Compliance

During the RSE process, the site team (including the City) did not report any exceedances of discharge standards or other compliance related standards.

4.8 Safety Record

During the RSE process, the site team (including the City) did not report any health and safety concerns or incidents related to the remedial activities.

5.0 EFFECTIVENESS OF THE SYSTEM TO PROTECT HUMAN HEALTH AND THE ENVIRONMENT

5.1 GROUND WATER

There continues to be a continuing source of ground water impacts at the OHM facility. Concentrations of PCE in ground water above 1,000 ug/L continue to be found sporadically at all three elevations where data are collected (17-20 ft bgs, 30 ft bgs, 50 ft bgs). Sometimes very high concentrations are detected (such as 75,000 ug/L of PCE at PCX-1D in April 2007 or 10,000 ug/L at PCX-5B in April 2008) with much lower values detected before and after. It is likely that the combined efforts of AS/SVE and ISCO have provided some (and perhaps substantial) concentration reductions, but it is apparent that these efforts have not entirely remediated this source area. The sporadic nature of the high concentration values suggests that there may be localized changes to the shallow ground water flow system that occur due to the AS/SVE operations and/or the ISCO injections. It is also possible that sporadic nature of the high concentration values could be due to pulses of new contamination being released to the ground water system due to rainfall events and/or a rising and falling water table. The concentrations of PCE and daughter compounds immediately downgradient of the OHM facility appear to be lower than historical ground water concentrations observed between the OHM facility and the railroad tracks. This potentially suggests that remediation efforts to date (including AS/SVE and ISCO) have reduced the strength of the continuing source at the OHM facility. Nevertheless, the RSE team believes there is sufficient source strength remaining at the OHM facility to impact ground water with VOC concentrations above standards for many years if it is not more fully remediated or contained.

An additional area of concern is an apparent gap in hydraulic capture between GET system extraction wells EW-03 and EW-04. As discussed in Section 4.2.1, the latest site modeling report (Appendix D of the 2008 GET System Annual Performance Report, April 2009) identified that full capture is not occurring in the area between EW-03 and EW-04, and that migration continues between these wells to the southeast. That modeling report further identified that pumping rate increases at EW-03 and EW-04, or installation of an additional well, is needed to address this issue, and that current pumping rates are maintained to prevent drawing in nonstrippable ground water contaminants associated with the Columbus FMGP and Deyke and Pollard Oil sites. During the RSE site visit it was stated by the site team that, although some VOC impacts appear to extend south or southeast beyond the reach of the extraction wells, these impacts appear to not be increasing significantly (i.e., a “steady-state” condition). The RSE team does not fully agree with this assessment. As discussed in Sections 4.2.1 and 4.2.2, a slug of higher VOC concentrations appears to be migrating to the south towards (and through) this gap between EW-03 and EW-04. It is quite possible that higher VOC concentrations exist east of the MW-202 and MW-203 clusters. There is the potential that concentrations of VOCs may continue to increase at the MW-202 and MW-203 clusters (and/or east of those clusters) over the next several years, and that VOC impacts may spread further to the southeast into an area where there are no current monitoring wells. The site team may need to more fully address the potential ramifications of these observations.

The water supply provided by the effluent of the GET system consistently meets drinking water standards. Furthermore, there appear to be institutional controls in place to generally prevent consumption of impacted water. However, the RSE team notes that the eastern boundary of the institutional controls (16^{th} Avenue) may not be sufficient south of the railroad tracks. As discussed above, it is possible that the plume is migrating to the southeast in this area, and it is possible the VOC concentrations above standards may be detected now or in the future east of 16th Avenue.

5.2 SURFACE WATER

No impacts to surface water have been observed or are anticipated.

5.3 AIR

Emissions from the AS/SVE system are treated with vapor carbon, so no significant impacts are anticipated from that system. For the GET system, VOC influent concentrations are quite low (generally less than 50 ug/L), resulting in only minor emissions of VOCs to the atmosphere.

$$\frac{1500\ \text{gal}}{\text{min}} \times \frac{3.785\ \text{L}}{\text{gal}} \times \frac{0.05\ \text{mg}}{\text{L}} \times \frac{1\ \text{kg}}{10^6\ \text{mg}} \times \frac{2.2\ \text{lbs}}{\text{kg}} \times \frac{1440\ \text{min}}{\text{day}} \times \frac{365\ \text{day}}{\text{yr}} = \frac{328\ \text{lb}}{\text{yr}}$$

By comparison, the criteria for a minor source under the NDEQ air quality operating permit program is 5 tons per year (or 10,000 pounds per year) of any one hazardous air pollutant (HAP). PCE, TCE, and vinyl chloride are listed as HAPs (cis-1,2-DCE is not).

With respect to vapor intrusion, during the RSE site visit the RSE team inquired if potential for vapor intrusion has been evaluated in the immediate vicinity of the OHM facility, such as at residences immediately to the south. It was stated that there has been some evaluation regarding the potential for vapor intrusion throughout the plume, but it was not clear if there had been specific evaluation of vapor intrusion immediately adjacent to the OHM facility. After the RSE site visit, information regarding previous vapor intrusion studies was provided by the RPM, including some analysis at the OHM facility using a PID (there were detections of VOCs) and an analysis performed on a time-integrated summa canister sample from the basement of one residence on 22nd Street located downgradient of the OHM facility. At the residence there was PCE detected in the air sample (1.1 ug/m^3), but this concentration was below the EPA Region 9 criteria of 3.3 ug/m^3 for PCE in ambient air. The site has indicated that the potential need for additional evaluation of the vapor intrusion pathway will be considered during the next Five-Year Review which is due in 2010.

5.4 SOIL

At the OHM facility there is the potential for PCE product to be present above the water table below the dry cleaner building in the clays immediately below ground surface. This represents a potentially continuing source of ground water impacts, and it cannot be fully investigated or remediated while dry cleaning operations continue at the site.

5.5 WETLANDS AND SEDIMENTS

These media are not affected or potentially affected by site contamination.

6.0 RECOMMENDATIONS

Cost estimates provided herein have levels of certainty comparable to those done for CERCLA Feasibility Studies (-30%/+50%), and these cost estimates have been prepared in a manner generally consistent with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, July, 2000. The costs and sustainability impacts of these recommendations are summarized in Tables 6-1 and 6-2.

6.1 RECOMMENDATIONS TO IMPROVE EFFECTIVENESS

6.1.1 EVALUATE THE NEED FOR FURTHER EVALUATION OF POTENTIAL FOR VAPOR INTRUSION NEAR OHM FACILITY

Although some evaluation of the potential for vapor intrusion near the OHM facility was provided to the RSE team, it is recommended that the sufficiency of those evaluations be considered by the site team, and that the potential need for additional evaluation of the vapor intrusion pathway in the vicinity of the OHM facility should be evaluated by the site team. The site team has indicated that the potential need for additional evaluation of the vapor intrusion pathway will be considered during the next Five-Year Review, which is due in 2010. No cost has been estimated for this recommendation because it is planned to be included within the Five-Year Review.

The affect on the environmental footprints of this recommendation are not quantified since no specific action beyond discussions and reporting is made at this time.

6.1.2 DISCONTINUE PUMPING AT EW-04 AND SHIFT PUMPING WEST TO EW-03

As discussed in Section 4.2.1, EW-04 extracts water that is currently below standards for VOCs, and it potentially increases the potential for water to escape capture to the east of EW-03. It makes sense to terminate extraction at EW-04, and increase extraction at EW-03 to the extent possible (perhaps requiring a larger pump to be installed at EW-03) if piping can accommodate more water at EW-03 than the current pump can generate, and if there is adequate available drawdown to support the increased pumping rate. To the extent that water currently pumped at EW-04 cannot be allocated to EW-03, some could be also allocated to EW-01R. The RSE team notes that the site team is concerned that increased pumping at EW-03 could cause PAHs from adjacent sites to extracted, and if necessary, a simple pre-treatment unit with GAC to treat the PAHs could be implemented for water from this well before it is combined with water from the other wells. This recommendation should have a relatively insignificant cost to implement, unless a new pump is required at EW-03 or pre-treatment for EW-03 is in fact needed (there may be a need to periodically monitor MW-3 for PAH's, but this extra cost will likely be offset by saved electricity from not pumping EW-04).

The environmental footprint of this recommendation is relatively minor given that the pump in EW-04 is powered by renewable hydroelectric power and that the chemicals that are added to the extracted water are added anyway prior to distributing the water to the public.

6.1.3 Address Calibration Issues with the Flow Model

As discussed in Section 4.2.1, comparison of simulated versus observed conditions (including observations already noted in the GET quarterly reports) suggests that the existing model does not accurately represent the flow system under current pumping conditions. The RSE team believes this model is an important tool for assisting with capture zone evaluation and future decisions regarding pumping locations/rates. In particular, some of the re-calibration should include comparison of simulated versus observed drawdown over time caused by pumping at specific extraction wells. These data can be collected by doing short-term shutdown tests at individual extraction wells (e.g., for several days, one extraction well at a time) and measuring changes in water level over time at nearby monitoring wells before and during the shutdown tests with transducers (plus at a well beyond the influence of that extraction well to serve as a control). Previous pump test data from EW-01R may also be available for this type of analysis. Also, shut-down of EW-04 is recommended above, and changes in water level resulting from that action could also be monitored to provide the information required. This type of transient calibration near extraction wells, in response to changed pumping stresses, is important because the ability of the model to accurately predict capture depends on the ability of the model to predict drawdown due to pumping. Re-calibration should also address the overall match of water levels versus time (as noted in Section 4.2.1, many of the hydrographs from the recent model update indicate that simulated water levels are too low after GET extraction began, especially in the latter part of the calibration period). The RSE team believes the fieldwork associated with several shutdown tests could be collected for less than $15,000, and updating the existing model could be performed for less than $40,000.

The environmental footprints of this recommendation are not quantified as they are expected to be relatively low and minor in comparison to the benefits of the recommendation with respect to remedy protectiveness.

6.1.4 Address Potential Plume Migration to the Southeast (Delineation and ICs) and Associated Potential Actions

As discussed in Sections 4.2.1 and 4.2.2, the VOC concentrations have been increasing at the MW-202 and MW-203 clusters, higher concentrations could exist to the east of those clusters, and this portion of the plume may continue to grow in extent to the southeast beyond MW-202 and MW-203. The RSE team notes that there are no monitoring wells to the east or southeast of MW-203 to provide for delineation now or in the future. Furthermore, the institutional controls that are in place are bounded to the east by 16^{th} Avenue, and it is possible that VOCs above standards have migrated (or will migrate) east of 16^{th} Avenue south of the railroad tracks. The RSE team recommends that the site team develop and implement a strategy for addressing additional plume delineation and extending the boundary of the institutional controls.

One approach for delineation would be to collect direct push samples from intervals corresponding to the A and B zones, with sampling for VOCs, followed by installation of several permanent wells clusters. Approximately 3 days of direct push sampling in the region south and east of MW-203 would likely be appropriate, at an approximate cost of $40,000 (including a brief work plan, field work, analysis at the contract lab, and a short report). If relatively low VOC concentrations are determined throughout the area (e.g., similar to those at the MW-202 and MW-203 clusters) then subsequent addition of two clusters of monitoring wells with two intervals (A and B zones) would likely be appropriate to monitor concentrations over time to make sure concentrations do not get significantly worse. These four wells might cost on the order of $50,000 to install, and an additional $10,000 per year to sample quarterly with analysis for VOCs. If much higher VOC concentrations are found east or southeast of the MW-203 cluster, then additional permanent wells may be needed for delineation and tracking of concentration trends over time. The RSE team has no basis for estimating the cost of extending the institutional controls to the east, but assumes it could be accomplished for less than $15,000.

Assuming that plume expansion to the southeast is occurring, the need to address that expansion with remedial measures will need to be evaluated by the site team. The outcome of that evaluation may depend on the results of the delineation activities suggested above. However, the RSE team provides the following thoughts regarding pros and cons of various potential alternatives.

- *Additional Extraction Well*. It is conceivable that a new extraction well could be added, perhaps in the vicinity of MW-203. The water could be piped to the existing pipeline north of the railroad tracks, or in a separate pipeline south of the railroad tracks (along 10th Street). This location would be more conducive to creating an overlapping zone of capture with EW-03 than the current location of EW-04. If the well is placed near the MW-203 cluster, then the MW-203 cluster would provide for water level measurements in the close proximity of the new extraction well. This new well might draw in mobile BTEX compounds from the upgradient Deyke and Pollard oil sites, but those compounds should be readily addressed by the air stripper in the GET system. It is less likely that PAHs would be drawn in to this new well at substantial concentrations because PAHs are generally less mobile than VOCs, but if necessary, a simple pre-treatment unit with GAC to treat the PAHs could be implemented for water from this well before it is combined with water from the other wells. This option is relatively straightforward to implement and would eliminate the gap in capture that currently exists between EW-03 and EW-04. A disadvantage is that new infrastructure is required. It is also possible that updated modeling could show that the gap in capture between EW-03 and EW-04 could be addressed with higher rates at those wells. If that is the case, pre-treatment might also be required to address the PAHs from the other nearby sources.

- *Enhanced Bioremediation.* The presence of vinyl chloride downgradient of the Deyke and Pollard oil sites suggests that it is possible to drive reductive dechlorination beyond cis-1,2-DCE if the aquifer is driven to more reducing conditions. Injections of electron donor material (e.g., emulsified vegetable oil, molasses, lactate) could be implemented throughout a treatment zone (with addition of microbes if needed) in the area south of the railroad tracks not captured by the GET extraction system. The injection approach would be similar to the ISCO injections previously performed. However, unlike ISCO which is consumed rapidly, the enhanced bioremediation approach generally provides for a treatment period of up to a year or more before needing to be fortified. An advantage of this approach is that it does not require additional infrastructure. A disadvantage is that there is a chance the full reductive dechlorination will not be accomplished if insufficient donor is added. The site team also noted that it is generally difficult to adequately stimulate bioremediation for treating ground water where total VOC concentrations are less than 100 µg/L at the start of treatment. This is due to the inability to grow large quantities of dechlorinating biomass at low contaminant concentrations. Therefore, conducting enhanced bioremediation at the toe of the plume may not be feasible.

- *Monitoring Only*. This would only be appropriate if it can be determined that, based on modified extraction rates at EW-04 and EW-03 recommended above, sufficient capture is then provided and that any contamination already beyond the modified capture zone will attenuate over time and will not negatively impact potential receptors. This would obviously be a lower cost alternative if it could be justified from an effectiveness standpoint.

The RSE team estimates that evaluating these and other potential alternatives after the plume delineation activities are performed might require on the order of $50,000. The actual implementation costs cannot be estimated at this time.

