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June – August 2000 Groundwater And Soil Gas Data Analysis, Distler Brickyard Superfund Site, Hardin County, Kentucky

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Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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Charles J. Taylor[2]

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1. Bechtel BWXT Idaho LLC, Idaho Falls, Idaho
2. U.S. Geological Survey, Water Resources Division, Louisville, Kentucky

Idaho National Engineering and Environmental Laboratory
Environmental Remediation Technologies Department
Idaho Falls, Idaho 83415

Prepared for the
U.S. EPA National Exposure Research Laboratory, Technology Support Center,
Characterization and Monitoring Branch
and for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
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Approved by

Kenneth S. Moor, Program Manager	Date
Lance N. Peterson, Project Manager	Date

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ABSTRACT

This report describes the results of groundwater and soil gas sampling conducted at the Distler Brickyard Site, Hardin County, Kentucky, June-August, 2000. The purpose of the sampling activities was to address remaining data gaps regarding the feasibility of monitored natural attenuation (MNA) for remediation of chloroethene/ane contamination. Specifically, data gaps fall into four categories: 1) effect of seasonal recharge on contaminant concentrations, 2) geochemical conditions in the Fine Grained Alluvium (FGA), 3) conditions along the flowpath between Wells GW-11 and MW-3, and 4) the extent of aerobic degradation in the Coarse Grained Alluvium (CGA).

A data collection strategy composed of both groundwater sampling and passive soil vapor sampling devices (Gore-Sorbers⊇) was used. The Gore-Sorber⊇ technology was used to collect data from the FGA, which because of its low hydraulic conductivity and variable saturation makes collection of groundwater samples problematic. Gore-Sorbers were deployed in 15 wells, most of them being in the FGA, and groundwater samples were collected in 17 wells, which were mostly in the CGA. Both sampling methods were utilized in a subset of wells (7) in order to determine the general comparability of results obtained from each method.

Results indicate that water levels in both the FGA and CGA were higher in June-August 2000 than in October 1999, likely due to increased infiltration of precipitation through the FGA during the wetter months. Redox conditions in the FGA and downgradient CGA were iron-reducing, less reducing than in October-1999. In general, concentrations of chloroethenes/anes were higher in June-August 2000 than October 1999. Trichloroethene (TCE) was present at concentrations as high as 65 σg/L in the FGA and 19 σg/L in the CGA. This is substantially higher than the maximum concentration in October 1999 of 11 σg/L. The following conclusions were drawn from these data collection activities: 1) two potential contaminant source areas remain at the site, 2) redox conditions are less reducing than October 1999, 3) anaerobic reductive dechlorination (ARD) continues to take place in the FGA, and 4) seasonal fluctuations in recharge affect water levels, redox conditions, contaminant concentrations, and ARD reactions.

Possible final remedial response actions include 1) monitored natural attenuation, 2) monitored natural attenuation with physical source removal, or 3) monitored natural attenuation with source removal via enhanced ARD. All of these remedies will require the collection of additional data in three areas: 1) the nature and extent of the GW-3/UDBW-11 source area and the flux rate and fate of contaminants from it, 2) the magnitude and timing of recharge fluctuations, and 3) the local hydraulic gradient and groundwater flow directions. Each remedy may also have specific additional data collection requirements. This document will serve as the basis for the selection of the appropriate remedy by the state and federal regulators.

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ACRONYMS

ARD	anaerobic reductive dechlorination
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbons
CGA	coarse grained alluvium
DCA	dichloroethane
DCE	dichloroethene
EPA	Environmental Protection Agency
FGA	fine grained alluvium
ft MSL	feet above mean sea level
gpm	gallons per minute
MAH	monocyclic aromatic hydrocarbons
MCL	maximum contaminant level
MNA	monitored natural attenuation
PCE	tetrachloroethene
POM	polymeric organic materials
PTFE	polytetrafluoroethylene
RA	remedial action
SVOC	semi volatile organic compound
TCA	trichloroethane
TCE	trichloroethene
USGS	United States Geological Survey
VC	vinyl chloride
VOC	volatile organic compound

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1. INTRODUCTION

In October 1999 a groundwater sampling event was conducted to evaluate suspected intrinsic biodegradation of chlorinated ethenes and ethanes at the Distler Brickyard Site in order to determine whether monitored natural attenuation (via intrinsic degradation) could be a feasible remedial technology for existing contamination. The results indicated that a monitored natural attenuation remedy could be feasible however, additional data were required. For this reason, additional sampling was conducted. This report describes the data collection activities conducted at the Distler Brickyard Site during July-August, 2000, summarizes the results obtained from these activities, and identifies potential long-term remedies. This document will provide a basis for the selection of a potential remediation technology for the site.

1.1 Site Background

The Distler Brickyard Site is located on unconsolidated alluvial and glacial outwash deposits along the Ohio River in northern Hardin County, Kentucky (Figure 1-1). The alluvium consists of two hydrostratigraphic units: the upper Fine Grained Alluvium (FGA) and the underlying Coarse Grained Alluvium (CGA). The FGA is approximately 12-m (40-ft) thick and consists of silty clays with sand and peat lenses. The CGA is composed of coarse sand and gravel and is present in the western portion of the Site. Where present, it ranges from 0.4- to 6-m (1.5- to 20-ft) thick (de la Pena 1989, Duffey et al. 1983). The FGA/CGA are underlain by siltstone and limestone bedrock at a depth of 12- to 18-m (40- to-60 ft) below ground surface.

The 28-ha (70-acre) site is a former brick manufacturing plant that was used as a waste recycling and storage facility between 1976 and 1979. During waste storage and recycling activities, drums of waste were stored aboveground. For this reason, the sources of contamination at the Site were drums spilling or leaking onto the soil surface and subsequently infiltrating to the water table (approximately 25 to 30 ft). Groundwater sampling during 1983 through 1985 indicated that groundwater in the vicinity of Monitoring Well GW-11 was the most highly contaminated at the Site. Analysis of data collected through 1985 identified a contaminant plume with the source area located near GW-11 (Anderson and Bomberger 1986) (Figure 1-1). The contaminants of concern included chlorinated aliphatic hydrocarbons (CAHs) (trichloroethene [TCE] and 1,1,1-trichloroethane [1,1,1-TCA] and degradation products), monocyclic aromatic hydrocarbons (MAHs) (i.e., petroleum hydrocarbons), and ketones.

The U.S. Environmental Protection Agency (EPA) published a Record of Decision in 1986 specifying the following remedial action (RA) activities (EPA 1998):

- Excavation of contaminated soil
- Extraction and treatment of contaminated groundwater
- Operation and maintenance of a groundwater treatment system.

Excavation of 382 m^3 (500 yd^3) of contaminated soil from the GW-11 area was completed in October 1988, and construction of the groundwater treatment system began in 1989 (OHM 1990). There