There is a significant difference in the environmental footprints of these three options. Assuming the monitoring only option is considered a baseline or reference approach (because it would likely be a component of each option), the analysis can focus on the incremental footprints associated with the additional extraction well and the enhanced bioremediation options. The following table reflects the incremental carbon footprint of these two options. An arbitrary but reasonable operational period of 5-years is assumed. The assumptions used in completing the table are presented in Attachment B.

	Units	**CO2 equiv. Emission Factor (lbs)**	**Additional Extraction Well**		**Enhanced Bioremediation**	
			Quantity	**CO2e (lbs)**	**Quantity**	**CO2e (lbs)**
Energy						
Electricity*	kWh	0	400,000	0	0	0
Diesel	gallons	22	410	9,020	11,400	250,800
Gasoline	gallons	19	0	0	4,400	83,600
Energy Subtotal				**9,020**		**334,400**
Materials						
Steel	pounds	2	5,000	10,000	0	0
HDPE	pounds	2	11,200	22,400	0	0
EVO	pounds	3.5	0	0	500,000	1,750,000
Other			20% mark-up	6,500	10% mark-up	175,000
Materials Subtotal				**38,900**		**1,925,000**
Total				**47,920**		**2,259,400**

EVO = emulsified vegetable oil
** Emission factor for electricity is assumed to be zero due to the use of renewable hydroelectric power*

<u>*Other Environmental Footprints*</u>

The additional extraction well would require the materials as described in Attachment B (and other materials and equipment that were not specified). In addition, some disposal or materials recycling would be required for the asphalt and/or concrete removed during the trenching process, and the drill cuttings and mud from drilling and developing the well. There would be a negligible effect on local water resources given that all of the water extracted would be for beneficial purposes. There would be an effect on the local commercial and residential neighborhoods from construction activities, but the effect on local ecosystems would be negligible given the urban/suburban setting of the project.

The enhanced bioremediation approach would require the materials described in Attachment B (and other materials and equipment that were not specified). In addition, some disposal would be required for disposables used during the injection process. There would be a negligible effect on local water resources given that all of the water extracted for make-up water would be reinjected. Water quality would generally be improved during the 5-year period and the lingering effects of the in-situ bioremediation should attenuate before the remaining VOCs. There would be an effect on the local commercial and residential neighborhoods from injections activities, but the effect on local ecosystems would be negligible given the urban/suburban setting of the project.

As a general note, the carbon footprint of the additional extraction well is very small relative to the enhanced bioremediation option because of the renewable hydroelectric power that is used to power the pump. In the absence of quantifying other environmental footprints, the carbon footprint can be used as an indicator, assuming that other pollutants, waste, and raw materials usage would generally scale with the carbon footprint.

6.2 RECOMMENDATIONS TO REDUCE COSTS

6.2.1 DISCONTINUE ISCO AFTER CONTRACT IS COMPLETED

As discussed in Section 4.3.4, the ISCO injections have likely reduced some VOC mass and concentrations at the OHM facility and at the mid-plume injection locations, but the ISCO has not provided complete remediation of VOCs in either area, and it is not clear that the ISCO injections will provide any benefit with regard to the overall remediation timeframe. This recommendation to discontinue the ISCO injections technically will not save any money since the site team already plans to discontinue the ISCO injections, but rather this recommendation is intended to convey the RSE team's concurrence with that approach.

The environmental footprint for the ISCO project is substantial relative to the footprints of the other (arguably more effective) components of the remedy.

6.2.2 CONTINUE TO USE PDBS WITHOUT EXTENSIVE COMPARISONS

The PDB data have not matched low-flow results well at the OHM wells but have matched the low-flow data well at the 11 FMGP wells and two treatability study (TS) wells. The current plan is to use PDBs to sample the FMGP and TS wells, which will save about a day worth of labor for four samplers, but revert to low-flow sampling at OHM. RSE team concurs with this approach assuming extensive comparisons with data from low-flow sampling be curtailed to save on sampling costs and reporting effort. The site team has indicated that no further comparisons of the PDB and low-flow datasets are planned. If PDB results are to be used for important remediation decisions or comparison to cleanup standards, then those specific results could be confirmed with samples obtained by low-flow sampling. No specific cost savings are quantified herein since this is a continuation of the current practice, but some savings will clearly be achieved by curtailing the comparisons between samples from PDBs versus low-flow sampling.

This recommendation has a negligible effect on the environmental footprint of the remedy.

6.2.3 REDUCTIONS IN MONITORING/REPORTING

This is a complex site where flow conditions have changed and multiple remedial approaches have been implemented. Nevertheless, the total estimated cost of $375,000 per year for sampling and reporting for the combined GET and AS/SVE system is an extremely large number, and an attempt to reduce the sampling and reporting cost is merited.

The RSE team makes the following suggestions:

- Currently there are two separate quarterly reports (GET system, AS/SVE plus ISCO), plus two separate annual reports (GET system, AS/SVE plus ISCO). This results in 10 report submittals per year. It is recommended that this be reduced to one annual comprehensive report per year for all current or future components of the remedy (i.e., a reduction from ten submittals per year to one submittal per year). This will significantly reduce duplication in reporting. In addition, all data will be reported in the same place. Currently, for instance, ground water quality data for wells at the OHM facility are reported in the AS/SVE reports and water quality for the other site wells are reported in the GET reports. Providing all the data in a unified report would be preferable.

- The site team has done a commendable job of sampling wells in "clean" areas annually rather than quarterly. The RSE team suggests changing some of the wells currently sampled quarterly to either semi-annually or annually.

    - For the 25 wells currently sampled quarterly at the OHM facility, it is suggested that sampling associated with long-term monitoring be performed annually. This will result in 75 fewer samples taken per year. If an aggressive remediation approach is implemented at the OHM facility (see Section 6.4.1) then this annual LTM sampling schedule might be augmented by additional process monitoring samples for a limited time while the aggressive remedy is conducted, but that should be considered as part of a specific remedy option and not a component of LTM.

    - For the remainder of the site, it is suggested that quarterly sampling be reserved for the portion of the plume from the MW-26 cluster to the southeast towards the MW-203 cluster. This area is of greatest concern with respect to changing concentration over time given the current flow directions (which are more to the southeast than was the case when the plume developed), the continuing potential source at the OHM facility, and the potential expansion of the plume to the southeast discussed earlier. It is suggested that the 28 wells (listed below) be sampled semi-annually rather than quarterly. This will result in 56 fewer samples taken per year.

MW-1A	MW-2A	MW-3A	MW-4A	MW-5A
MW-6A	MW-8A	MW-11A	MW-13A	MW-14A
MW-17A	MW-206A	KV-5	MW-1B	MW-2B
MW-3B	MW-4B	MW-5B	MW-6B	MW-8B
MW-9B	MW-11B	MW-13B	MW-14B	MW-17B
MW-206B	KV-4	MW-13C		

- It is suggested that comprehensive water levels be collected semi-annually rather than quarterly, with both water level maps presented in the annual report.

- It is suggested that plume maps for the comprehensive sampling round (October) be presented in the annual report. If there are significant deviations from those data in samples collected in other quarterly or semi-annual events, those can be explained in the text of the annual report.

- For sampling rounds other than the comprehensive sampling round, it is suggested that sampling results be processed and reviewed by the consultant when they are received (e.g., update concentration trend plots), and if any of the results are unexpected and significant with respect to a potential short-term decision, then that could be reported in a short memo to the EPA RPM. Similar treatment could be given to an issue with a component of the remedy that requires timely attention.

The RSE team believes that implementing the monitoring and reporting recommendations above should provide significant cost savings. Reducing the number of samples taken by approximately 131 per year as described above (plus some related QA/QC sampling), and reducing the water level events from quarterly to semi-annual, might save on the order of $60,000 per year on sampling labor plus equipment and travel. We estimate that an annual reporting budget of $100,000 per year should be sufficient for generating a comprehensive annual report plus any interim data processing as the year progresses, resulting in savings on reporting on the order of $85,000 per year. Thus, the RSE team estimates that the annual costs for sampling and reporting could be reduced by approximately $145,000 per year if these recommendations are implemented. The RSE team notes that the City of Columbus has expressed some concern about reducing the sampling frequency to less than quarterly.

Based on the emission factors presented in Table 4-1, reducing the analysis by 131 samples per year (plus some related QA/QC sampling) might reduce the carbon footprint by approximately 13,000 pounds of carbon dioxide per year. The amount of materials usage and disposal by the laboratory associated with this site would also be reduced. The reduction in the sampling effort should also reduce the carbon footprint but not by a significant amount given that the majority of the footprint (as calculated) is based on travel to and from the site from the consultant/contractor offices, and roughly the same amount of travel would still need to occur.

6.2.4 PROJECT MANAGEMENT AND TECHNICAL SUPPORT MOVING FORWARD

As presented in Section 4.4, the following annual costs were estimated based on information provided to the RSE team:

- Project Management - $ 75,000 per year (GET + AS/SVE + ISCO)
- Engineering Support - $200,000 per year (GET + AS/SVE + ISCO)

These represent combined cost estimates for HGL and CDM. The manner in which the costs were provided to the RSE team makes it difficult to determine how much of the costs pertain to each component of the remedy (GET, AS/SVE, ISCO). However, on a move-forward basis, the ISCO support should end after 2009, and it is possible that operation of the AS/SVE system will also be terminated based on recommendations in this RSE report. Since the GET system is expected to operate for an extended period of time, the RSE team recommends that project management and engineering support costs for the GET system be clearly documented and managed independently from other investigation or remediation activities. For the GET system alone these costs are expected to be substantially lower than the amounts provided above, and based on experience of the RSE team reviewing other Fund-lead sites, a budget of $50,000 per year for project management and $50,000 per year for engineering support should be adequate for the GET system. With respect to other potential investigations, remedial actions, or special projects (such as a GeoProbe investigation, extending institutional controls, evaluating options for the OHM facility, etc.) the cost for associated project management and/or engineering support should be treated as independent "one-time" or "annual" tasks that are completely separate items from annual O&M of the GET system. In this manner, the long term costs of the GET system can be tracked and managed.

Therefore, the RSE team believes move-forward project management and engineering support costs for the GET system alone should be approximately $175,000 per year less than the costs estimated in Section 4.4 for the combined GET plus AS/SVE plus ISCO remedies. The cost impacts from other items beyond the GET system will depend on what items are performed, and if those are "one-time" or "annual" cost items.

6.3 Recommendations for Technical Improvement

6.3.1 Measure and Track Specific Capacity of Wells

During the RSE site visit it was stated that the specific capacity of the extraction wells is not measured or tracked. The specific capacity of each extraction well is calculated as the pumping rate divided by the drawdown at that extraction well (i.e., gpm per ft of drawdown). The value of tracking this parameter is that a decline in specific capacity indicates well fouling and can serve as an indicator for performing well rehabilitation. The measurement of drawdown (i.e., versus a non-pumping condition) at an individual well can be complicated by several factors, such as regional water level changes and interference from the other extraction wells. However, corrections can be made for background water levels based on changes in water level far away from the extraction wells, and the interference between wells is a relatively minor impact especially if extraction rates remain relatively consistent over time. Therefore, adding this to the routine monitoring at the site will only involve measuring depth to water at each extraction well when other site water levels are measured, and then performing a few simple calculations. This is not expected to have any impact on annual costs.

6.3.2 Consider VFDs for Extraction Well Pumps

The extraction well pumps (totaling 90 HP) contribute significantly to the overall electricity usage of the GET system, and the pumps are throttled to reduce flow. The flow could be more efficiently controlled with VFDs, and this would reduce electricity usage and electrical costs. At the time the GET system was designed it was determined that the cost for installing variable frequency drives (VFDs) was not justified. It was determined at that time to regulate the flow rate with a manual valve at the well head. The electricity used by the facility is renewable hydroelectric power, reducing electrical usage with VFDs would not significantly reduce the environmental footprint of the remedy. Similarly, because the electrical rates are so low (approximately $0.03 per kWh), the cost savings would not be as significant as they would be at many other locations in the country. If hydroelectric power capacity in the region is recognized as being relatively limited, the site team might consider installing VFDs to help conserve that capacity. The RSE team estimates that installing VFDs might reduce electrical usage on the order of 150,000 kWh to 200,000 kWh per year. Purchasing and installing the five VFDs might cost approximately $25,000, and savings of approximately $5,000 per year might result. The site team has indicated that use of VFDs for the extraction wells will be considered by EPA and the City of Columbus if automated flow adjustment is desired.

6.4 Considerations for Gaining Site Close Out

6.4.1 Consider alternate Actions at OHM Facility

As discussed earlier in this report, the RSE team believes that the combined efforts of AS/SVE and ISCO at the OHM facility have provided some (and perhaps substantial) concentration reductions, but it is apparent that these efforts have not entirely remediated this source area. Furthermore, there are areas beneath the existing dry-cleaning building that cannot be fully investigated or addressed by the current remedial approaches. Remaining subsurface impacts at the OHM facility could be a source of dissolved ground water impacts downgradient of the OHM facility for many years.

The RSE team recommends that a "remedy alternatives" report for the OHM facility be prepared, for an estimated cost of approximately $50,000 (no field work is assumed for preparing this report). The following potential options should be evaluated (all except the second bullet below assume that operation of the AS/SVE system would be discontinued):

- *Separate P&T System at the OHM Facility* – This would presumably consist of one new extraction well, treatment via a tray-stripper, and discharge to ground water a short distance downgradient of the extraction well (in several injection wells or a trench located just beyond the expected capture zone of the extraction well). An advantage of this approach is that it would provide reliable hydraulic containment of the source area if properly designed and implemented, eliminating the potential for new ground water impacts to occur downgradient of the OHM facility. This option would not require any further investigation of the OHM facility, and would not require the cleaning business to be relocated. Also, the City could likely operate this system very cost-effectively as an addition to the existing operation of the GET system. A disadvantage is that this would be a long-term cost item that would likely operate indefinitely, and that new infrastructure would be required. This option would likely require a modification to the ROD.

- *Augment extraction locations for AS/SVE*. This would presumably consist of continued operation of the AS/SVE system with additional locations added for air injection and withdrawal. The advantage is that some additional mass removal might occur, and the use of existing infrastructure would be maximized. However, this option would be subject to the same limitations of the existing AS/SVE system, which include difficulties due to subsurface heterogeneities, high water tables, and inaccessible areas under the building (unless the existing dry cleaning business is relocated). The likelihood of eliminating the source area with this approach is relatively low.

- *Enhanced Bioremediation* – This would presumably involve injections of electron donor material (e.g., emulsified vegetable oil, molasses, lactate) throughout a treatment zone (with addition of microbes if needed) at the OHM facility. The injection approach would be similar to the ISCO injections previously performed. However, unlike ISCO which is consumed rapidly, the enhanced bioremediation approach generally provides for a treatment period of up to a year or more before needing to be fortified. An advantage of this approach is that it does not require additional infrastructure. A disadvantage is that there is a chance the full reductive dechlorination will not be accomplished if insufficient donor is added. As with AS/SVE and ISCO, the existing business provides a limitation to accessible areas unless that business is relocated. This option would likely require a modification to the ROD.

- *Thermal Treatment* – This could include use of resistive heating or steam. An advantage of this approach is that subsurface heterogeneities might not be as much of a limitation compared to ISCO, bioremediation, or AS/SVE. Precautions would need to be implemented to address potential impacts to neighboring businesses and residences. The high water table would cause potential issues with collection of vapors (some form of ground water pumping might be required to lower the water table, which may not be practical given the high hydraulic conductivity of the shallow aquifer and the need to subsequently treat/discharge that water). This option would require relocation of the existing dry cleaning business, and would likely be rather expensive to implement. This option would likely require a modification to the ROD.

- *Excavation* – This would presumably include excavation to the water table which includes mostly clay. This would require relocation of the existing dry cleaning business. During the RSE site visit it was stated that this option was previously considered, but the AS/SVE was selected because the contractor convinced the site team that AS/SVE could quickly eliminate the source area. This option would include significant cost and disruption. Another disadvantage is that it would not address any residual DNAPL that might be present below the water table.

- *More ISCO* – This has not proven to be fully effective at eliminating the VOCs in the treatment areas, so this alternative would likely not be favored from an effectiveness standpoint.

- *No-Action* – Given the potential for continued impacts to ground water downgradient of this source area, this is likely an unacceptable option with respect to protectiveness.

The environmental footprints for the above options are not specifically estimated. Rather the remedial options are classified into two different categories: "relatively low environmental footprint" and "relatively high environmental footprint".

The P&T, continued AS/SVE, and thermal remediation options all are considered to have relatively low environmental footprints, primarily because the primary resource that will go into the remedies is hydroelectric power, which has a very small environmental footprint (given that the hydroelectric facility has already been constructed). All of the remedies would involve construction, but it is likely that the construction activities will be fairly similar. The P&T system would likely include the installation of a new extraction well, installation of an air stripper or additional GAC units, piping, and controls. Continued AS/SVE would need to include additional sparge and extraction points to be effective, but the remainder of the system could likely remain the same. The thermal remedy would likely include the most significant construction activities, but because of the short-term nature of the project much of the materials and equipment would be reused at other facilities. Although the thermal remedy would likely require extended closing or relocation of the facility, the environmental footprint of this would likely be comparable to the P&T system or AS/SVE system continuing to occupy the treatment building on the property for many years.

The ISCO, bioremediation, and excavation options are considered to have relatively high environmental footprints. The ISCO and bioremediation options are in this category because they depend on the manufacturing of a significant amount of material in other parts of the country. The manufacturing facilities likely do not use a high proportion of renewable energy, and the materials must be transported to the site and injected. The injection activities alone would likely have a similar footprint to the "relatively low footprint" options mentioned above, and the materials (e.g., potassium permanganate or EVO) would all be additional to the footprint. The excavation option would involve fairly extensive construction activities and would also likely involve transport and disposal of material, which occupies landfill space. It would also require relocation of the facility and demolition of the existing building.

In summary, the evaluation of these options in the "remedy alternatives" report should include the reliability of containing or remediating the source area, the up-front and life-cycle costs, the impacts to the community (visual, noise, odor, etc.), and the need to relocate the existing business (which has a financial cost and would require substantial administrative effort). A small P&T system may ultimately be preferred, even though it does not eliminate the subsurface impacts immediately beneath the OHM facility and it might operate for an indefinite period.

6.5 Recommendations for Improved Sustainability

No specific recommendations are provided in this category, but sustainability has been considered during the development of the above specific recommendations. One general recommendation is to note the very high environmental footprint associated with the ISCO injections relative to the P&T and AS/SVE activities at this site, and to recognize the "environmental value" of implementing remedies that utilize the renewable energy provided locally through hydroelectric power rather than implementing remedies that depend on chemical manufacturing in other parts of the country. The electricity used by this remedy is provided from a hydroelectric facility with a very limited environmental footprint (given that the hydroelectric facility has already been constructed).

Table 4.1 Energy and Atmosphere Footprint Analysis

	Quantity	Unit	CO2 equiv emission factor (lbs/unit)	CO2 equiv total (lbs)	CO2 equiv % of Total
P&T System (over 10 years)					
Energy					
Electricity	15,000,000	kWh	0	0	0%
Diesel	0	gallons	0	0	0%
Gasoline	2,000	gallons	19	38,000	4%
Energy subtotal				**38,000**	**4%**
Materials					
Polyphosphate dispersant	NA	NA	NA	0	0%
Hydrochloric acid	16,000	gallons	3.2	51,200	5%
Materials subtotal				**51,200**	**5%**
Other Services					
Process monitoring analysis	$100,000	dollars	1	100,000	10%
Groundwater monitoring analysis	$50,000	dollars	1	50,000	5%
Disposal of acid wash residuals	NA	NA	NA	0	0%
Other services subtotal				**150,000**	**14%**
P&T Subtotal (lbs over 10 years)				**239,200**	**23%**
ISCO Applications	*Values for ISCO are for Life of ISCO Project*				
Energy					
Diesel	3,600	gallons	22	79,200	8%
Gasoline	1,500	gallons	19	28,500	3%
Energy subtotal				**107,700**	**10%**
Materials					
Potassium Permanganate	$450,000	dollars	1	450,000	43%
Materials subtotal				**450,000**	**43%**
ISCO Subtotal (for life of ISCO project)				**557,700**	**54%**
AS/SVE (over 10 years)					
Energy					
Electricity	2,780,000	kWh	0	0	0%
Gasoline	5,500	gallons	19	104,500	10%
Energy subtotal				**104,500**	**10%**
Materials					
GAC	70,000	pounds	2	140,000	13%
Materials subtotal				**140,000**	13%
Waste Disposal					
Diposal of water from knockout tanks	NA	NA	NA	0	0%
Disposal subtotal				**0**	**0%**
AS/SVE Subtotal (lbs over 10 years)				**244,500**	**23%**
Remedy Total Over Nominal 10-yr Period (lbs)				**1,041,400**	

Usage and Emission Factor Notes for Table 4-1.

Except where otherwise noted, information regarding emission factors was obtained from EPA Climate Leads Program, the National Renewable Energy Laboratory life-cycle inventory at www.nrel.gov/lci, or the EUROPA Reference Life-Cycle Database. Costs used in deriving emission factors are consistent with costs during Spring 2009. The emission factors developed here are rough approximations based on simplifying assumptions. They are intended to provide only approximate environmental footprints to help understand the affects potential changes to the remedy may have on the footprint of the remedy.

Electricity

Quantity

- GET System – 1.5 million kWh based on electricity bills, motor sizes, and VFD settings
- AS/SVE System – 278,000 kWh based on 2008 electricity bills, recognizing that the system operated intermittently

Emission Factor – A negligible emission factor is assumed given that the power is generated from a hydroelectric facility and that typical activities for maintaining that hydroelectric facility and the transmission lines are fundamental aspects of operation and are not incremental as part of the GET and AS/SVE system operation.

Diesel

Quantity – Diesel usage results from operating the ISCO injection equipment, transportation of the ISCO injection equipment to the site, and delivery of the potassium permanganate. Estimates are derived as follows:

- Approximately 135 days of injections are assumed based on an average rate of four ISCO locations per day (which is consistent with the pace at the site) and a total of 539 injection locations by the time the ISCO work is completed in 2009. The ISCO operator reported that approximately 12 gallons of diesel is used per day of injection. Therefore, diesel usage for the injections is approximately 1,620 gallons.
- The ISCO equipment is housed in Indianapolis, which is approximately 700 miles from the site. The round trip will have been made approximately 8 times by the conclusion of the ISCO contract, and fuel usage of 10 miles per gallon is a reasonable approximation to fuel usage for the rig used for the injections. The diesel usage for transportation is therefore approximately 1,120 gallons.
- A diesel usage rate of 0.023 gallons per ton mile and a transport distance of 500 miles are assumed for estimating the diesel used for transporting potassium permanganate to the site. Over the course of the contract (through 2009) the total mass of potassium permanganate injected will have been approximately 150,000 pounds (75 tons). This translates to approximately 860 gallons of diesel.

Emission Factor – 22 pounds of carbon dioxide per gallon of diesel (Climate Leaders.

Gasoline

Quantity – Gasoline is used for transportation to and from the site and to power the ISCO injection pump. The ISCO injection pump requires approximately 10 gallons per week or 270 gallons over the course of the project. Gasoline usage for transportation is estimated as follows:

- For two support vehicles for the ISCO contractor (assuming 700 miles each way, 8 round trips over the course of the project, and 15 miles per gallon), gasoline usage is approximately 1,500 gallons over the course of the project.
- For routine AS/SVE maintenance, one trip per week for 52 weeks per year, at a distance of 160 miles roundtrip, and an average fuel economy of 15 miles per gallon, estimated gasoline usage is approximately 550 gallons per year.
- For CDM's participation in the quarterly sampling, one trip per quarter for four quarters per year, at a distance of 600 miles roundtrip, and an average fuel economy of 15 miles per gallon, estimated gasoline usage is approximately 160 gallons per year.
- For HGL's participation in the quarterly sampling, one trip per quarter for four quarters per year, at a distance of 160 miles roundtrip, and an average fuel economy of 15 miles per gallon, estimated gasoline usage is approximately 40 gallons per year.

Emission Factor – 19 pounds of carbon dioxide per gallon of gasoline (Climate Leaders).

Granular Activated Carbon

Quantity – 7,000 pounds per year based on the change out of one 2000-pound liquid phase GAC unit per year and two 5,000-pound vapor phase GAC unit every two years.

Emission Factor – 2 pounds of carbon dioxide per pound of GAC, see Attachment B.

Potassium Permanganate

Quantity – Based on the reported usages, approximately 150,000 pounds (75 tons) of potassium permanganate has been used throughout the injection program.

Emission Factor – 1 pound of carbon dioxide per dollar of chemicals, based 10% of the cost of the materials resulting from the direct use of fossil fuels or electricity derived from fossil-fuels, and approximately 10 pounds of carbon dioxide emitted per $1 of fossil fuels consumed. 10 pounds would represent a blend of natural gas, diesel, gasoline, and coal. The cost of the permanganate is assumed to be approximately $3 per pound for a total cost of $450,000 for the life of the ISCO project.

Other Treatment Chemicals

Quantity – Approximately $75,000 per year is spent on a variety of chemicals for the treatment plant; however, the majority of these chemicals (including the dispersant for iron and manganese) are already added for supplying water to the public. Only the hydrochloric acid and disinfectant for acid washing and disinfecting the air stripper are "additional" for the purposes of evaluating environmental footprints. Acid washing is conducted once a quarter and uses approximately 400 gallons of 30% hydrochloric acid for a total usage of approximately 1,600 gallons of 30% hydrochloric acid per year. Relatively minor amounts of sodium hydroxide and sodium hypochlorite are used to neutralize the acid washing waste and to disinfect the air stripper. The specific gravity of 30% hydrochloric acid is 1.14. Given the density of water is approximately 8.34 pounds per gallon, one gallon of 30% hydrochloric acid solution includes approximately 2.85 pounds of hydrochloric acid. This translates to a usage of approximately 4,600 pounds of hydrochloric acid per year.

Emission Factor – Hydrochloric acid can be produced by combining the hydrogen and chlorine gas generated as intermediates in the production of sodium hypochlorite and dissolving the resultant hydrogen chloride gas in water. With the hydrogen and chlorine combined, the sodium hydroxide would remain unused and available for distribution. Assuming the footprint for sodium hypochlorite production is evenly distributed among the intermediate products of sodium hydroxide, hydrogen, and chlorine gas, the footprint for each intermediate would be the same (approximately 1.1 pounds of carbon dioxide per pound of hydrochloric acid). This translates to a total of approximately 5,100 pounds of carbon dioxide for the 1,600 gallons of 30% hydrochloric acid or 3.2 pounds of carbon dioxide per gallon of 30% hydrochloric acid.

Other Services

Quantity – For disposal of the acid wash residual to the POTW, the carbon and other air emission footprints is assumed to be non-additional (NA) because the volumes discharged are extremely small compared to the capacity of the POTW. No operational changes are made as a result of this discharge and no operational changes would be made if the discharge was discontinued. For laboratory services, a breakdown of materials and energy are not directly quantified. The emission factor used is based on a percentage of service cost directed toward energy from fossil fuels. Approximately $60,000 in laboratory analysis is assumed and likely includes fuel for transport, electricity for operating the laboratory and equipment, chemicals and disposables associated with sample preparation and analysis, and disposal.

Emission Factor – 1 pounds of carbon dioxide per dollar spent on the service, based on 10% of the cost resulting from direct use of fossil fuels and approximately 10 pounds of carbon dioxide per $1 of fossil fuels consumed. 10 pounds of carbon dioxide would represent a blend of natural gas, diesel, gasoline, and coal.

References

Climate Leader GHG Inventory EPA-430-K-08-004, May 2008

National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (www.nrel.gov/lci) maintained by Alliance for Sustainable Energy, LLC.