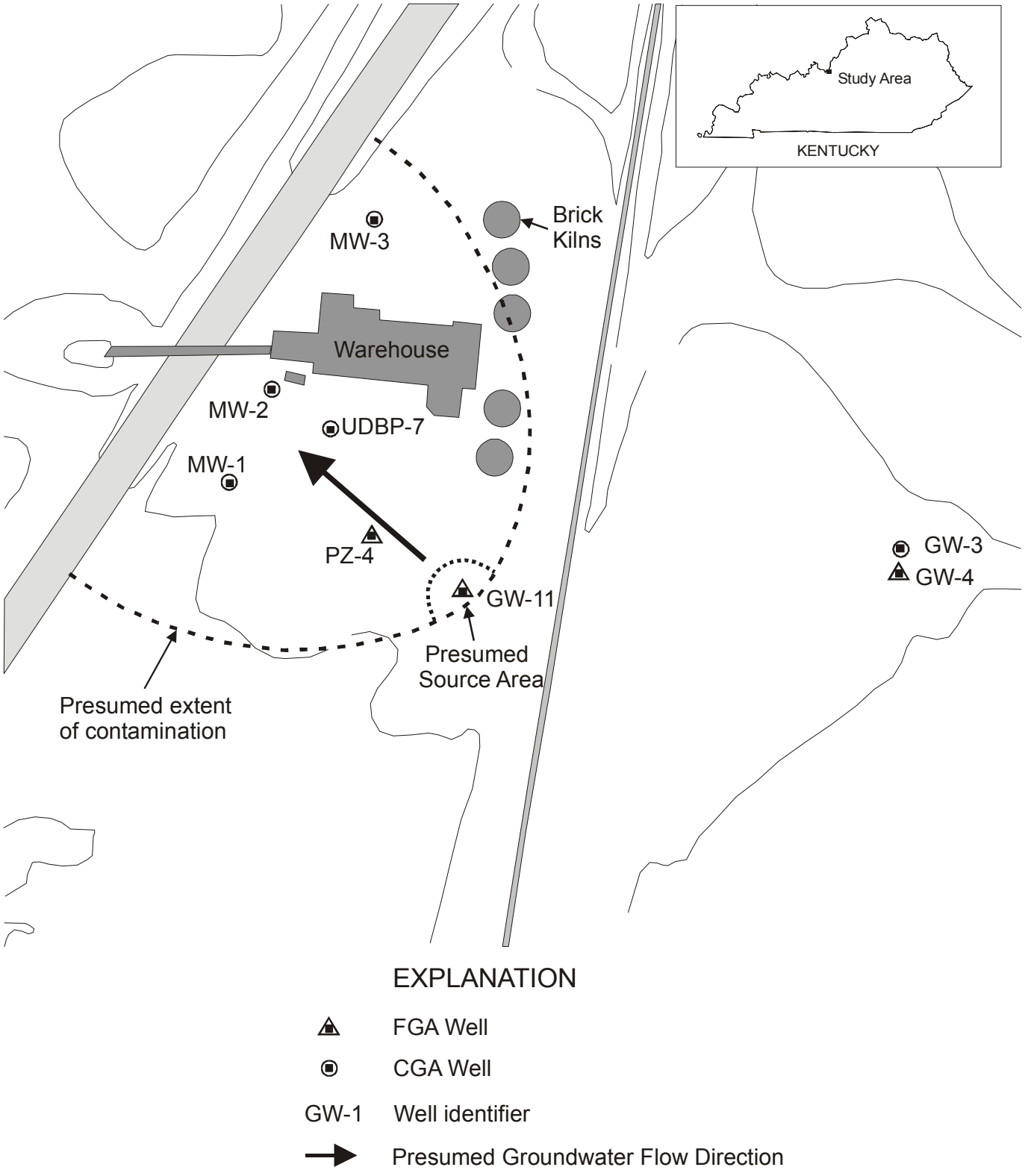


Figure 1-1. Conceptual model of Distler Brickyard Site contamination prior to October 1999.

is no documentation of soil removal from the area around GW-4, another potential source area. Analysis of data collected during operations of the groundwater treatment system indicated that most of the contaminants were located in the FGA, which because of its relatively low hydraulic conductivity (10^{-8} to 10^{-4} cm/s), exhibits low flow rates (EPA 1998). Due to the low hydraulic conductivity in the FGA, advective transport of contaminants through the FGA to the CGA is slow. Thus, removal of contaminants by groundwater extraction and treatment is not an effective remediation method for this aquifer system.

1.2 Results of Previous Sampling Events

Previous investigations (Anderson and Bomberger 1986, U.S. Geological Survey [USGS] in preparation) revealed evidence that suggested biodegradation (via anaerobic reductive dechlorination [ARD]) of CAHs was occurring in the FGA. The evidence for ARD of CAHs in the FGA included:

- The absence of TCE and tetrachloroethene (PCE), and the decrease in concentrations of 1,1,1-TCA in the FGA
- The presence of the biodegradation product chloroethane (CA) in the FGA
- The widespread occurrence of the intermediate biodegradation products dichloroethene (DCE) and dichloroethane (DCA) in both the FGA and CGA
- The predominance of *cis*-1,2-DCE and 1,1-DCA, the biologically-favored degradation products, over *trans*-1,2-DCE and 1,1-DCE (Vogel et al., 1987; Barbee 1994, USGS in preparation).

These investigations also indicated that conditions in the CGA were less favorable for ARD than in the FGA. The groundwater in the CGA may be oxygenated due to recharge from the Ohio River, and electron donors necessary for ARD may be absent. This interpretation was supported by the presence of primary contaminants PCE, TCE, and 1,1,1-TCA in the CGA and the absence of the degradation product chloroethane. The absence of petroleum hydrocarbons also suggested oxidizing conditions (USGS in preparation).

In October 1999, groundwater sampling activities were conducted to evaluate the existence of natural attenuation processes (specifically ARD of CAHs) in the aquifer system. A complete description of the results is presented in Martin et al. 2000, and contour plots of the results are presented in Appendix C of this report. In summary, results indicated that redox conditions in the FGA around GW-11 were favorable for reductive dechlorination, and an active dechlorination zone existed in this area (Figure 1-2). TCE migrated from the GW-11 area downgradient to the CGA at concentrations slightly above the Maximum Contaminant Level (MCL) (Figure C-2). Downgradient in the CGA, conditions were aerobic and less chlorinated degradation products CA and VC were not present.

Based on these results, it was hypothesized that natural attenuation in the form of biodegradation was occurring at the site. Corollaries to this hypothesis include the following:

- The soil removal activities conducted in 1988 have been effective in removing the bulk of chloroethene and chloroethane contamination from the GW-11 area.
- ARD has and appears to continue to degrade remaining chlorinated compounds in the FGA in the GW-11 area. This degradation is sufficient to prevent the migration of CAHs into the CGA at concentrations above the MCLs, with the exception of TCE, which is present in the CGA at approximately twice the MCL of 5 σg/L.
- Natural aerobic biodegradation of degradation products may be occurring in the CGA.