Table 6-1. Cost Summary Table

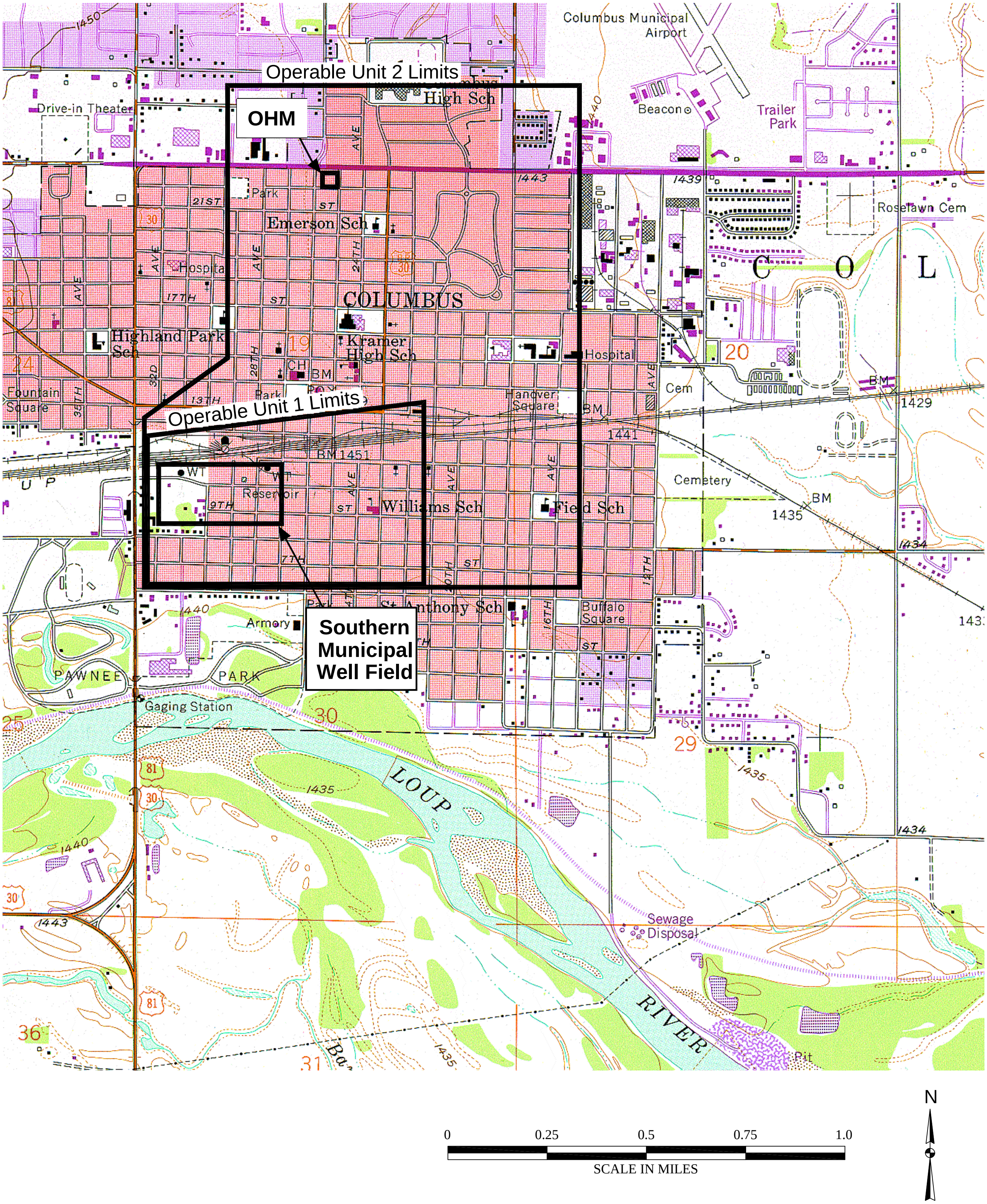
Recommendation	Reason	Additional Capital Costs ($)	Estimated Change in Annual Costs ($/yr)	Estimated Change in Life-Cycle Costs $*	Estimated Change in Life-Cycle Costs (net present value) $**
6.1.1 Evaluate the Need for Further Evaluation of Potential for Vapor Intrusion Near OHM Facility	Effectiveness	$0	$0	$0	$0
6.1.2 Discontinue Pumping at EW-04 and Shift Pumping West to EW-03	Effectiveness	Negligible	Negligible	Negligible	Negligible
6.1.3 Address Calibration Issues with the Flow Model	Effectiveness	$55,000	$0	$55,000	$55,000
6.1.4 Address Potential Plume Migration to the Southeast (Delineation and ICs) and Associated Potential Actions	Effectiveness	$155,000	$10,000	$355,000	$304,000
6.2.1 Discontinue ISCO After Contract is Completed	Cost-Effectiveness	$0 (already planned)	$0 (already planned)	$0 (already planned)	$0 (already planned)
6.2.2 Continue to Use PDBs Without Extensive Comparisons	Cost-Effectiveness	Not quantified	Not quantified	Not quantified	Not quantified
6.2.3 Reductions In Monitoring/Reporting	Cost-Effectiveness	$0	($145,000)	($2,900,000)	($2,160,000)
6.2.4 Project Management and Technical Support Moving Forward	Cost-Effectiveness	$0	($175,000)***	($3,000,000)***	($2,608,000)***
6.3.1 Measure and Track Specific Capacity of Wells	Technical Improvement	$0	$0	$0	$0
6.3.2 Consider VFDs for Extraction Well Pumps	Technical Improvement	$25,000	($5,000)	($100,000)	($50,000)
6.4.1 Consider Alternate Actions at OHM Facility	Site Closeout	$50,000	$0	$50,000	$50,000

Costs in parentheses imply cost reductions
* assumes 20 years of operation with a discount rate of 0% (i.e., no discounting)
** assumes 20 years of operation with a discount rate of 3% and no discounting in the first year
*** does not include “one-time” or “annual costs” associated with project management or engineering support for items other than GET system operation, which should be tracked separately and not as part of routine annual O&M

Table 6-2. Sustainability Summary Table for Recommendations

Recommendation	Reason	Effects on Sustainability
6.1.1 Evaluate the Need for Further Evaluation of Potential for Vapor Intrusion Near OHM Facility	Effectiveness	Minor
6.1.2 Discontinue Pumping at EW-04 and Shift Pumping West to EW-03	Effectiveness	Minor
6.1.3 Address Calibration Issues with the Flow Model	Effectiveness	Minor
6.1.4 Address Potential Plume Migration to the Southeast (Delineation and ICs) and Associated Potential Actions	Effectiveness	Minor
6.2.1 Discontinue ISCO After Contract is Completed	Cost-Effectiveness	Minor (already planned)
6.2.2 Continue to Use PDBs Without Extensive Comparisons	Cost-Effectiveness	Minor
6.2.3 Reductions In Monitoring/Reporting	Cost-Effectiveness	Minor
6.2.4 Project Management and Technical Support Moving Forward	Cost-Effectiveness	Minor
6.3.1 Measure and Track Specific Capacity of Wells	Technical Improvement	Minor
6.3.2 Consider VFDs for Extraction Well Pumps	Technical Improvement	Minor
6.4.1 Consider Alternate Actions at OHM Facility	Site Closeout	Varies depending on option selected

ATTACHMENT A



C:\CAD\10th Street\GETS-PSR-2008\SiteLocMap_Fig1-1.dwg 04-06-09 15:36

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Task Order Number: 3370-002
Revised: 4/7/09 MMG
Source: USGS 7.5 minute Topographic Map, Columbus, NE, 1958, photorevised 1976.

Legend

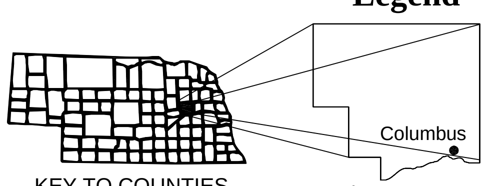
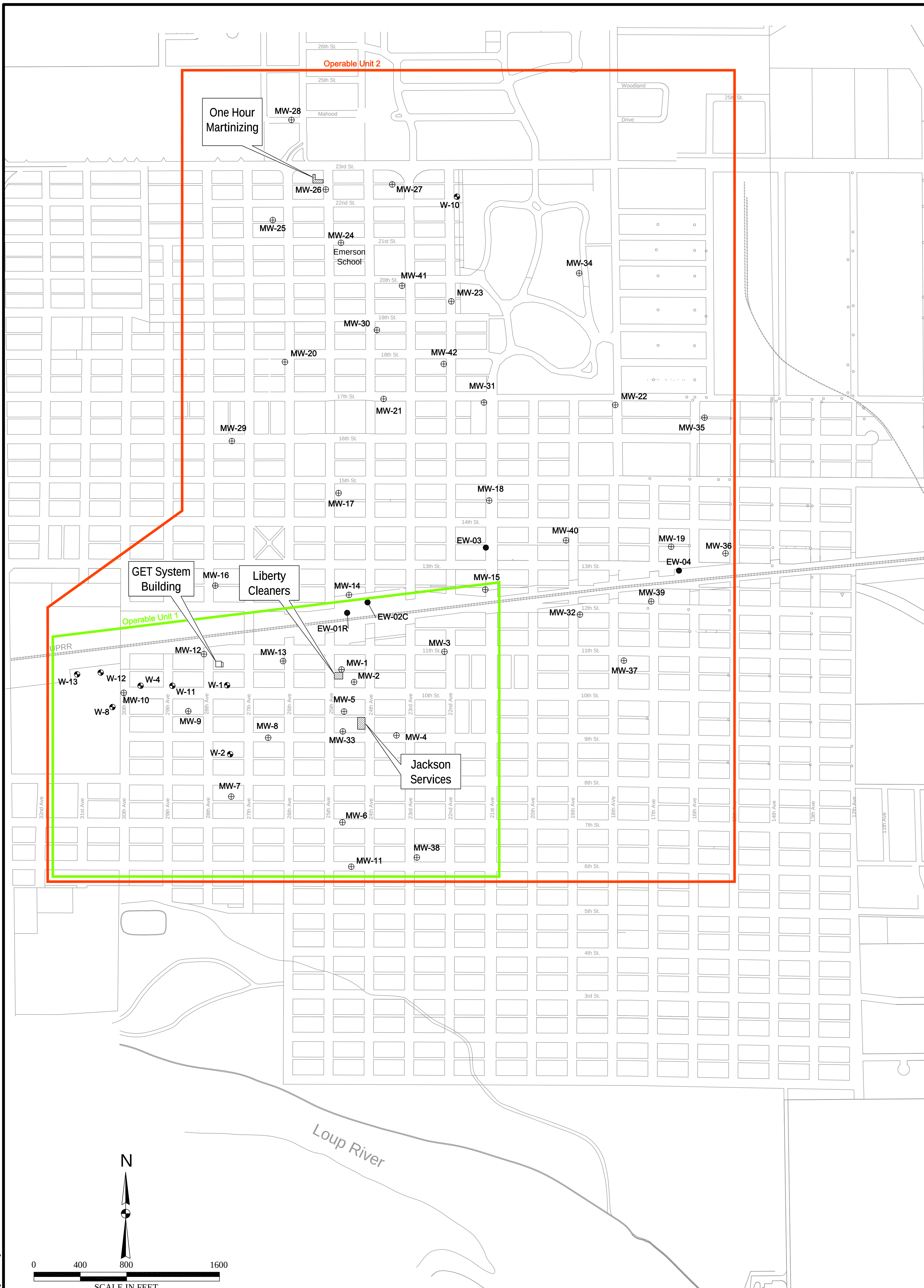


Figure 1.1

Site Location Map



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Task Order Number: 3370-002
Revised: 4/7/09 MMG

HGL HydroGeoLogic, Inc

CDM

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- Operable Unit 1 Limits
- Operable Unit 2 Limits
- Source Area

Figure 1.2

Site Map

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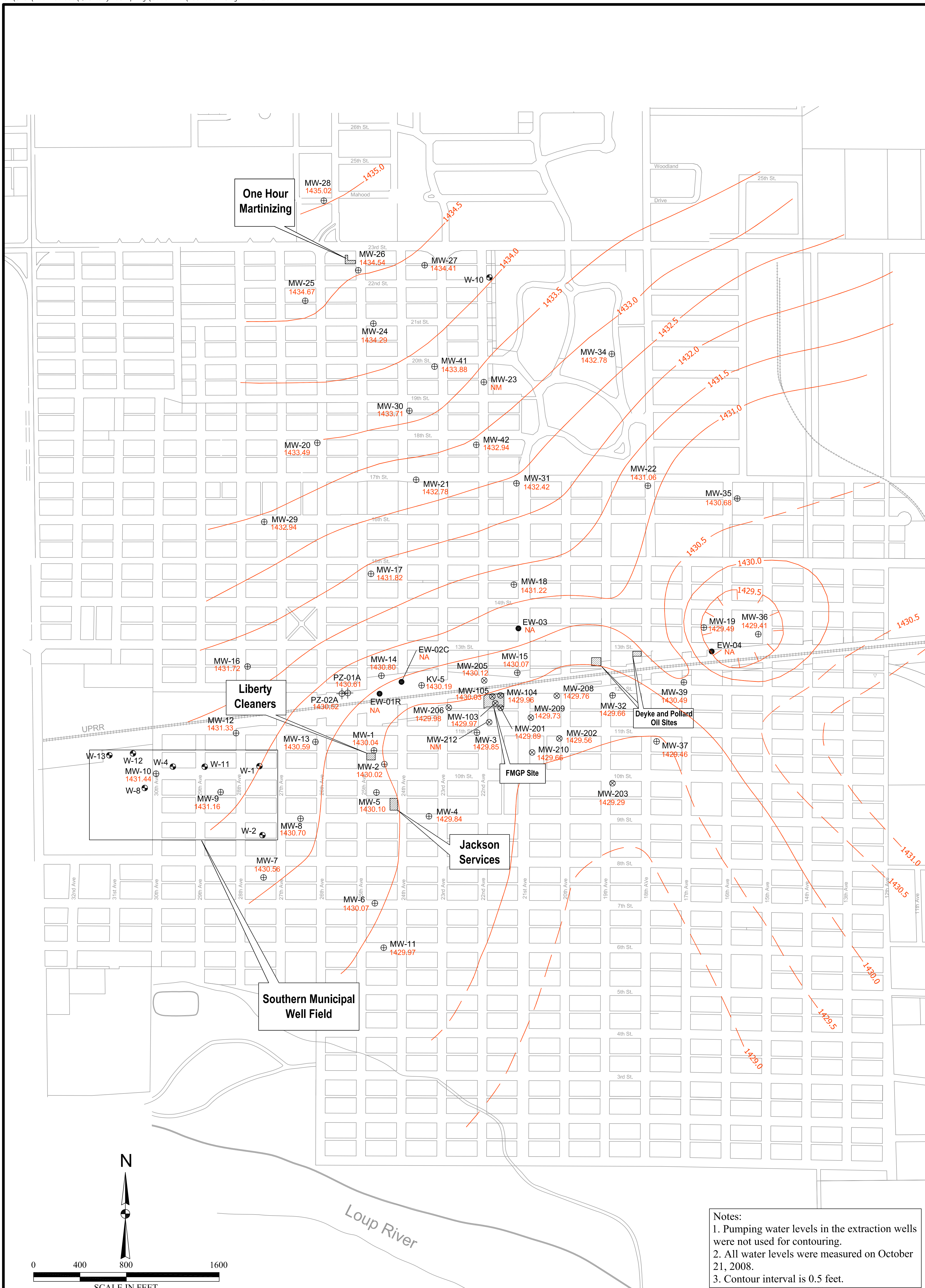


Notes:
1. Pumping water levels in the extraction wells were not used for contouring.
2. All water levels were measured on October 21, 2008.
3. Contour interval is 0.5 feet.

Filename: Y:\...\QuarterlySampling\2008-10\AseriesGW.dwg
Task Order Number: 3370-002
Revised: 1/23/09 KBR

HGL HydroGeoLogic, Inc CDM

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Piezometer Location
- Potential Source Areas
- 1428.62 Groundwater Level at A-Level Wells (feet amsl)
- NM Not Measured
- NA Not Applicable
- — — Estimated

Figure 1

"A" Level Wells Potentiometric Surface Shallow Aquifer October 2008

Notes:
1. Pumping water levels in the extraction wells were not used for contouring.
2. All water levels were measured on October 21, 2008.
3. Contour interval is 0.5 feet.
*MW-23B and MW-31B are screened in Middle Aquifer.

Filename: Y:\...\QuarterlySampling\2008-10\BseriesGW.dwg
Task Order Number: 3370-002
Revised: 1/23/09 KBR

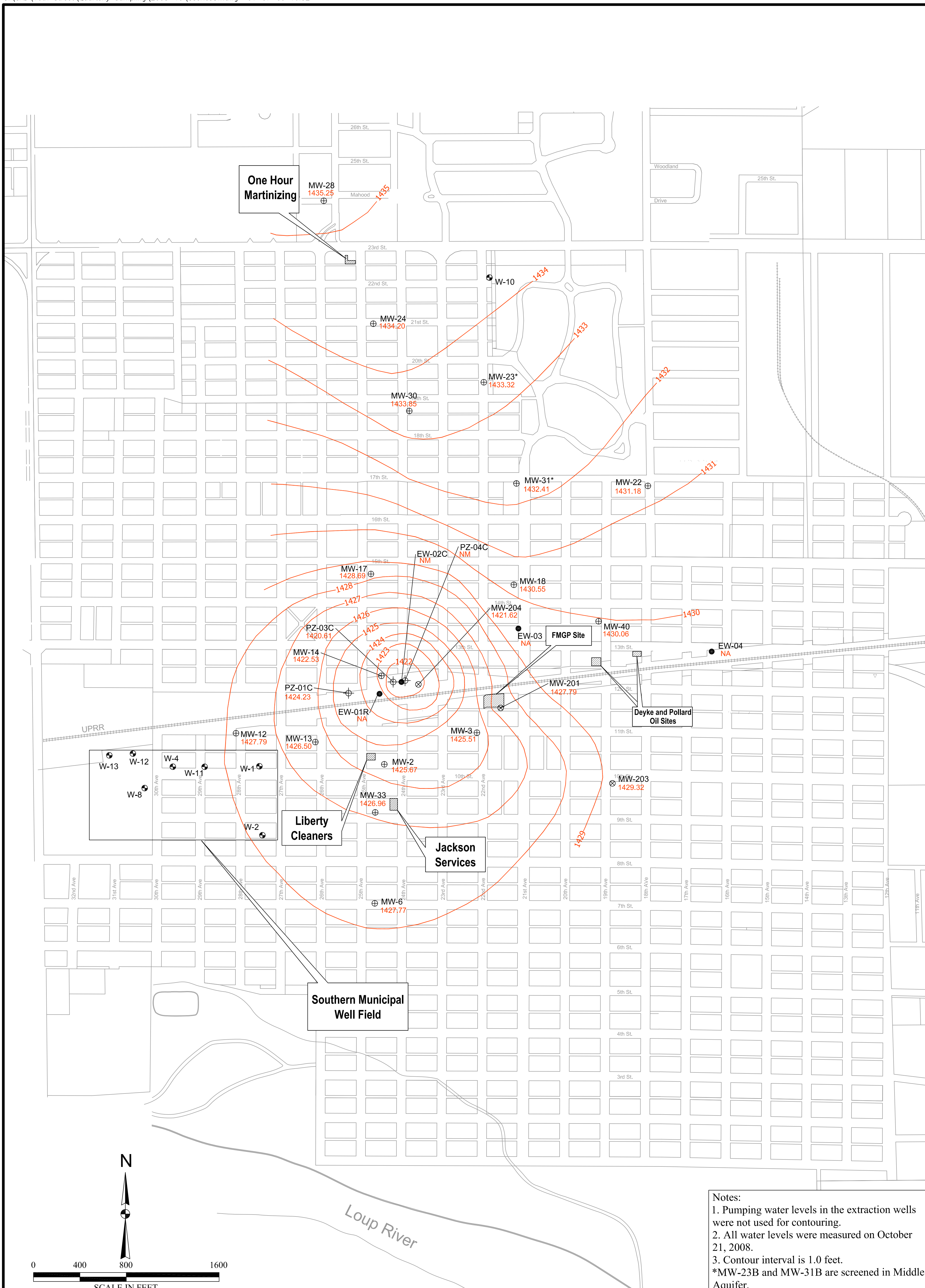
HGL HydroGeoLogic, Inc
CDM

Legend

⊕ (filled quadrants)	Municipal Well Location
⊕	Monitoring Well Nests
●	Extraction Well Location
⊗	FMGP Monitoring Well Location
(hatched)	Potential Source Areas
1428.62	Groundwater Level at B-Level Wells (feet amsl)*
NA	Not Applicable
NM	Not Measured

Figure 2

"B" Level Wells Potentiometric Surface Shallow Aquifer October 2008



Notes:
1. Pumping water levels in the extraction wells were not used for contouring.
2. All water levels were measured on October 21, 2008.
3. Contour interval is 1.0 feet.
*MW-23B and MW-31B are screened in Middle Aquifer.

Filename: Y:\...\QuarterlySampling\2008-10\CseriesGW.dwg
Task Order Number: 3370-002
Revised: 1/07/09 MMG

HGL HydroGeoLogic, Inc
CDM

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Piezometer
- Potential Source Areas
- 1428.62 Groundwater Level at C-Level Wells (feet amsl)
- NM Not Measured
- NA Not Applicable

Figure 3

"C" Level Wells Potentiometric Surface Middle Aquifer October 2008

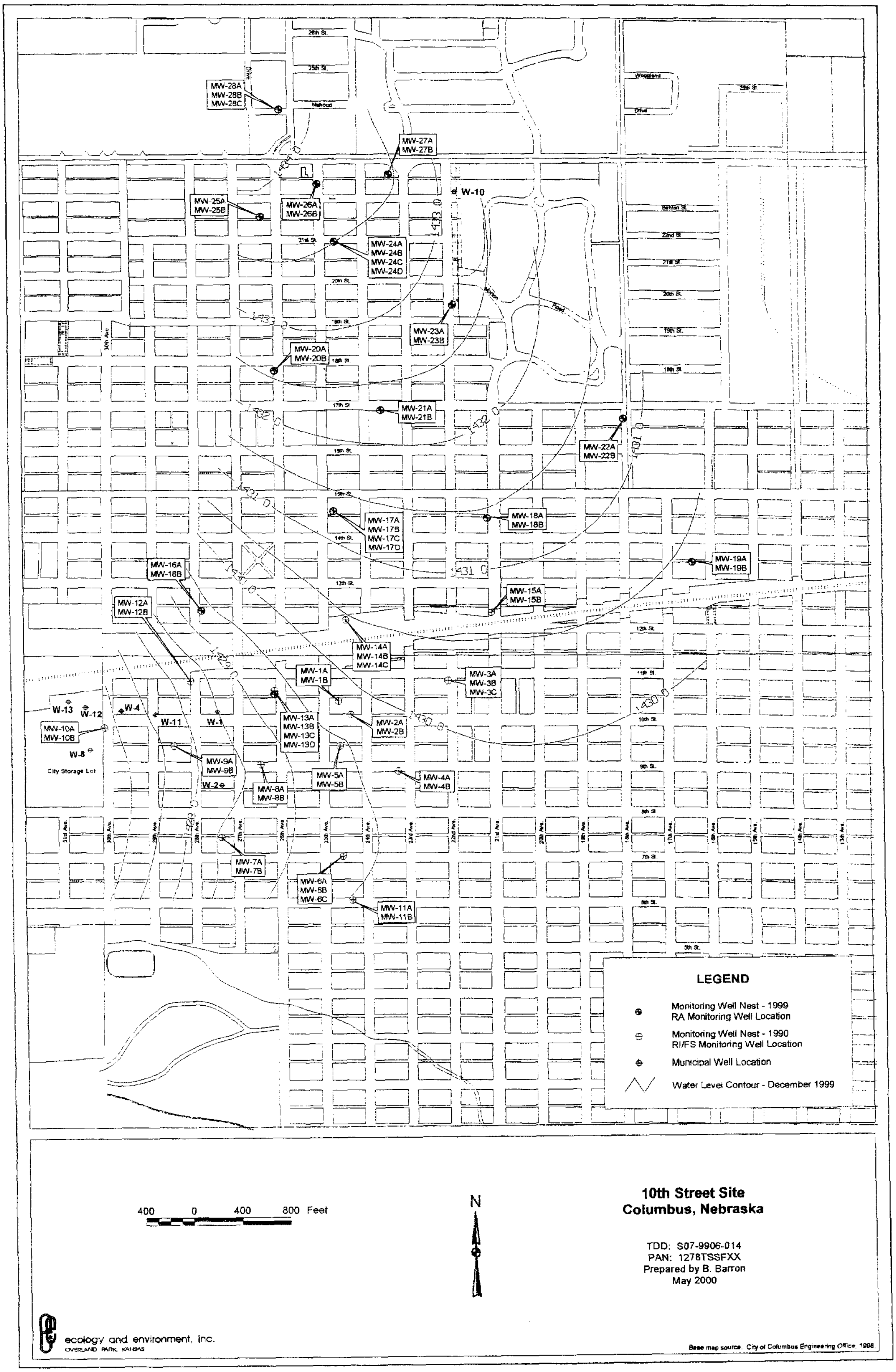


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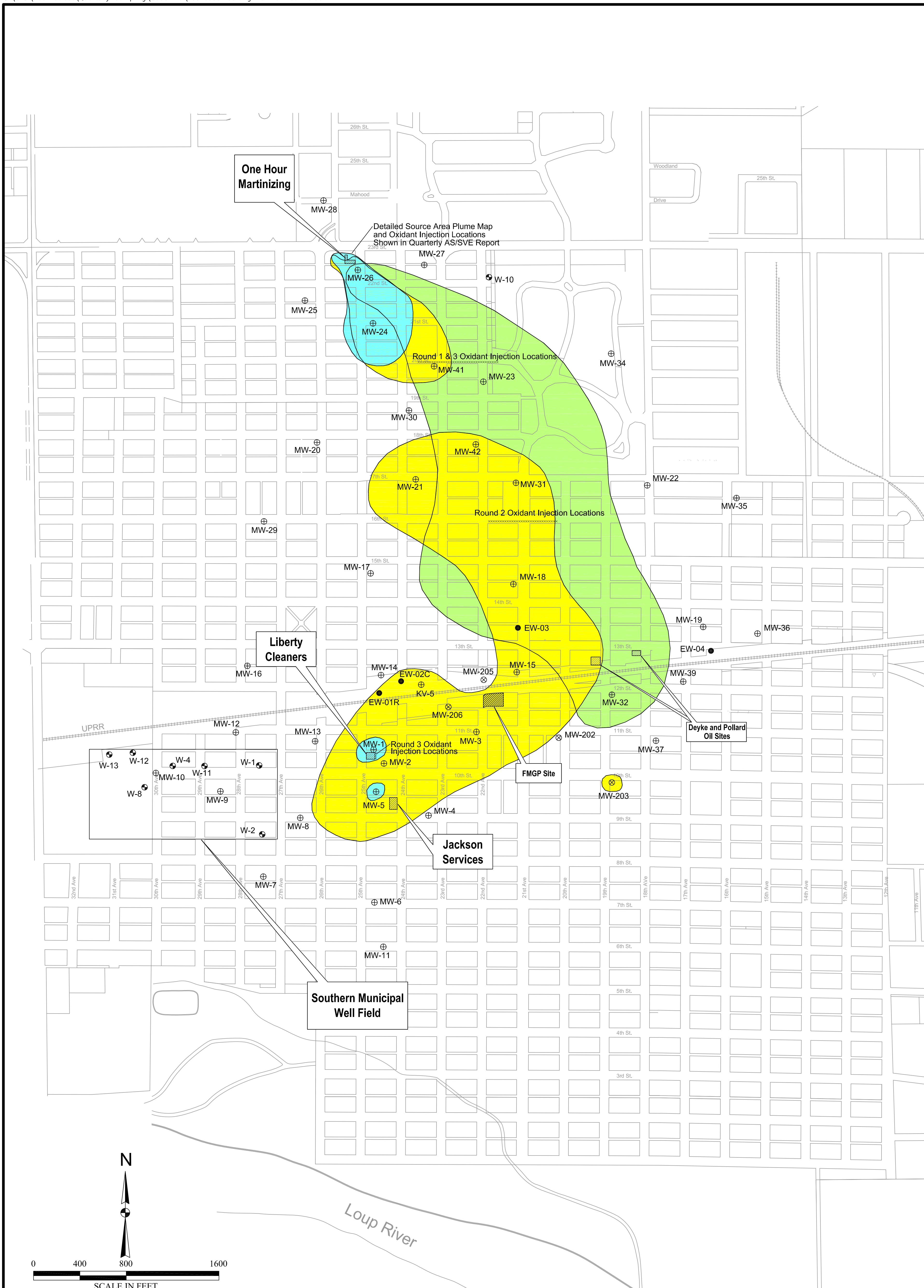
Figure 2-7: Water Level Elevation Contour Map - A-Series Monitoring Wells (December 1999)



Filename: Y:\...\2008-10\AseriesCombo.dwg
Task Order Number: 3370-002
Revised: 1/07/09 MMG