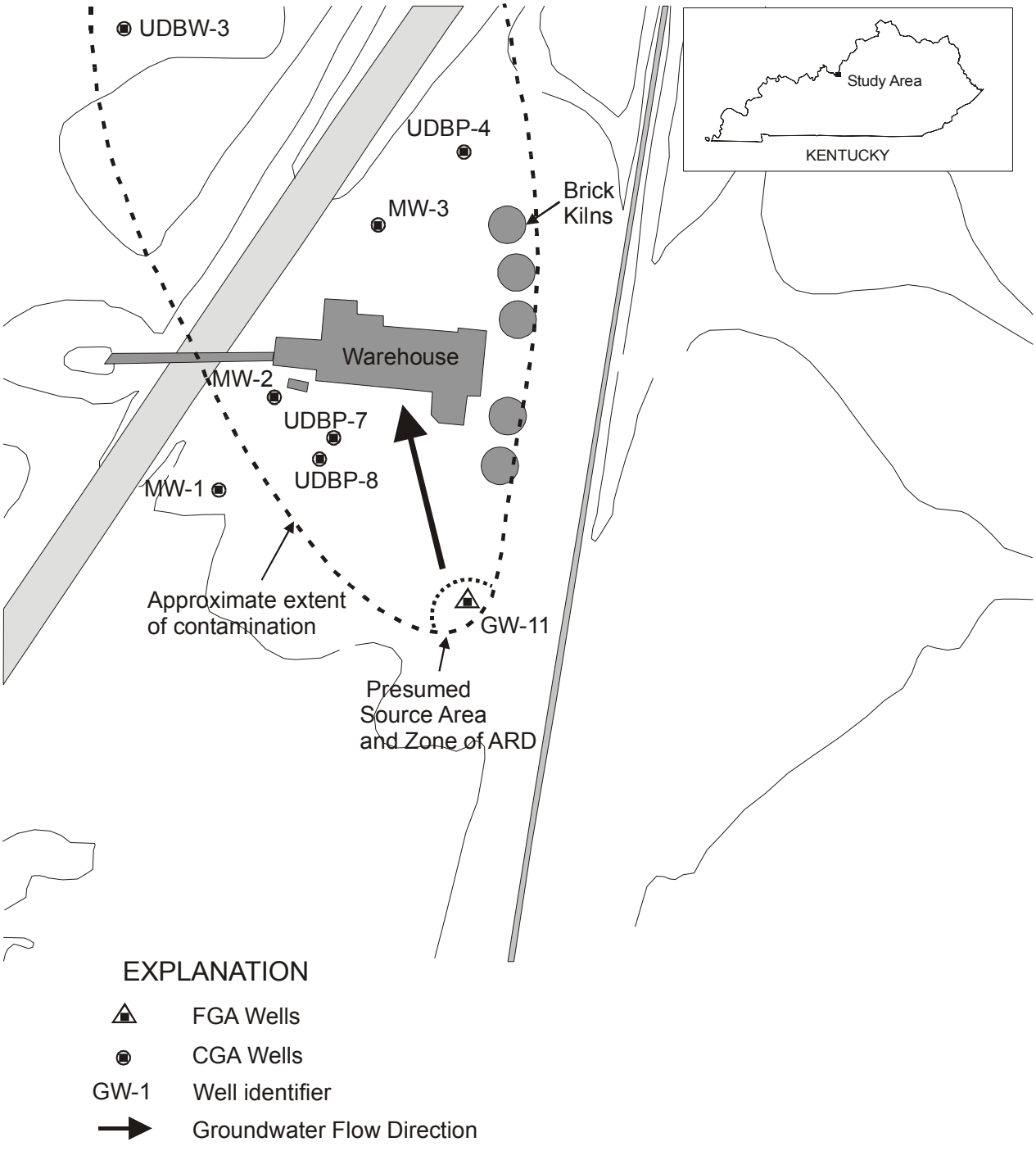


Figure 1-2. Conceptual model of Distler Brickyard Site after October 1999.

2. GOALS FOR DATA COLLECTION ACTIVITIES

Groundwater sampling conducted in October 1999 led to the hypothesis that natural attenuation via ARD of chlorinated ethenes/anes was occurring in the FGA at the Distler Brickyard Site. However, in order to confirm this hypothesis, additional data were needed. Data gaps were identified so that specific data needed to evaluate the above hypothesis could subsequently be identified. These data gaps were as follows:

- **Data Gap 1: Effect of seasonal recharge on contaminant concentrations.** Previous investigations indicated that the contaminant concentrations fluctuate seasonally (USGS in preparation). The October 1999 sampling event was conducted following an extremely dry summer season. The effect of renewed recharge through the FGA could result in a remobilization of contaminants and cause concentrations to rise. Changing recharge could also result in a shift in the local groundwater flow direction. This information will be very important to the evaluation of the extent of source degradation, which will in turn affect the selection of the appropriate remedial remedy.

- **Data Gap 2: FGA conditions.** The geochemical conditions in the FGA were previously evaluated based on data from a single monitoring location (GW-11). In order to determine the extent of FGA contamination, to define the extent of the dechlorination zone, and to evaluate the extent of source degradation, more monitoring in the FGA is necessary. Again, this information has important implications for assessment of source degradation and subsequent remedial actions.

- **Data Gap 3: Conditions along the GW-11 → MW-3 flowpath.** The contaminant distributions and redox conditions indicate that the flowpath from the presumed source area in the FGA at GW-11 is northerly (toward MW-3 and UDBP-4) rather than to the northwest (toward MW-2) as previous studies indicated. This flowpath may be influenced by the topography of the bedrock surface in this area. It also may be affected by seasonal fluctuations in recharge from infiltration of precipitation through the FGA and influx to the CGA from the Ohio River (USGS, in preparation). Additional monitoring locations along this flowpath are necessary in order to define the eastern boundary of the plume as it migrates towards MW-3 and UDBP-4.

- **Data Gap 4: The extent of aerobic degradation in the Coarse Grained Aquifer (CGA).** In order to determine the extent of aerobic degradation of ARD reaction products in the CGA and off-site contaminant migration, monitoring locations north and west of MW-3 and UDBP-4 are necessary. The concentrations of ARD degradation and mineralization products (dichloroethenes [DCEs], dichloroethanes [DCAs], vinyl chloride [VC], chloroethane [CA], ethene, ethane, and carbon dioxide) will be used to determine the fate of contamination in the CGA.

3. FIELD ACTIVITIES

The field activities conducted at the site during June-August 2000 included monitoring well installation, groundwater sampling, and passive soil vapor monitoring using Gore-Sorbers⊇. Three new monitoring wells were installed during a two-week period in June, 2000. Groundwater sampling was conducted July 10–21, 2000. Passive soil vapor monitoring was performed from August 3–21, 2000.

3.1 Monitoring Well Installation

Three new monitoring wells (B-1, B-2, C-1) were installed at the site in June 2000 (Figure 3-1). Well logs and completion diagrams are presented in Appendix A. New well B-1, located south of the warehouse, was installed to a depth of 64 ft. Approximately 2 ft of brick were present on the surface, and brown clay was present from 2 to 35 ft bgs. A brown sand was present below the brown clay from 35 to 60 ft bgs. Approximately 4 ft of gray clay were present at the bottom of the borehole from 60 to 64 ft bgs. Small amounts of gravel were also present at the bottom of the borehole, possibly indicating the presence of the CGA in this location. The screened interval is located from 53 to 63 ft bgs. This well yielded sufficient groundwater for sampling.

Well C-1 is located west of GW-11 (Figure 3-1). It was installed to a depth of 52 ft. As in B-1, approximately 2.5 ft of brick were present at the surface underlain by 27.5 ft of brown clay (2.5 to 30 ft bgs). A brown sand was present from 30 to 42 ft bgs, and a wet sand was encountered from 42 to 52 ft bgs. Some gravel was encountered possibly indicating the presence of CGA at this location. The screen was installed in the sand from 42 to 52 ft bgs. This well yielded sufficient groundwater for sampling.

Well B-2 is located east of the kilns (Figure 3-1). This well was drilled to a depth of 57 ft. As in B-1 and C-1, 2 ft of brick were encountered at the surface. A red clay was present from 2 to 7 ft bgs, and a brown clay was present from 7 to 32 ft bgs. Sandy clay and a brown clay were present from 32 to 52 ft bgs and 52 to 57 ft bgs, respectively. No gravel was encountered, indicating that the CGA may not be present at this location. The screened interval is from 42 to 57 ft bgs. A longer (15 ft) screen was used in order to increase groundwater yield so groundwater samples could be collected from this well. This well yielded sufficient groundwater for sampling.

3.2 Groundwater Sampling

Groundwater samples were collected from fourteen existing wells and three newly constructed wells at the Site between July 12 and July 21, 2000 (Figure 3-1 and Table 3-1). In general, field conditions were good for sampling. The weather was sunny, hot, and humid during much of the month. However, major thunderstorm events occurred in the area over several successive weeks in June and July, generating significant rainfall prior to and during the sampling period. As a consequence, groundwater levels were relatively high in the FGA wells compared to those encountered during the October 1999 sampling effort. (Table 3-2). In the CGA wells, ground-water levels were approximately 2.5 ft higher than in October 1999. Despite the recent precipitation, the area is still considered to be in moderate-severe drought, mostly due to residual effects of the 1999 drought.

3.2.1 Sampling of Wells

Despite relatively high ground-water levels, most wells at the Site remain difficult to sample. A summary of the wells sampled, sampling method, and problems encountered is presented in Table 3-3.

High turbidity and suspended solids are problematic in most of the FGA wells and in many CGA wells completed with 4-inch diameter steel casing (these wells have caps that do not seal). Overall, well yields are generally low, recovery rates are slow, and excessive drawdown during purging and sampling is difficult to control even at withdrawal rates of less than 1 gallon per minute (gpm). The difficulty in sampling caused by these field conditions was exacerbated by the relatively large quantity of water required to complete the full list of sampling constituents—approximately 3 gallons per well. In all but

Table 3-1. Summary of sampling method and locations.