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Potential Source Areas

TCE > 5 ug/L

PCE > 5 ug/L

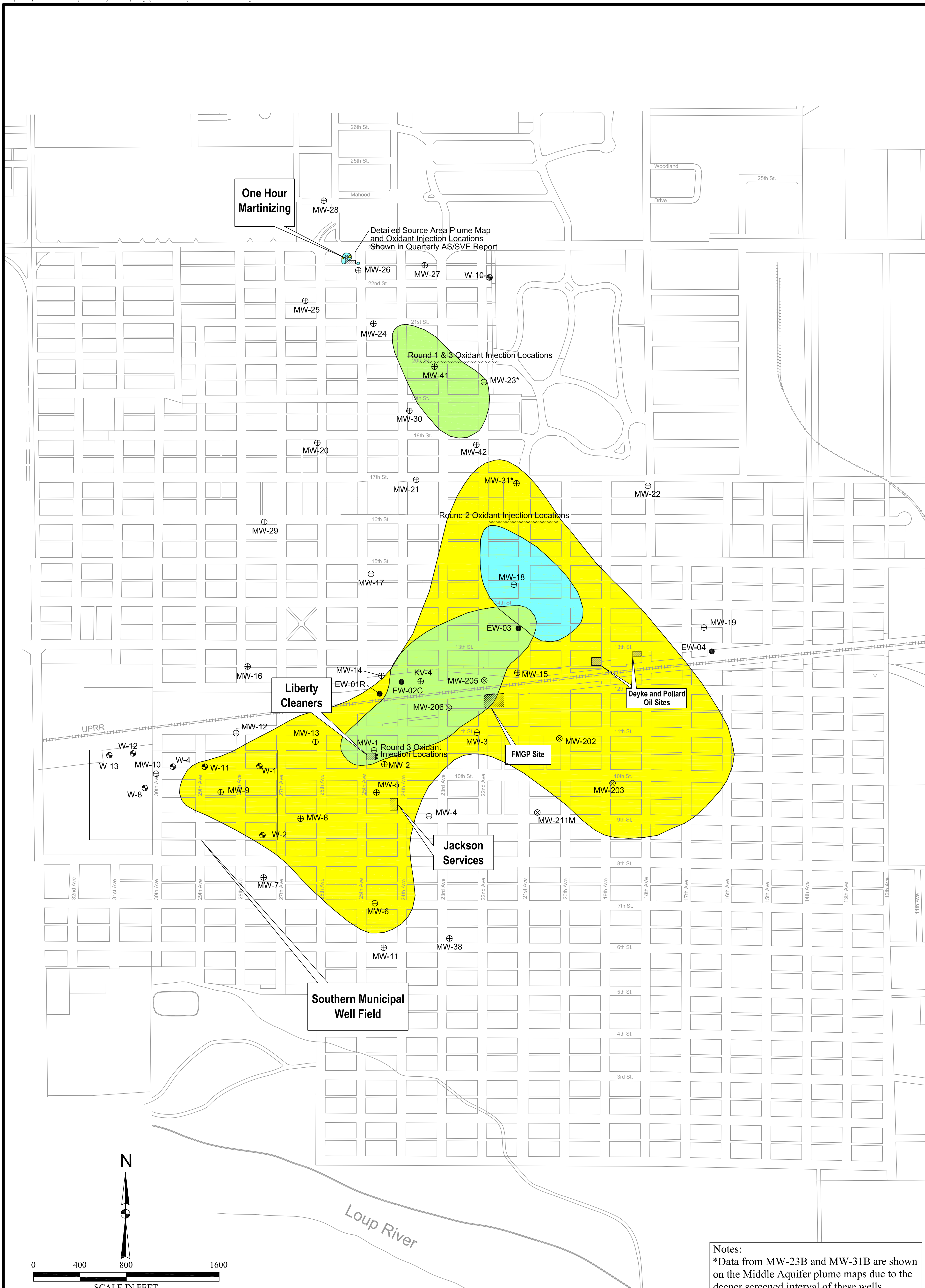
cis-1,2-DCE > 70 ug/L

HGL HydroGeoLogic, Inc

CDM

Figure 7

"A" Level Wells
Combined Contaminant Plume
Shallow Aquifer
October 2008



Notes:
*Data from MW-23B and MW-31B are shown on the Middle Aquifer plume maps due to the deeper screened interval of these wells.

Filename: Y:\...\2008-10\BseriesCombo.dwg
Task Order Number: 3370-002
Revised: 1/07/09 MMG

HGL HydroGeoLogic, Inc CDM

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Potential Source Areas

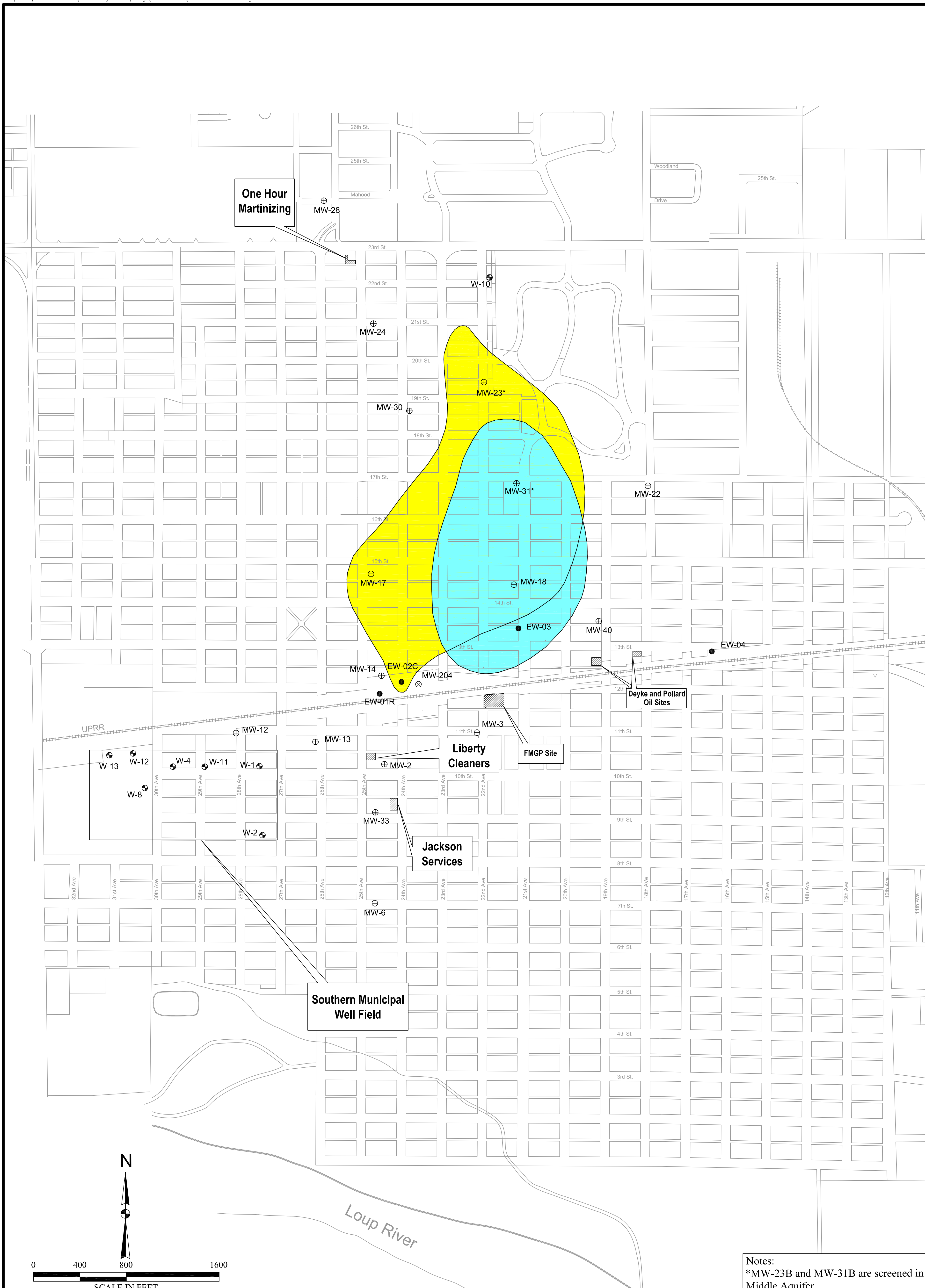
TCE > 5 ug/L

PCE > 5 ug/L

cis-1,2-DCE > 70 ug/L

Figure 11

"B" Level Wells
Combined Contaminant Plume
Shallow Aquifer
October 2008



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Task Order Number: 3370-002
Revised: 1/07/09 MMG

HGL HydroGeoLogic, Inc

CDM

Legend

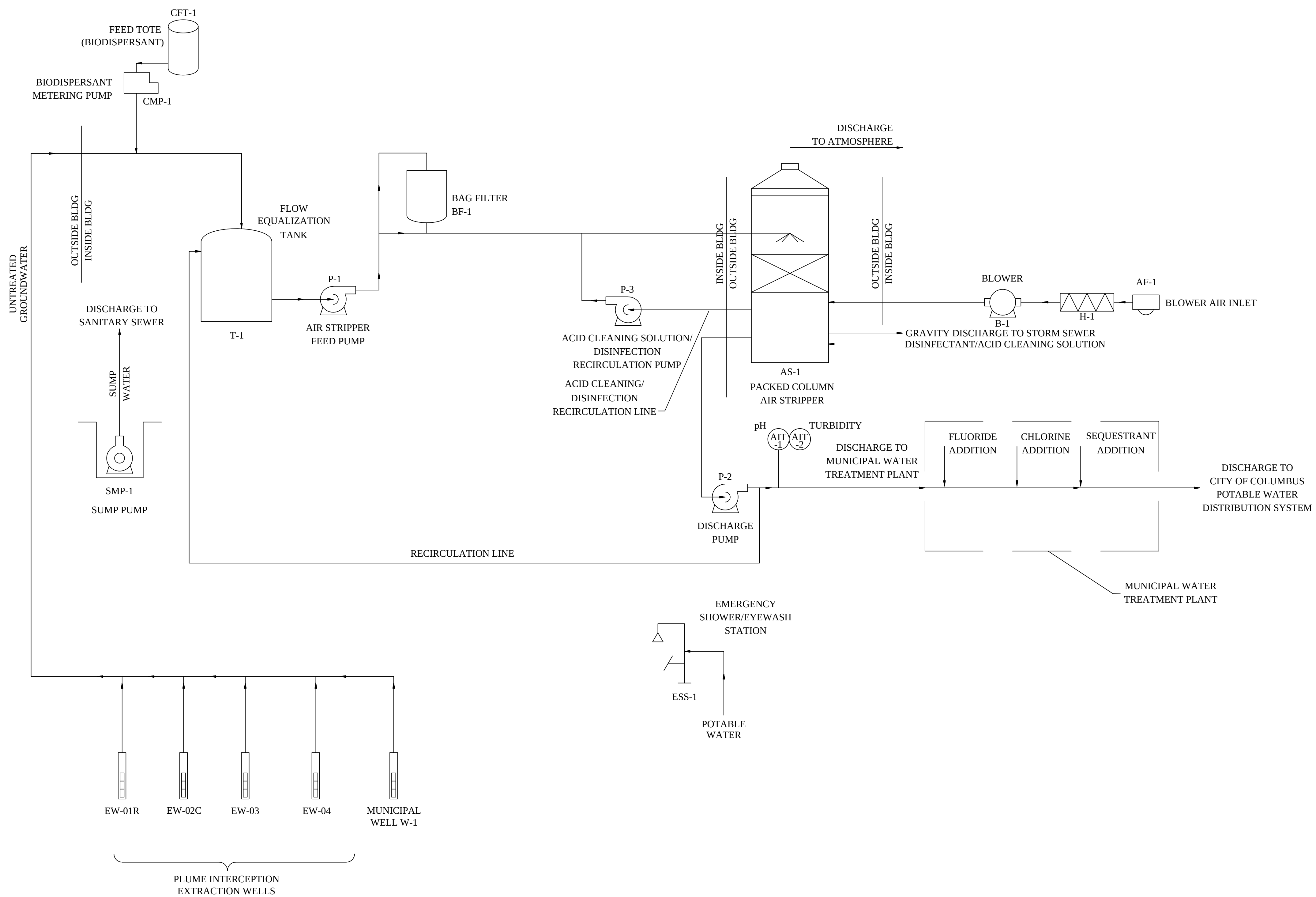
- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Potential Source Areas

TCE > 5 ug/L

PCE > 5 ug/L

Figure 14

**"C" Level Wells
Combined Contaminant Plume
Middle Aquifer
October 2008**



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2008 GET System Annual Performance Summary Report
10th Street OU2 Site, Columbus, Nebraska

Figure 1.5
GET System Process Flow Diagram

U.S. EPA
Region 7

Legend

AF-1	BLOWER AIR FILTER INLET
AIT-1	pH ANALYSIS
AIT-2	TURBIDITY ANALYSIS
AS-1	AIR STRIPPER
B-1	AIR STRIPPER BLOWER
BF-1	BAG FILTER
CFT-1	CHEMICAL FEED TOTE
CMP-1	CHEMCIAL METERING PUMP
ESS-1	EMERGENCY SHOWER/EYEWASH STATION
EW-01R	UNCONFINED AQUIFER EXTRACTION WELL
EW-02C	CONFINED AQUIFER EXTRACTION WELL
EW-03	UNCONFINED AQUIFER EXTRACTION WELL
EW-04	UNCONFINED AQUIFER EXTRACTION WELL
H-1	DUCT HEATER
P-1	TRANSFER PUMP
P-2	EFFLUENT DISCHARGE PUMP
P-3	DISINFECTION RECIRCULATION PUMP
SMP-1	TREATMENT BUILDING SUMP PUMP
T-1	FLOW EQUALIZATION TANK
W-1	MUNICPAL WELL W-1

N

0 12.5 25 50
SCALE IN FEET

Filename: Y:\CAD\Tenth\GETS-PSR-2008\ProcessFlowDia_Fig1-5.dwg
Task Order Number: 3370-002
Revised: 4/7/09 MMG

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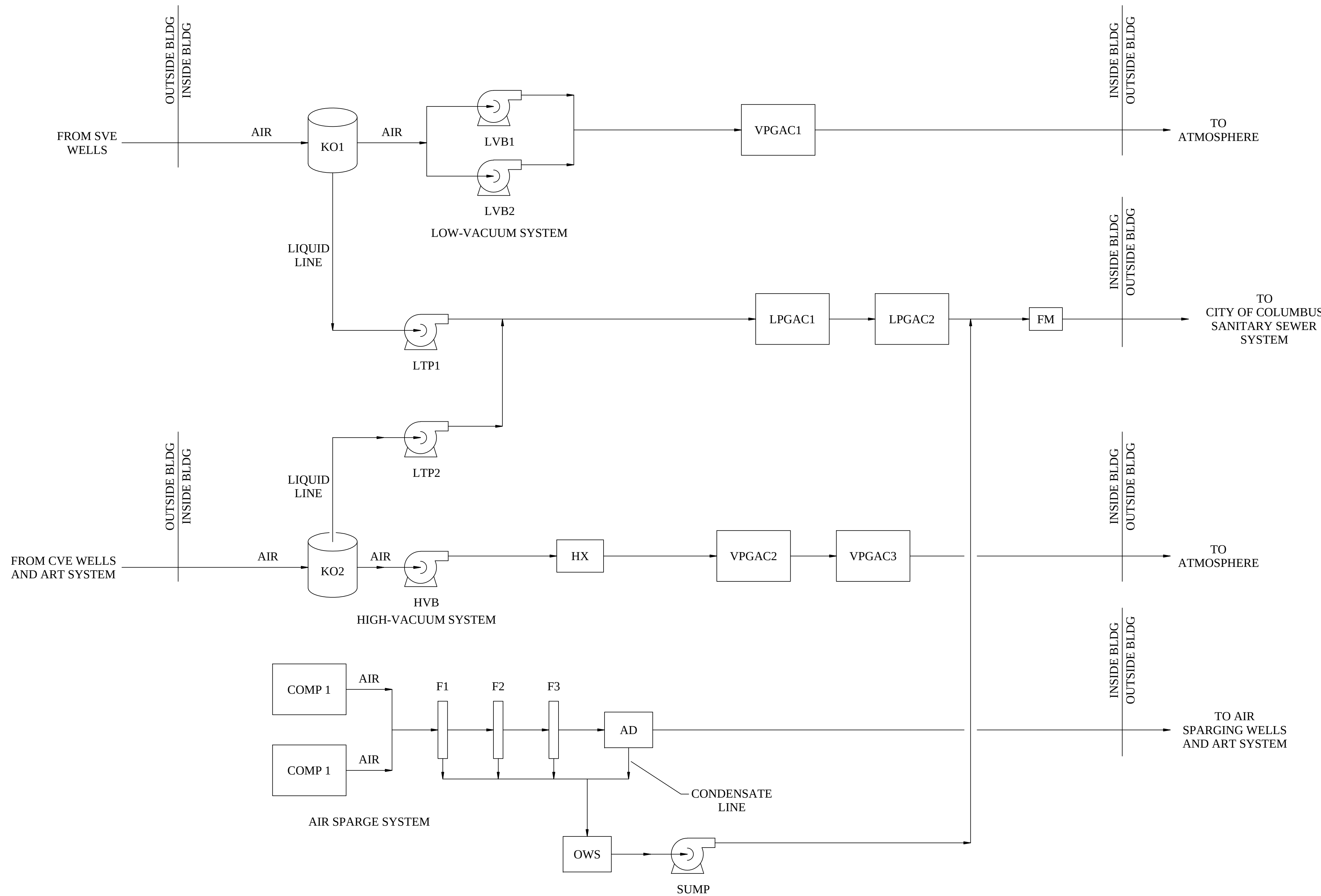
CDM