Well	Stratigraphic Designation	Groundwater Sample	Gore-Sorber⊇ Only
B-2	FGA	X	X
GW-2	FGA		X
GW-6	FGA		X
GW-5	FGA		X
GW-4	FGA		X
UDBW-2	FGA		X
GW-1	FGA		X
GW-11	FGA Sand	X	X
RW-11	FGA Sand	X	
GW-7	FGA Sand	X	X
MW-5	FGA Sand		X
PZ-IW-2	FGA Sand	X	X
B-1	FGA Sand	X	X
C-1	FGA Sand	X	
PZ-4	FGA/CGA	X	
GW-3	CGA		X
MW-1	CGA	X	X
MW-2	CGA	X	
MW-3	CGA	X	
MW-4	CGA	X	
UDBP-4	CGA	X	
UDBP-5	CGA	X	
UDBP-6	CGA	X	
UDBP-7	CGA	X	X
UDBP-8	CGA	X	

Table 3-2. Water levels October 1999 and July-August 2000.

Wells	Static Water Level (ftMSL) October 1999	Static Water Level (ftMSL) July 2000	Change from Oct. 1999 to July 2000 (ft)
FGA & FGA Sand			
B-2		400.43	
GW-11	413.33	413.66	0.33
RW-11		412.05	
GW-7		412.33	
PZ-IW-2		408.1	
B-1		387.48	
C-1		389.97	
PZ-4	387.95	389.05	1.1
CGA			
MW-1	388.39	390.69	2.3
MW-2	388.06	390.6	2.54
MW-3	387.76	390.2	2.44
MW-4		389.45	
UDBP-4	386.55	389.05	2.5
UDBP-5		390.3	
UDBP-6		390.19	
UDBP-7	388.66	390.99	2.33
UDBP-8	387.31	389.89	2.58

ft MSL = feet above mean sea level

Table 3-3. Summary of groundwater sampling activities July–August 2000.

Well	Stratigraphic Designation	Purging/Sampling Method	Comments
B-2	FGA	Grundfos Submersible Pump 0.5-1.0 gpm	None
MW-1	CGA		
UDBP-4	CGA		
UDBP-5	CGA		
UDBP-6	CGA		
UDBP-7	CGA		
UDBP-8	CGA		
GW-11	FGA Sand	Combination of submersible pump and bailer: Pump → Recharge → Repeat → Sample	Water level remained above screen
RW-11	FGA Sand		
PZ-4	FGA/CGA		
B-1	FGA Sand	Bailer	Insufficient recharge for submersible pump
C-1	FGA Sand		
MW-2	CGA	Bailer	Obstructions in well prevented the use of submersible pump
MW-3	CGA		
MW-4	CGA		
GW-7	FGA Sand	Bailer	Poor yield and slow recovery; Sampled for VOCs and field parameters only
PZ-IW-2	FGA Sand		
MW-5	FGA Sand	Not sampled	Rodent midden
UDBW-3	CGA	Not sampled	Inaccessible

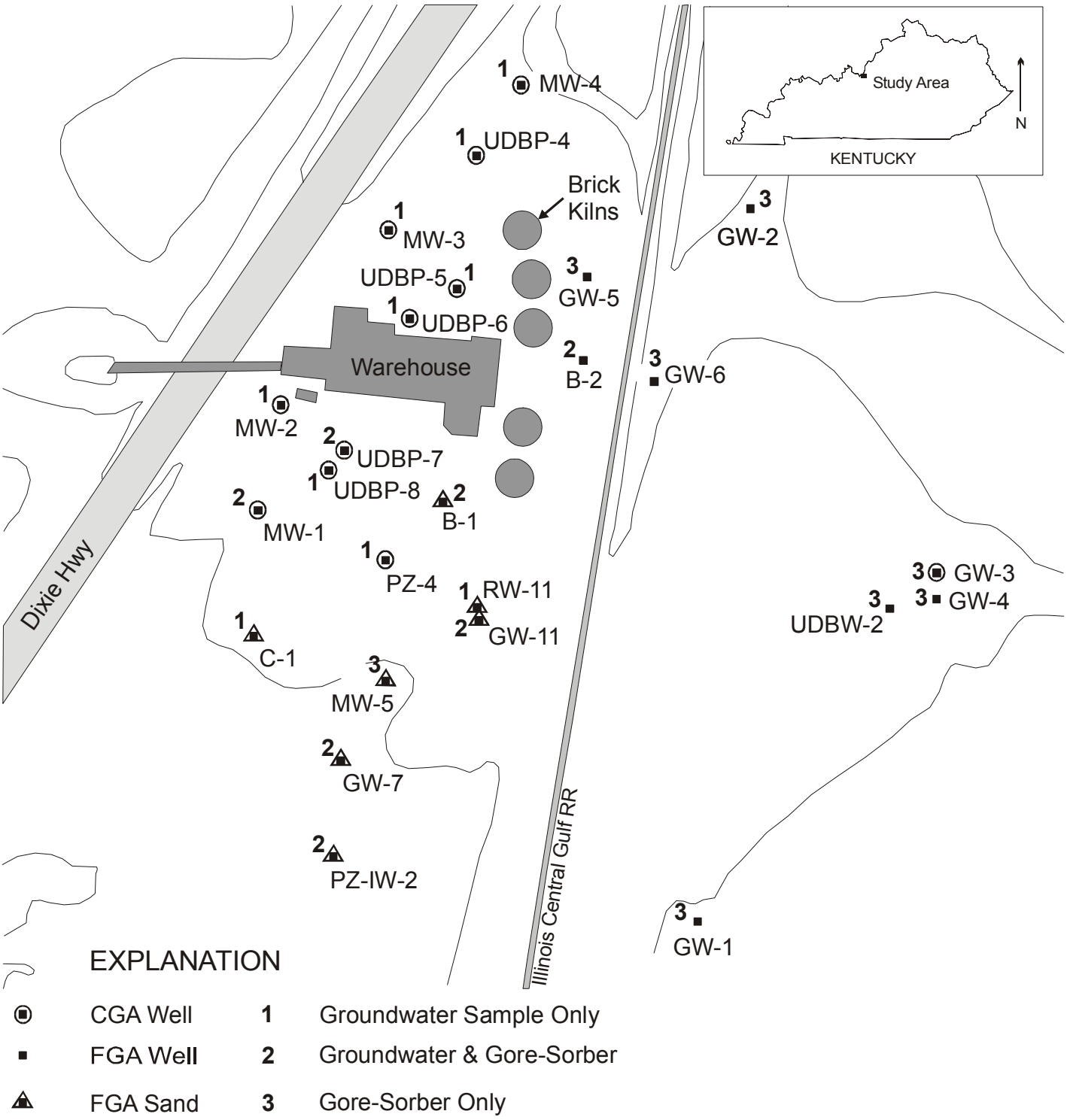


Figure 3-1. Locations of groundwater and Gore-Sorber⊇ sampling locations.

two wells, this volume exceeded the volume available in storage in each well prior to purging. Where pumping could be sustained at 0.5-1.0 gpm without drawing the water level down into the well screen, a Grundfos submersible pump was used to collect all samples. Wells sampled in this manner included: B-2 (newly constructed), MW-1, UDBP-4, UDBP-5, UDBP-6, UDBP-7, and UDBP-8.

Wells that could not sustain pumping at 0.5 gpm were sampled with a disposable Teflon bailer, or by a combination of low-flow pumping and bailing. In the latter method, the wells were purged using a pump to draw water levels down to, but not below the well screen. The well was allowed to recover, then pumped again while checking for the stabilization of field water-quality parameters (temperature, specific conductance, pH, and dissolved oxygen). This process was repeated until the well was judged sufficiently purged. Water samples for organics (VOCs) and unstable parameters (carbon dioxide, ferrous iron, and nitrite) were then collected through the pump discharge line. Samples for less-volatile, conservative constituents—chloride, sulfate, total and dissolved metals, dissolved organic carbon, total organic carbon, and nutrients (ammonia and phosphorus)—were collected by bailer as the well recharged and a sufficient quantity of water for each sample bottle was obtained. Wells sampled by the "combination" method include: GW-11, RW-11, and PZ-4.