2008 AS/SVE System Performance Summary Report
10th Street OU2 Site, Columbus, Nebraska

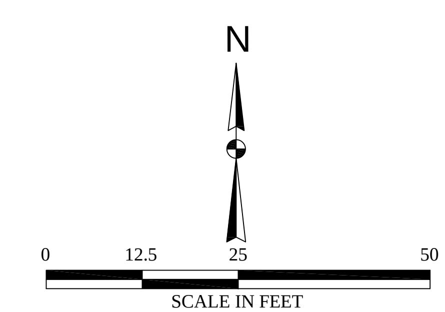
Figure 1.3
AS/SVE Process Flow Diagram

U.S. EPA
Region 7



Legend

AD	AIR DRYER
ART	ACCELERATED REMEDIATION TECHNOLOGIES INTEGRATED REMEDIATION SYSTEM
COMP	AIR COMPRESSOR
CVE	CLAY VAPOR EXTRACTION
F	OIL FILTER
FM	FLOW METER
HVB	HIGH VACUUM BLOWER
HX	HEAT EXCHANGER
KO	KNOCKOUT TANK
LPGAC	LIQUID PHASE GRANULAR ACTIVATED CARBON TANK
LTP	LIQUID TRANSFER PUMP
LVB	LOW VACUUM BLOWER
OWS	OIL WATER SEPARATOR
SUMP	SUBMERSIBLE PUMP
SVE	SAND VAPOR EXTRACTION
VPGAC	VAPOR PHASE GRANULAR ACTIVATED CARBON TANK



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Task Order Number: 3370-002
Revised: 3/27/09 MMG

HGL HydroGeoLogic, Inc
CDM

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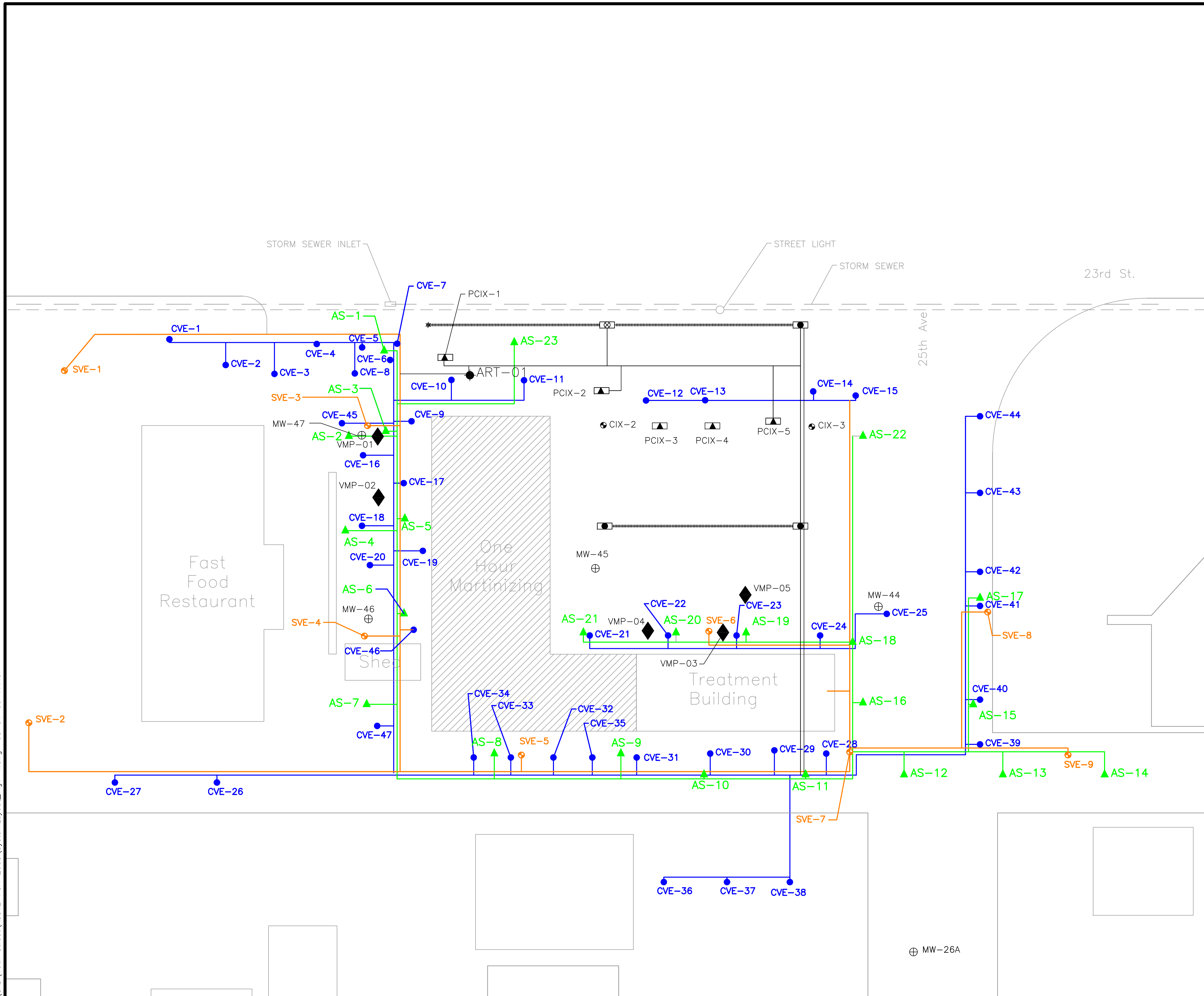
2008 AS/SVE System Performance Summary Report
10th Street OU2 Site, Columbus, Nebraska

Figure 1.4
OHM Source Area Site Layout

U.S. EPA
Region 7



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Legend

- ⊕ Monitoring well (MW)
- Sand Vapor Extraction (SVE) well (~20' Deep)
- Pilot Combined Injection and Extraction (PCIX) well
- Accelerated Remediation Technologies (ART) Integrated Remediation System well
- Clay Vapor Extraction (CVE) well (~6' Deep)
- Air Sparge (AS) well (~70' Deep)
- HVE Horizontal Vapor Extraction well
- CIX Combined Injection and Extraction well
- VMP-01 Vapor Monitoring Point (VMP)

Note:
1. At each location 2 soil vapor monitoring points were installed. One vapor monitoring point is screened at 6 feet bgs and the other at 12 feet bgs.

Filename: Y:\CAD\Tenth\ASSVE-PSR-2008-SystemLayout_Fig1-4.dwg
Task Order Number: 3370-002
Revised: 3/27/09 MMG

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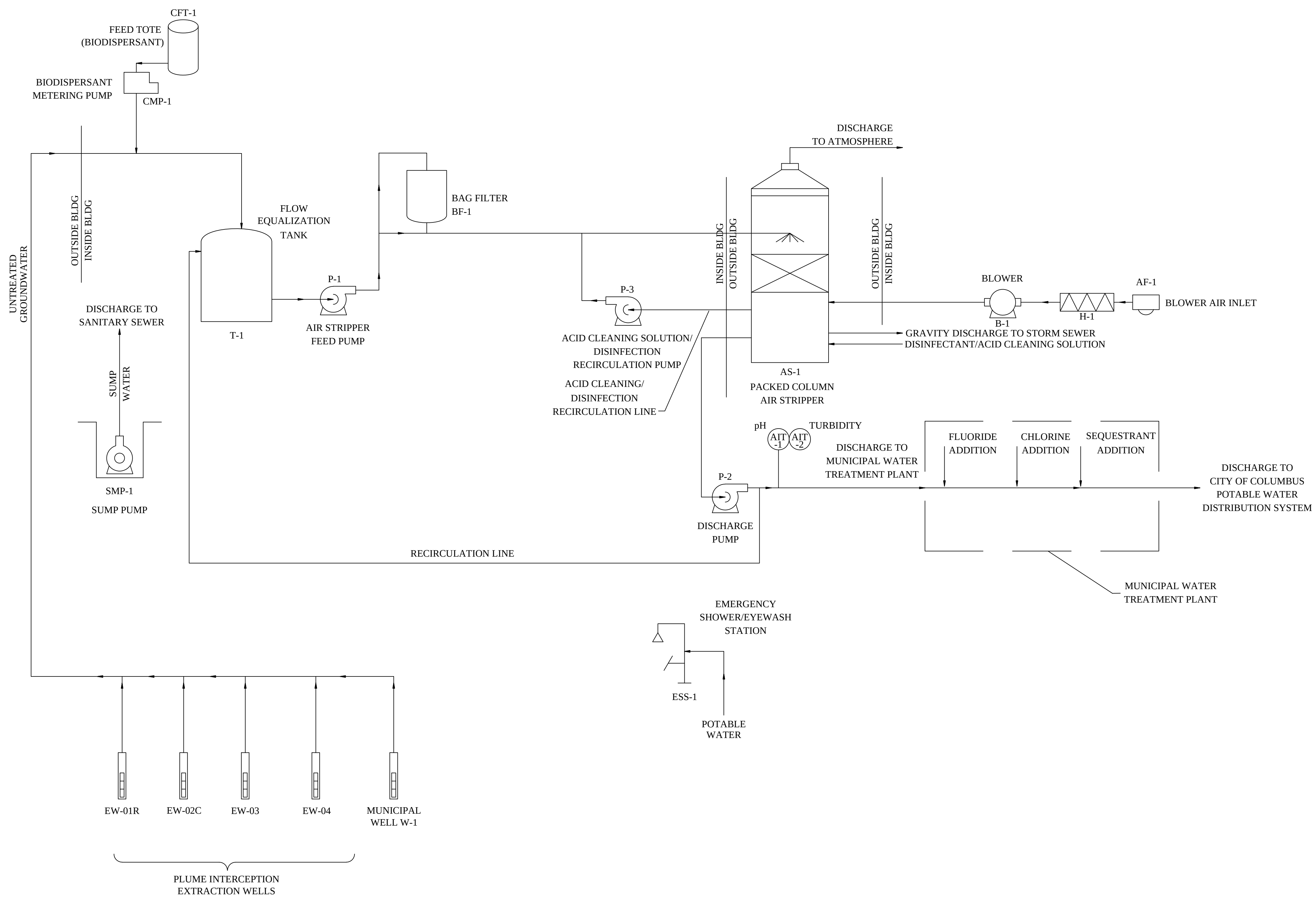
2008 GET System Annual Performance Summary Report
10th Street OU2 Site, Columbus, Nebraska

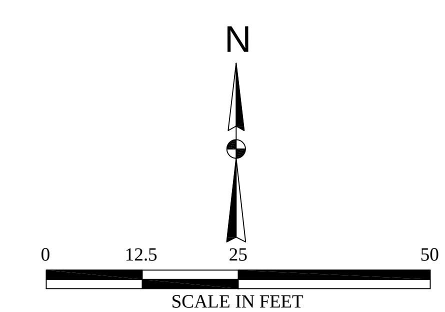
Figure 1.5
GET System Process Flow Diagram

U.S. EPA
Region 7



Legend

AF-1	BLOWER AIR FILTER INLET
AIT-1	pH ANALYSIS
AIT-2	TURBIDITY ANALYSIS
AS-1	AIR STRIPPER
B-1	AIR STRIPPER BLOWER
BF-1	BAG FILTER
CFT-1	CHEMICAL FEED TOTE
CMP-1	CHEMCIAL METERING PUMP
ESS-1	EMERGENCY SHOWER/EYEWASH STATION
EW-01R	UNCONFINED AQUIFER EXTRACTION WELL
EW-02C	CONFINED AQUIFER EXTRACTION WELL
EW-03	UNCONFINED AQUIFER EXTRACTION WELL
EW-04	UNCONFINED AQUIFER EXTRACTION WELL
H-1	DUCT HEATER
P-1	TRANSFER PUMP
P-2	EFFLUENT DISCHARGE PUMP
P-3	DISINFECTION RECIRCULATION PUMP
SMP-1	TREATMENT BUILDING SUMP PUMP
T-1	FLOW EQUALIZATION TANK
W-1	MUNICPAL WELL W-1



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Task Order Number: 3370-002
Revised: 4/7/09 MMG