Wells that did not recharge sufficiently fast enough to allow for sampling while pumping at 0.5 gpm without excessive drawdown were sampled with a bailer. These included: B-1, C-1, GW-7, and PZ-IW-2. Every effort was made to minimize turbulence and aeration of water samples collected with the bailers. Each trip down the well, the bailer was inserted slowly and carefully into the water and allowed to fill slowly. After retrieving the filled bailer from the well, a stopcock was inserted into the bottom of the bailer and used to dispense the sample. The stopcock was opened slowly and the flow out of the bailer was carefully controlled to provide a slow, laminar stream of water for filling sample bottles.

Three other wells: MW-2, MW-3, and MW-4, were also sampled by bailer, due to difficulty inserting the pump. These are 2-inch diameter stainless steel wells, and the joints between the sections of well casing are very rough and create obstructions that make it difficult to insert a pump. In MW-2, there is an obstruction approximately 15 ft below the surface that prevented the insertion of the Grundfos pump. A partial obstruction was also encountered in MW-3, which "hung up" the pump as it was being lowered. The pump was immediately withdrawn to prevent possible loss of the equipment.

3.2.2 Wells Partially Sampled or Not Sampled

Due to a combination of poor well yield, slow recovery and time constraints on sample collection, wells GW-7 and PZ-IW-2 were sampled for VOCs and field-determined water-quality constituents only. Well MW-5 was not sampled because of the presence of rodent midden (nesting material) in the well. Well UDBW-3, an off-site well sampled in October 1999, could not be sampled at this time due to inaccessibility—under the present field conditions, vehicles could not travel the rutted, dirt trail that must be taken to reach this well.

3.3 FGA Sampling—Gore-Sorbers⊇

In order to collect additional contaminant distribution data within the FGA, a passive soil vapor sampling device (Gore-Sorber⊇) was used. The Gore-Sorber⊇ is 15 to 25 mm long and contains 40 mg of a suitable sorbent specific to the compounds of interest (typically polymeric or carbonaceous resins). The sorber is sheathed in the bottom of a vapor-permeable insertion and retrieval cord that is fashioned with a loop. Both the retrieval cord and sorbent container are constructed solely of inert, hydrophobic, microporous Gore-Tex⊇ expanded polytetrafluoroethylene (PTFE). The PTFE membrane is hydrophobic (water-repellent) yet allows vapor transfer. This allows volatile and semi-volatile organic compound (VOC and SVOC) vapors to penetrate the module and collect on the sorbent. When the samplers are

deployed, soil vapors come into contact with and are sorbed to the sorbent inside the sampler. The detection of the particular compounds of interest on the sorbent indicates their presence in the formation. The use of this approach allows for the detection of contaminants without having to collect a groundwater sample. For this reason, the use of these samplers can provide qualitative information on the presence of VOCs and SVOCs in low permeability or unsaturated units, like the FGA at the Distler Brickyard site.

Gore-Sorbers⊇ were deployed in 15 wells (Figure 3-1 and Table 3-1). The samplers were hung above the water level in each well (if water was present) and the well was sealed at the surface. The samplers were left in the wells for 18 days. Following the equilibration period, samplers were removed and returned to the Gore Laboratory for analysis.

Gore-Sorbers⊇ were chosen to provide qualitative results that give an indication of the presence or absence of remaining FGA contamination. The data are reported by the Gore Laboratory as mass (σg) of TCE (for example) per sorber. Equivalent soil gas concentrations cannot be calculated due to the varying volumes of air in each well, thus equivalent equilibrium groundwater concentrations also cannot be calculated. For these reasons, the Gore-Sorbers⊇ were used to detect the presence or absence of contaminants as an indicator of remaining FGA source material. The magnitude and resultant threat to groundwater posed by a source cannot be determined by this sampling method.

4. RESULTS

The results of groundwater and soil gas sampling are presented in four sections: site groundwater flow system, water levels, redox conditions, and contaminant concentrations.

4.1 Site Groundwater Flow System

As part of this sampling effort, historical site data were reviewed in order to determine what was known about the groundwater flow system at the site. Developing an understanding of the flow and transport system is necessary for the deployment of any remedy at this site. For this reason, site data were reviewed to determine the hydraulic conductivity in the FGA and CGA, the hydraulic gradient at the site, the specific discharge, and the average linear groundwater velocity. This information is used to approximate the travel time to the nearest downgradient receptor.

Hydraulic conductivities (K_h) in the FGA near GW-11 were determined from pumping test data performed during installation of the FGA groundwater extraction wells (ICF Kaiser 1994). As indicated in Table 4-1, the hydraulic conductivities in the FGA near GW-11 are around 0.23 ft/day. Hydraulic conductivities in the CGA were determined from pumping test data performed during installation of the CGA groundwater extraction wells (OHM 1989). The hydraulic conductivity in the CGA ranges from 671 ft/day to 1627 ft/day (average of 1026 ft/day) (Table 4-1). These results indicate an increase in hydraulic conductivity from the FGA to the CGA of at least four orders of magnitude.

Hydraulic gradients (dh/dl) are difficult to determine at the site because the spatial distribution and reliability of head measurements in FGA wells are lacking, and some CGA wells exhibit little or no significant differences in head. Moreover, water levels in many CGA wells exhibit seasonal or Ohio River stage-dependent changes that appear to reverse or shift groundwater flow locally in the aquifer. For example, water levels measured in wells MW-1, MW-2, and UBDP-7 during the July 2000 sampling round seem to depict possible groundwater mounding in the vicinity of these wells that seems to reverse the usual northwest flow direction in that part of the site. Synoptic groundwater-level measurements collected in December 1995, seem to best represent hydraulic heads under relatively stable aquifer conditions (USGS 2000, in prep.), and are used to calculate hydraulic gradients along the hypothesized groundwater flow paths presented in Table 4-2. As expected based on the hydraulic conductivities of the FGA and CGA, the gradient between GW-11 and PZ-4 (FGA) is significantly steeper than gradients for either of the CGA flow paths.

Calculation of estimated specific discharge (q) in the FGA and CGA aquifer zones are given by Darcy's Law: $q = K_h (dh/dl)$ (Freeze and Cherry, 1979). The specific discharge for the FGA was calculated using the average hydraulic conductivity value in Table 4-1 and the gradient between GW-11 and PZ-4 (Table 4-2). Two specific discharge values were calculated for the CGA using the lowest and highest hydraulic conductivity values presented in Table 4-1. A gradient of 0.01 was used (Table 4-2). The estimated specific discharge for the FGA is 0.049 ft/day (Table 4-3). The specific discharges for the CGA range between 6.7 and 16.3 ft/day. The specific discharge (q) and the porosity (n) were used to calculate the average linear velocity (v) according to: $v = q/n$ (Freeze and Cherry, 1979). The specific discharge for the FGA was 0.049 ft/day and both the specific discharge values calculated for the CGA (6.7 and 16.3 ft/day) were used. Porosity values used in the calculations in Table 4-4 were based on a range of values reported for gravel, sand, silt, and clay by Freeze and Cherry (1979). For both the FGA and CGA, high and low values of porosity were used; 0.25 and 0.50 were used for the FGA and 0.25 and 0.40 were used for the CGA (Freeze and Cherry, 1979). The average linear velocity was calculated for each combination of specific discharge and porosity in both the FGA and CGA (Table 4-4). Ignoring mass removal processes (dispersion, sorption, degradation) that may occur along a flowpath, the travel time between GW-11 and a downgradient monitoring location was estimated using the data in Table 4-4. It was assumed that the distance between GW-11 and the CGA was 125 ft (based on the distance between

GW-11 and PZ-4. PZ-4 is assumed to approximate the eastern boundary of the CGA in this location). The downgradient monitoring location was assumed to be one mile (5280 ft) from the site. Using these assumptions and the data in Table 4-4, the fastest and slowest estimated travel times from GW-11 to a downgradient monitoring location approximately one mile away from the site are approximately 2 years and 4.3 years, respectively. Because of the relatively slow groundwater velocity in the FGA, this travel time estimate is controlled by the FGA.

Table 4-1. Hydraulic conductivity estimates for the FGA and CGA.

Location	Hydraulic Conductivity (K_h)
FGA (RW-9)	0.24 ft/day
FGA (RW-7)	0.23 ft/day
FGA (RW-9)	0.22 ft/day
FGA (RW-10)	0.22 ft/day
Average FGA K_h	*0.23 ft/day*
CGA (RW-1)	844 ft/day
CGA (RW-2)	963 ft/day
CGA (RW-5)	1627 ft/day
CGA (UDBP-2)	671 ft/day
Average CGA K_h	*1026 ft/day*

Table 4-2. Calculated hydraulic gradient in the FGA and CGA.

Flowpath	Head Difference, dh (ft)	Distance, dl (ft)	Calculated dh/dl
FGA: GW-11 → PZ-4	26.6	125	0.213
CGA: UDBP-8 → MW-2	0.93	65	0.014
CGA: UDBP-6 → MW-3	0.28	55	0.005
Average dh/dl for CGA			0.01

Table 4-3. Calculated groundwater velocities for the FGA and CGA.

	K_h (ft/day)	dh/dl	q (ft/day)
FGA	0.23	0.213	0.049
CGA-Slow	671	0.01	6.7
CGA-Fast	1627	0.01	16.3

Table 4-4. Travel time calculations.

Unit	Specific Discharge, q (ft/day)	Porosity, n	Average Linear Velocity, v (ft/day)	Travel Distance (ft)	Travel time, t (days)
FGA	0.049	0.25	0.10	125	1250
FGA	0.049	0.50	0.20	125	625
CGA	6.7	0.25	26.8	5280	197
CGA	6.7	0.40	16.8	5280	314
CGA	16.3	0.25	65.2	5280	81
CGA	16.3	0.40	40.8	5280	129
			Shortest Travel Time	625+81=706 dy=2 yrs	
			Fastest Travel Time	1250+314=1564 dy=4.3 yrs	

4.2 Water Levels

As stated in Data Gap 1, it was necessary to understand the influence of seasonal variations (including changes in precipitation and river stage) on concentrations and degradation of chlorinated ethenes and ethanes. It was hypothesized that an increase in precipitation and subsequent infiltration through the FGA may mobilize residual contaminants, resulting in increased concentrations in groundwater. Also, previous investigations have established a hydraulic connection between the CGA and the Ohio River (USGS, in prep.). It was hypothesized that the stage of the Ohio River may affect the local gradient and flow direction at the Distler Brickyard Site. For these reasons, water levels were monitored during the July 2000 groundwater sampling event and these results were compared to those collected during the October 1999 event to determine if any changes were observed.

Data indicate that the water levels in the CGA were approximately 2.5 feet higher in July 2000 than in October 1999 (Table 3-2). Well PZ-4, which is screened across both the FGA and CGA had a water level approximately 1.1 ft higher in July 2000. Water levels in the FGA appear to be slightly higher than in October 1999 (< 1 ft). It is assumed that increased precipitation during the spring months resulted in increased infiltration through the FGA.

4.3 Redox Conditions

Complete ARD of chlorinated ethenes and ethanes requires the absence of competing electron acceptors (oxygen, nitrate, iron (III), and sulfate) in order to be energetically favorable. The results of October 1999 groundwater sampling indicated sulfate-reducing to methanogenic conditions in the FGA in the GW-11 area and iron-reducing conditions extending into the CGA to UDBP-7 and UDBP-8 (Martin et al., 2000b) (Figure C-1). This suggested that conditions in the FGA around GW-11 were favorable for complete degradation of TCE and 1,1,1-TCA.

Redox data (dissolved oxygen, nitrate, iron (II), sulfate, and methane) were collected during the July 2000 groundwater sampling event to determine redox conditions in the FGA using additional FGA monitoring locations (Data Gap 2). Results indicate a mildly reducing zone (iron-reducing) in the FGA extending into the CGA to include UDBP-7 and UDBP-8. The remainder of the CGA was aerobic with dissolved oxygen concentrations between 2 and 7 mg/L. Sulfate concentrations were relatively high throughout the site (50-90 mg/L). Methane was present at relatively low concentrations (10-60 σg/L) within the FGA (Figure 4-1, Table B-1). These data suggest that redox conditions within the FGA in GW-11 area were somewhat less reducing in July 2000 than in October 1999.

4.4 Contaminant Concentrations

The distribution and concentration of primary contaminants PCE, TCE, and 1,1,1-TCA are of particular importance to the selection of the appropriate remediation technology for this site. October 1999 groundwater data indicated the presence of TCE in the CGA at concentrations up to 11 σg/L, approximately twice the MCL (MCL = 5 σg/L) (Figure C-2). 1,1,1-TCA was present at concentrations up to 10 σg/L (MCL = 200 σg/L) and PCE was not detected (Martin et al., 2000b). To determine the extent of FGA contamination (Data Gap 2) and if concentrations of PCE, TCE, and 1,1,1-TCA were affected by seasonal fluctuations in recharge (Data Gap 1), a sampling program including both passive soil vapor monitoring (Gore-Sorbers⊇) and groundwater sampling was used. All groundwater and Gore-Sorber⊇ VOC data are presented in Appendix B, Tables B-2 and B-3.

Results from July-August 2000 indicate that TCE is present in groundwater at concentrations up to 65 σg/L in the suspected GW-11/RW-11 source area (Figure 4-2). Gore-Sorber⊇ results also indicate the presence of TCE in this area and at the MW-5 location. TCE migrates to the CGA at concentrations up to 19 σg/L (PZ-4) and is between 4 and 8 σg/L downgradient at MW-3, UDBP-4, and MW-4. Results also indicate the presence of an additional potential source area in the eastern area of the site. Relatively high masses of TCE were detected in Gore-Sorbers⊇ in GW-4 and UDBW-2 (Figure 4-2). It does not appear that contamination from this area migrates down to the CGA, as TCE was not detected in GW-3; however, additional monitoring in this area is required to determine the fate and transport of GW-3/UDBW-2 contamination. PCE, 1,1,1-TCA, and 1,1,2-TCA were not detected above MCLs at any location.

The biological degradation products, *cis*-1,2-DCE and 1,1-DCA, had distributions similar to that of TCE (Figures 4-3 and 4-4). The highest concentrations were present in the GW-11/RW-11 area and decreased downgradient in the CGA. *Cis*-1,2-DCE was detected at concentrations above the MCL in the CGA at UDBP-7 and UDBP-8 (Figure 4-3). The non-biologically favored degradation products, *trans*-1,2-DCE, 1,1-DCE, and 1,2-DCA, were detected at GW-11, RW-11, PZ-4, UDBP-7, UDBP-8, and MW-1 at concentrations < 10 σg/L. 1,2-DCA was detected in concentrations above the MCL of 5 σg/L at two locations: UDBP-8 and UDBP-7 (Figure 4-5).

Chloroethane (CA), vinyl chloride (VC), ethene, and ethane indicate advanced degradation of chloroethenes and ethanes. CA and/or VC were present at four locations: GW-11, RW-11, PZ-4, and UDBP-8 (Figure 4-6). VC was present in concentrations above the MCL at GW-11. Ethene was present at two locations: GW-11 and RW-11 (Figure 4-7). Ethane was not present above the detection limit at any location. These data indicate the presence of active dechlorination in the GW-11/RW-11 source area.

Monoaromatic compounds were detected only at GW-11. GW-11 contained ethylbenzene at 45 σg/L and total xylenes at 89 σg/L, concentrations well below the MCLs for these compounds.