HGL HydroGeoLogic, Inc

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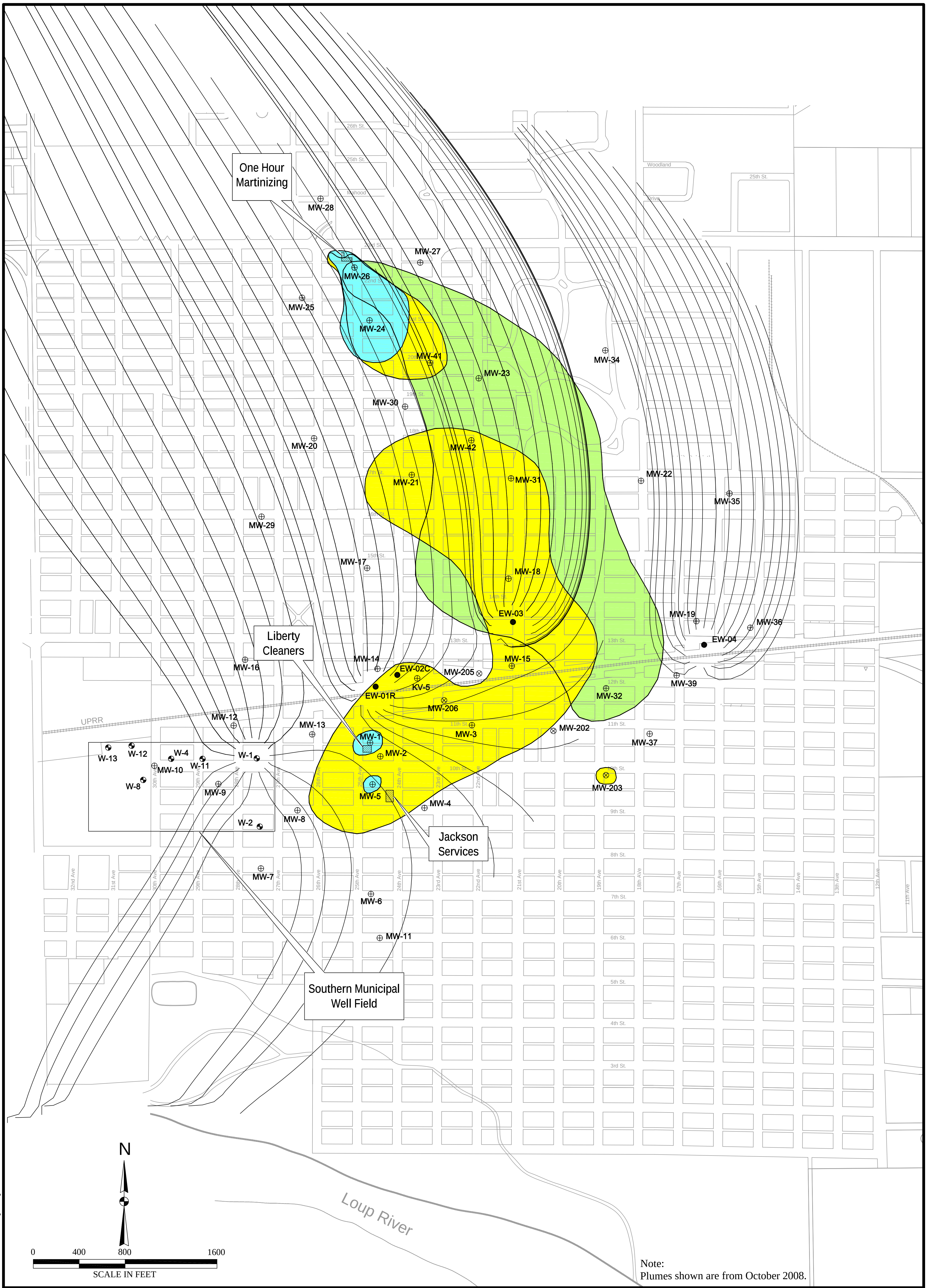

Filename: Y:\CAD\Tenth\AseriesCombo_Summer_Fig1.dwg
Task Order Number: 3370-002
Revised: 4/20/09 MMG

Legend

- Municipal Well Location
- Monitoring Well Nests
- Extraction Well Location
- FMGP Monitoring Well Location
- Source Area
- Particle Tracks

TCE > 5 ug/L

PCE > 5 ug/L

cis-1,2-DCE > 70 ug/L

Figure 1

Capture Zone 'A' Level Remediation Pumping (Summer)

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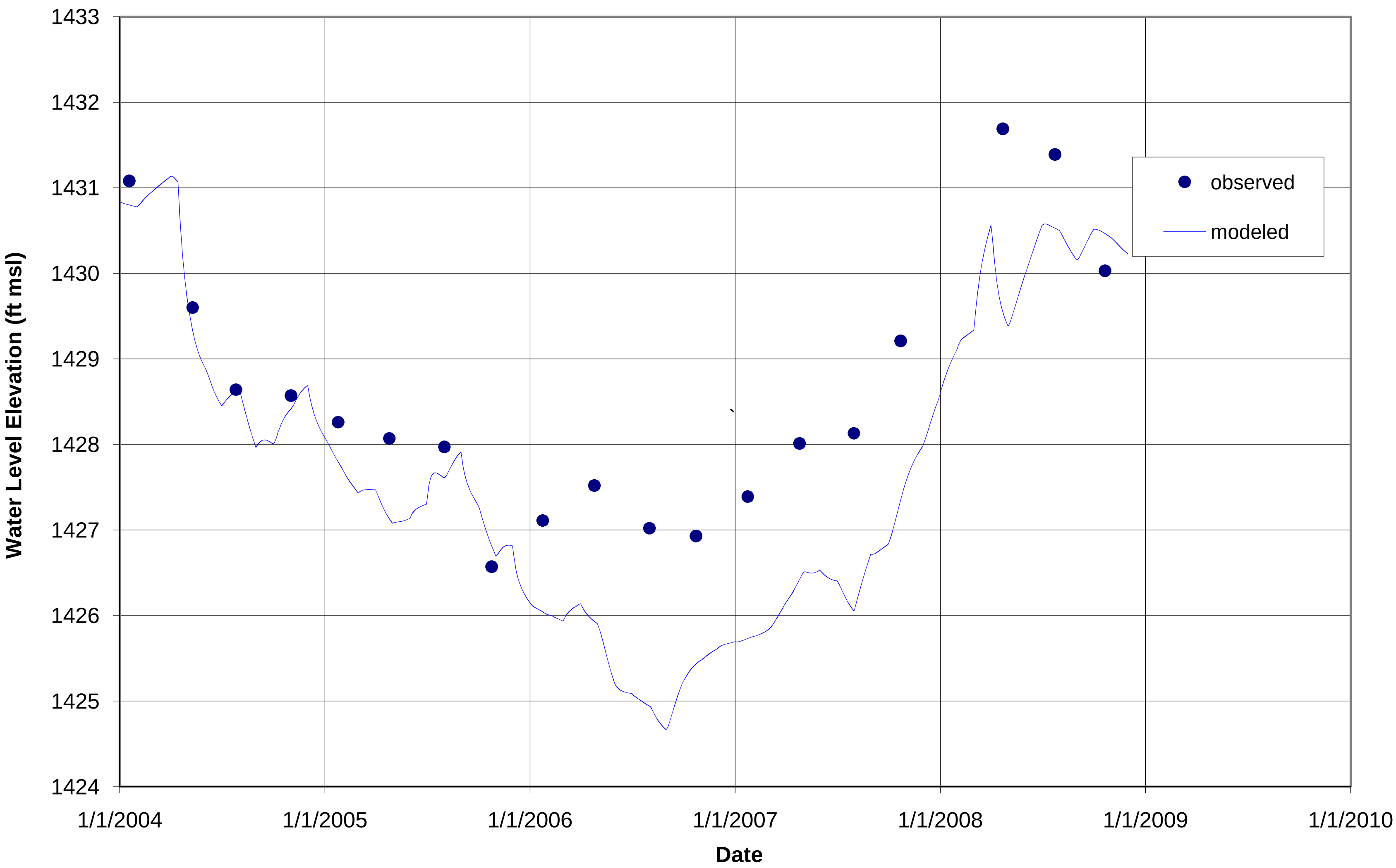
Modeled and Observed Water Level Data   Well # 2 MW-01B



ATTACHMENT B

Assumptions for Estimating the Energy Usage and Greenhouse Gas Emissions for the Additional Extraction Well Option

Project Assumptions:

- New 10-inch extraction well installed approximately 2,000 feet from the treatment plant
- Extraction well has similar design to that of EW-4 (including a 10-inch steel casing)
- Extraction well replaces capacity pumped from EW-4
- Activities include burying 6-inch HDPE SDR 11 pipe in to a depth of 4 feet in a 2-foot wide, 2,000-foot long trench
- Burying 2-inch HDPE conduit and electrical cable
- Local oversight can be provided to minimize travel.

Footprint Assumptions:

- A trenching production rate (including inefficiencies) of approximately 20 cubic yards per hour for trenching and similar time frames for backfilling and compacting, approximately 90 hours of equipment operation (three machines each operating for 30 hours) would be required to dig, bed, backfill and compact the trench. Assuming an average equipment horsepower of 100 HP, average operation at rated 70% load, and a brake specific fuel consumption at this load of 0.05 gallons per HP-hr, the diesel fuel usage would be approximately 315 gallons.
- Drilling a 125-foot deep 10-inch well would likely take two days and require approximately 24 gallons of diesel.
- Additional diesel usage (not quantified) would be required for asphalt cutting and surface repair.
- Native material is suitable for bedding and backfill
- 6-inch SDR 11 HDPE is approximately 5 pounds per foot. For 2,000 feet, the total weight is 10,000 pounds.
- Equivalent 2-inch SDR 11 HDPE (for conduit) is approximately 0.6 pounds per foot. For 2,000 feet, the total weight is 1,200 pounds.
- For the well casing, 10-inch steel casing is approximately 40 pounds per foot. For 125 feet, the total weight is 5,000 pounds.
- Equivalent carbon dioxide emission factor for HDPE is approximately 2 pounds of carbon dioxide per pound of HDPE (based on values derived from www.nrel.gov/lci for electricity, natural gas, diesel, and other fuels in developing the raw materials and then manufacturing the HDPE at the plant)
- Equivalent carbon dioxide emission factor of for steel is approximately 2 pounds of carbon dioxide per pound of steel (based on values derived from www.nrel.gov/lci for electricity, natural gas, diesel, and other fuels in developing the raw materials and then manufacturing the HDPE at the plant)
- An additional 20% "mark-up" on the diesel and materials accounts for the other activities and materials not specifically mentioned, including asphalt, copper wire, well vault, pump, instrumentation, etc.

- Operating the well would likely require approximately 80,000 kWh of electricity per year, but would have a minimal carbon footprint given that the electricity is provided from hydroelectric power.

Assumptions for Estimating the Energy Usage and Greenhouse Gas Emissions for the Enhanced Bioremediation Option

Project Assumptions:

- Use direct-push injections of emulsified vegetable oil (EVO) to establish a biobarrier that is 1,000 feet wide, 60 feet deep, and 30 feet long.
- Maintain the biobarrier for a period of 5 years to address the highest concentrations
- Approximately 300 injection locations (per year) would be required to evenly distribute the EVO, and parameters for ISCO injection process (for injections, transportation, and material delivery) apply to the bioremediation injections
- EVO requirements is based on a soil adsorptive capacity of 0.0005 pounds of EVO per pound of soil
- Soil is approximately 110 pounds per cubic foot
- Calculated EVO requirement is approximately 100,000 pounds per year for 5 years (500,000 pounds total)
- The carbon dioxide and methane produced from the degradation of the EVO is either negligible or non-additional in that it will remain in the subsurface for a long period of time and is derived from organic matter that would have decayed anyway.
- Bioaugmentation of microbes would be required for the first injection event only

Footprint Assumptions:

- The emission factor for EVO product is not readily available, but the LCA Food database www.lcafood.dk suggests approximately 3.5 pounds of carbon dioxide equivalents per pound of product.
- Approximately 75 rig-days would be required for injections per year resulting in approximately 900 gallons of diesel per year for the injections.
- Approximately 600 gallons of diesel and 800 gallons of gasoline would be required for transportation (i.e., usages for ISCO injections scaled by 75 days for bioremediation divided by 135 days for ISCO)
- Approximately 575 gallons of diesel per year would be required for delivering 50 tons of product from a distance of 500 miles per year (i.e., usages for ISCO injections scaled by 75 days for bioremediation divided by 135 days for ISCO)
- A 10% correction factor applies to account for microbe injections and additional monitoring that might be conducted for this approach that is not conducted for competing approaches.

Attachment B References

Climate Leader GHG Inventory EPA-430-K-08-004, May 2008

National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (www.nrel.gov/lci) maintained by Alliance for Sustainable Energy, LLC.

(EUROPA) European Reference Life Cycle Database (ELCD core database), version II compiled under contract on behalf of the European Commission - DG Joint Research Centre - Institute for Environment and Sustainability with technical and scientific support by JRC-IES from early 2008 to early 2009. (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm)

Footprint for vegetable oil obtained from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk

Derivation of Estimated Carbon Footprint for GAC

Information from Literature

Use of Adsorbents for the Removal of Pollutants from Wastewaters, by Gordon McKay, published by CRC Press, 1995, ISBN 0849369207

Table 8.1

Granular Carbon Regeneration Process Energy Requirements (15,000 kg/day Regeneration Rate)			
System	**Fuel, kJ/kg**	**Electricity, kWh/kg**	**Steam, kg/kg**
Electric infrared furnace	0	0.36	0
Multiple-hearth furnace	18,600	0.10	1.0
Rotary Kiln	23,300	0.07	1.0
Fluid bed furnace	11,700	0.11	0.8

1.2		Specific gravity of coal (www.engineeringtoolbox.com)
0.5		Specific gravity of GAC (Westates/Siemens)
0.7		Fraction of coal that is carbon (http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html)
0.27	lb CO2e/lb	Carbon footprint of extracting and delivering 1 lb of coal to a plant (EUROPA ELCD - Hard Coal)
14	lb CO2e	Carbon footprint of natural gas, including natural gas production (per therm) (NREL)
1.34	lb CO2e	Carbon footprint of electricity (per kWh) (EGRID, US Average)

Assumptions:

- Use fuel and electricity requirements for multiple hearth furnace to estimate energy required for regeneration

- Assume energy requirements for regeneration is the same as they are for initial activation

Calculations for Virgin Coal:

Carbon Footprint

2.4		Pounds of coal required to produce one pound of GAC
1.68		Pounds of that coal that is carbon
1		Pounds of carbon in one pound of GAC
0.68		Pounds of carbon from coal emitted to atmosphere
2.5	lb CO2e	Pounds of carbon dioxide emitted for burning off coal (measured as pounds of CO2)
0.65	lb CO2e	Pounds of CO2e emitted during coal extraction
8,920	Btus	Fuel required to activate one pound of GAC (2.2 pounds per kg and 1.055 kJ/btu)
1.2	lb CO2e	Pounds of CO2e emitted for combustion of natural gas during activation (100,000 btus per therm)
0.045	kWh	Electricity required to activate one pound of GAC (2.2 pounds per kg)
0.061	lb CO2e	Pounds of CO2e emitted for electricity generation
4.5	lb CO2e	Total CO2e emitted for carbon activation

Energy Footprint

2.4		Pounds of coal required to produce one pound of GAC
1440	Btus	Energy required during coal extraction
8,920	Btus	Fuel required to activate one pound of GAC (2.2 pounds per kg and 1.055 kJ/btu)
0.045	kWh	Electricity required to activate one pound of GAC
470	Btus	Energy required to generate that electricity (3,413 btus/kWh and 33% thermal efficiency)
10,800	Btus	Total energy required for virgin carbon activation

Calculations for Regenerated Coal

Footprint per Regeneration Cycle (including 10% virgin GAC to make-up for loss)

Energy	CO2e
8,920 + 10% x 10,800 = 10,000	1.2 + 0.061 + 10% x 4.5 = 1.7

Footprints over 10 Regeneration Cycles

Cycle	Energy	CO2e
1	10,800	4.5
2	10,400	3.1
3	10,300	2.6
4	10,200	2.4
5	10,200	2.2
6	10,100	2.1
7	10,100	2.1
8	10,100	2
9	10,100	2
10	10,100	1.9