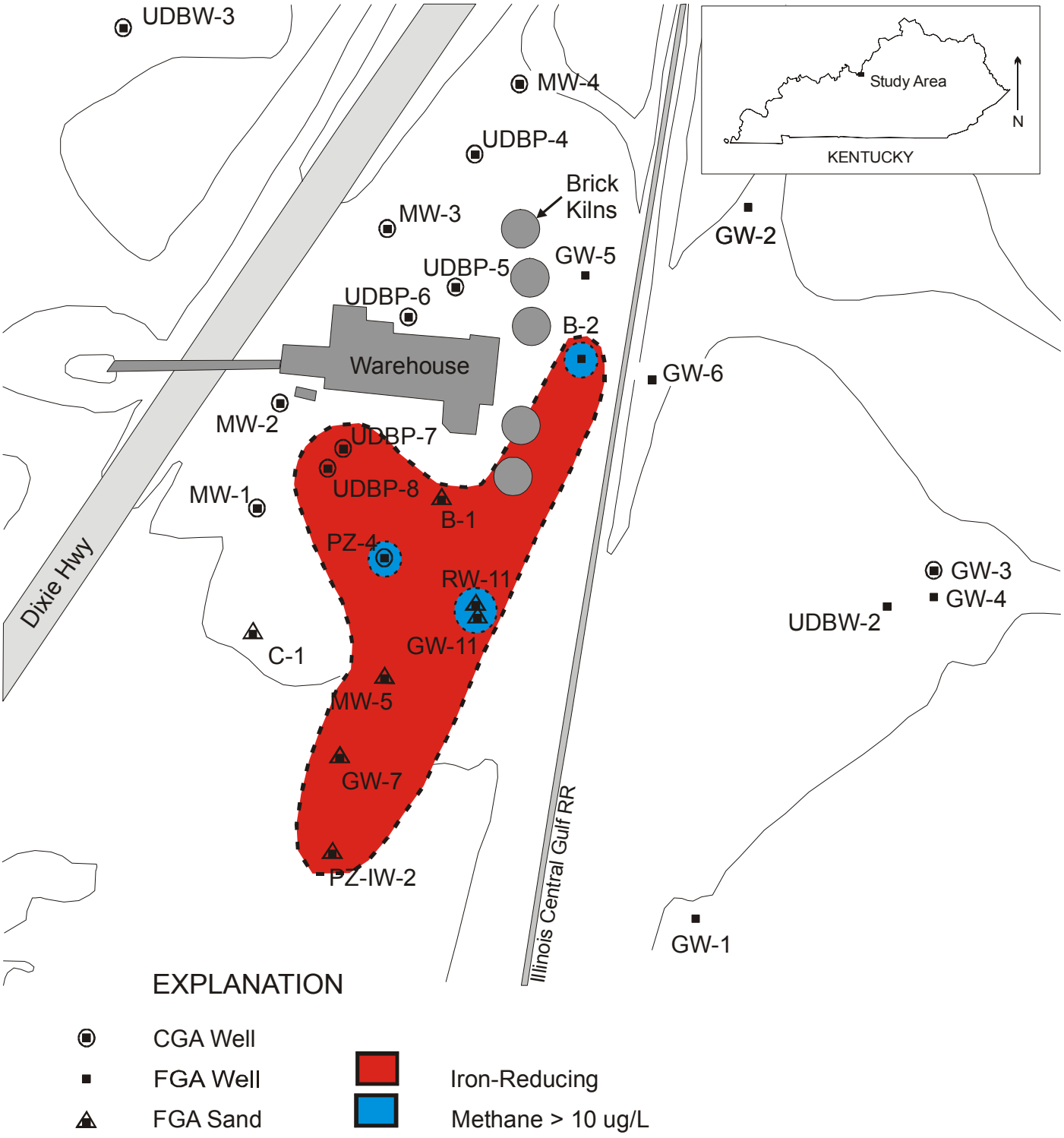


Figure 4-1. Redox conditions.

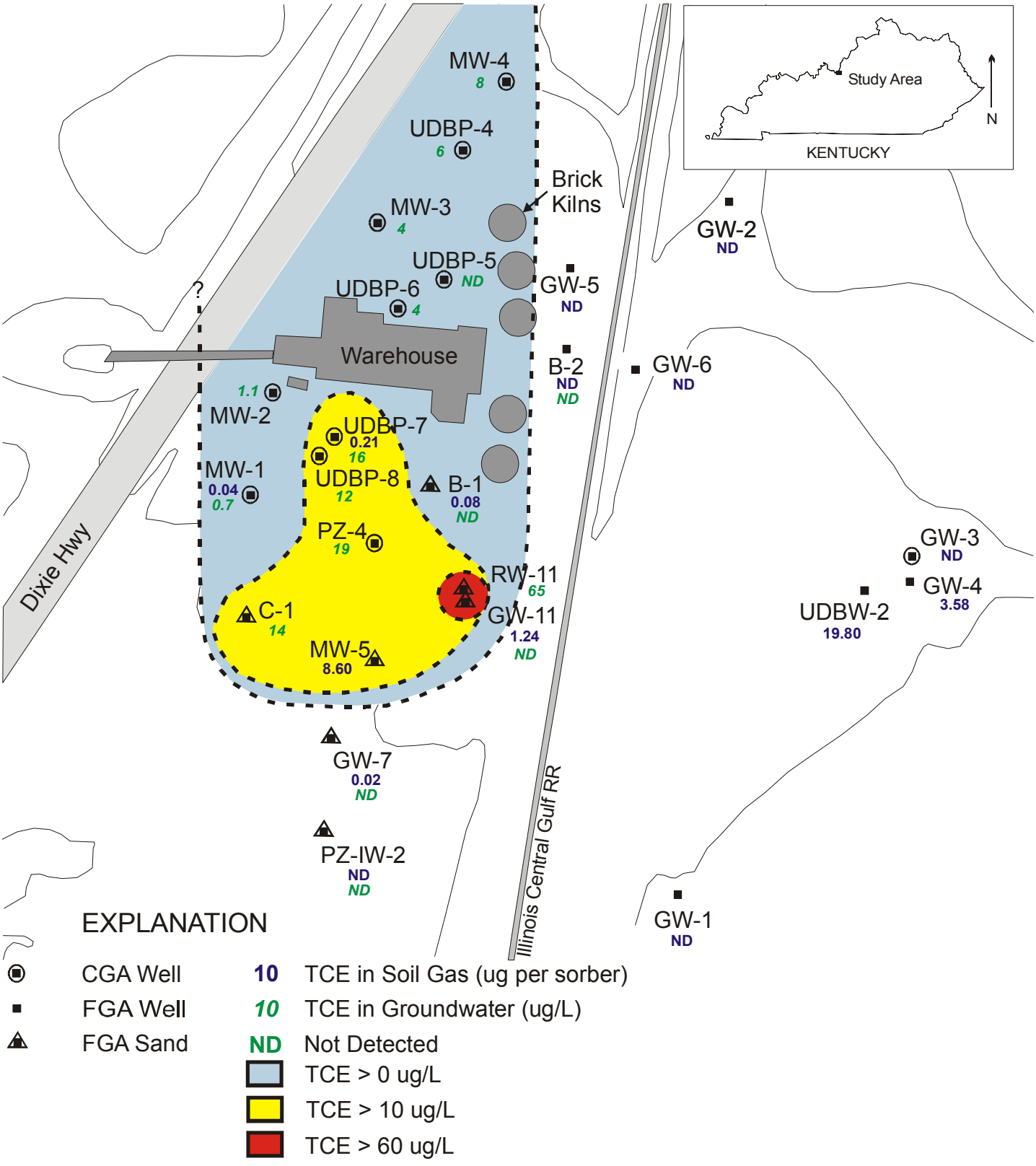
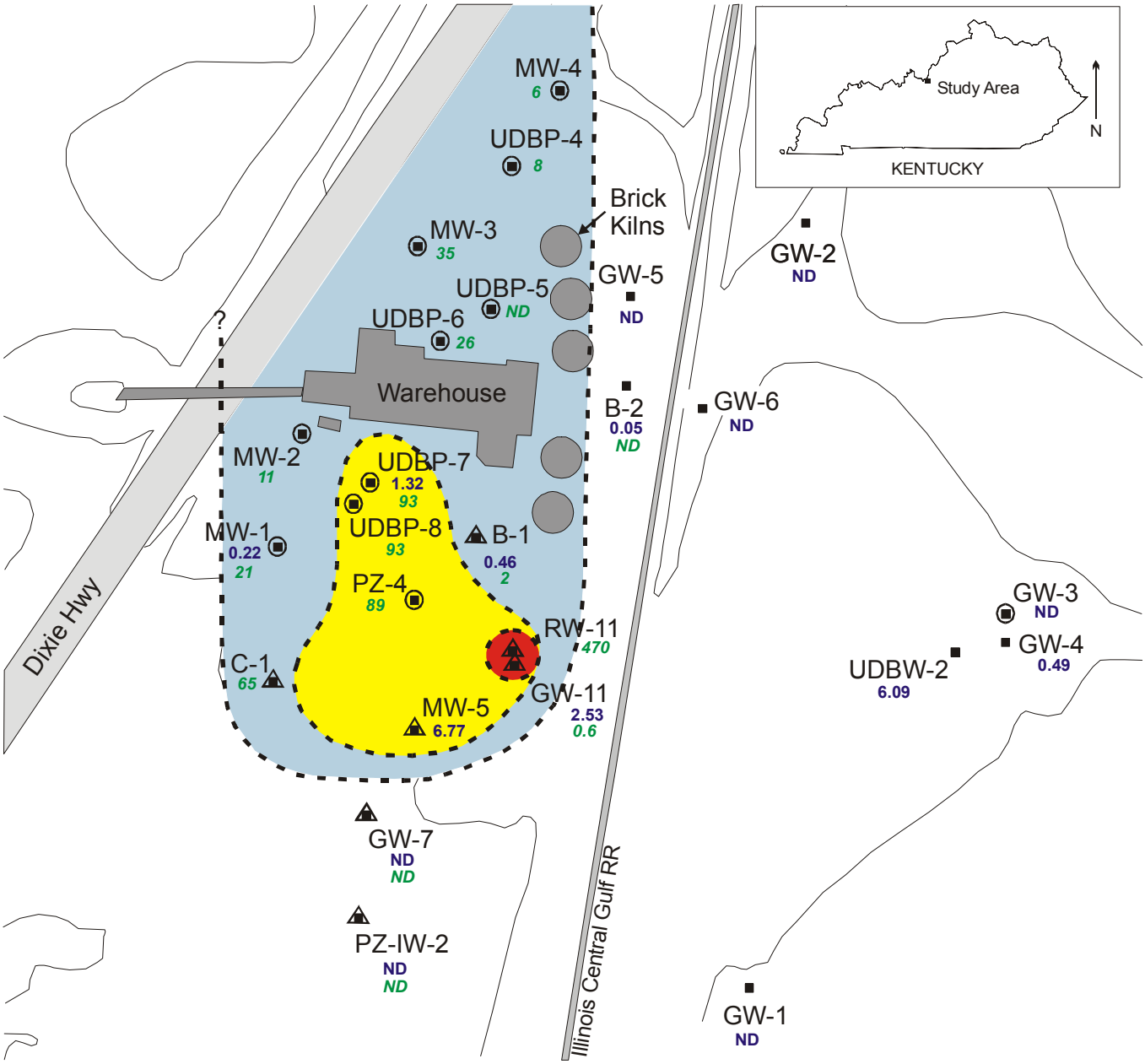


Figure 4-2. TCE concentrations.



EXPLANATION

◉	CGA Well	**10**	Cis-1,2-DCE in Soil Gas (ug per sorber)
■	FGA Well	***10***	Cis-1,2-DCE in Groundwater (ug/L)
▲	FGA Sand	**ND**	Not Detected
			Cis-1,2-DCE > 0 ug/L
			Cis-1,2-DCE > 70 ug/L
			Cis-1,2-DCE > 400 ug/L

Figure 4-3. cis-1,2-DCE concentrations.

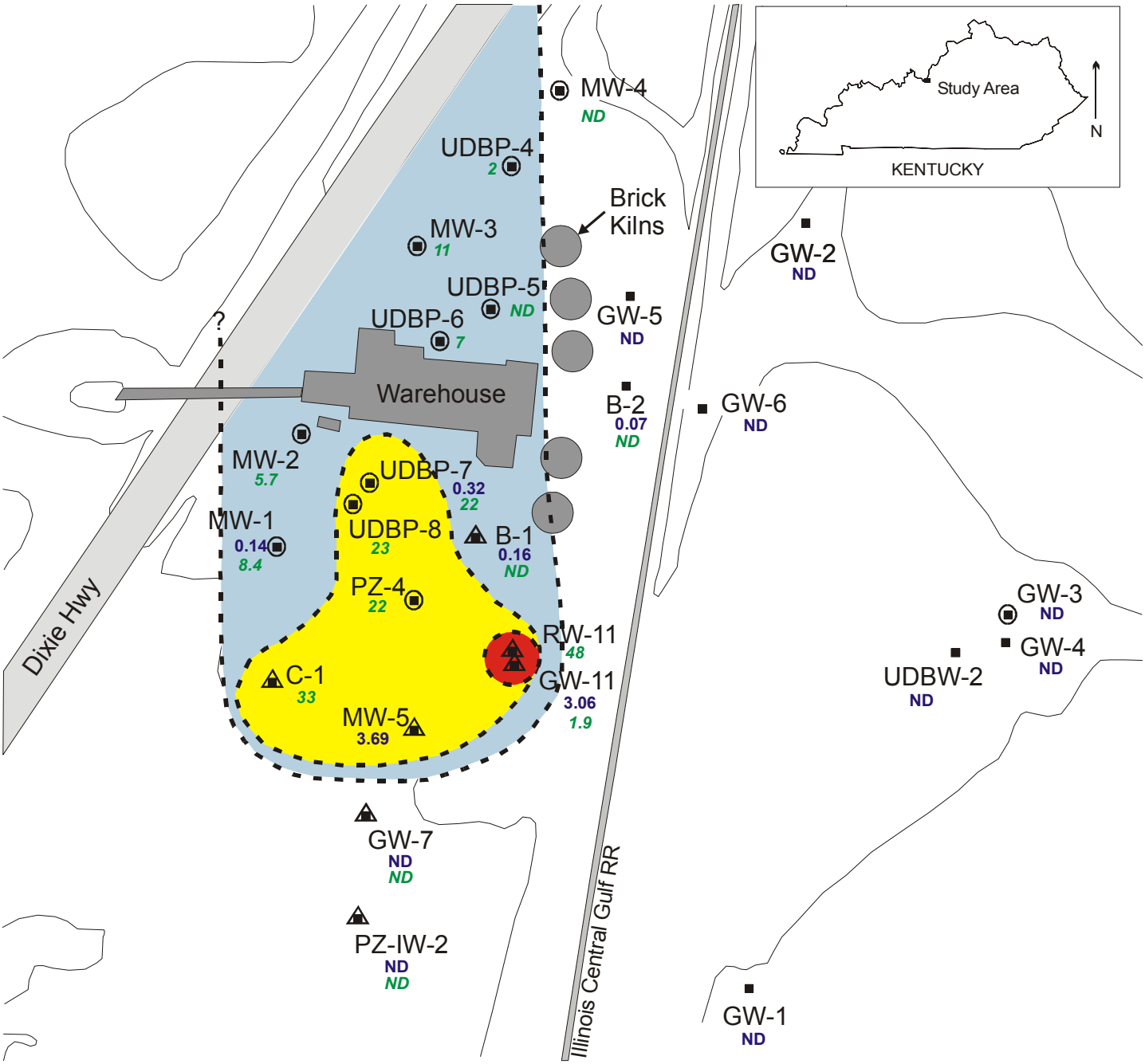


Figure 4-4. 1,1-DCA concentrations.

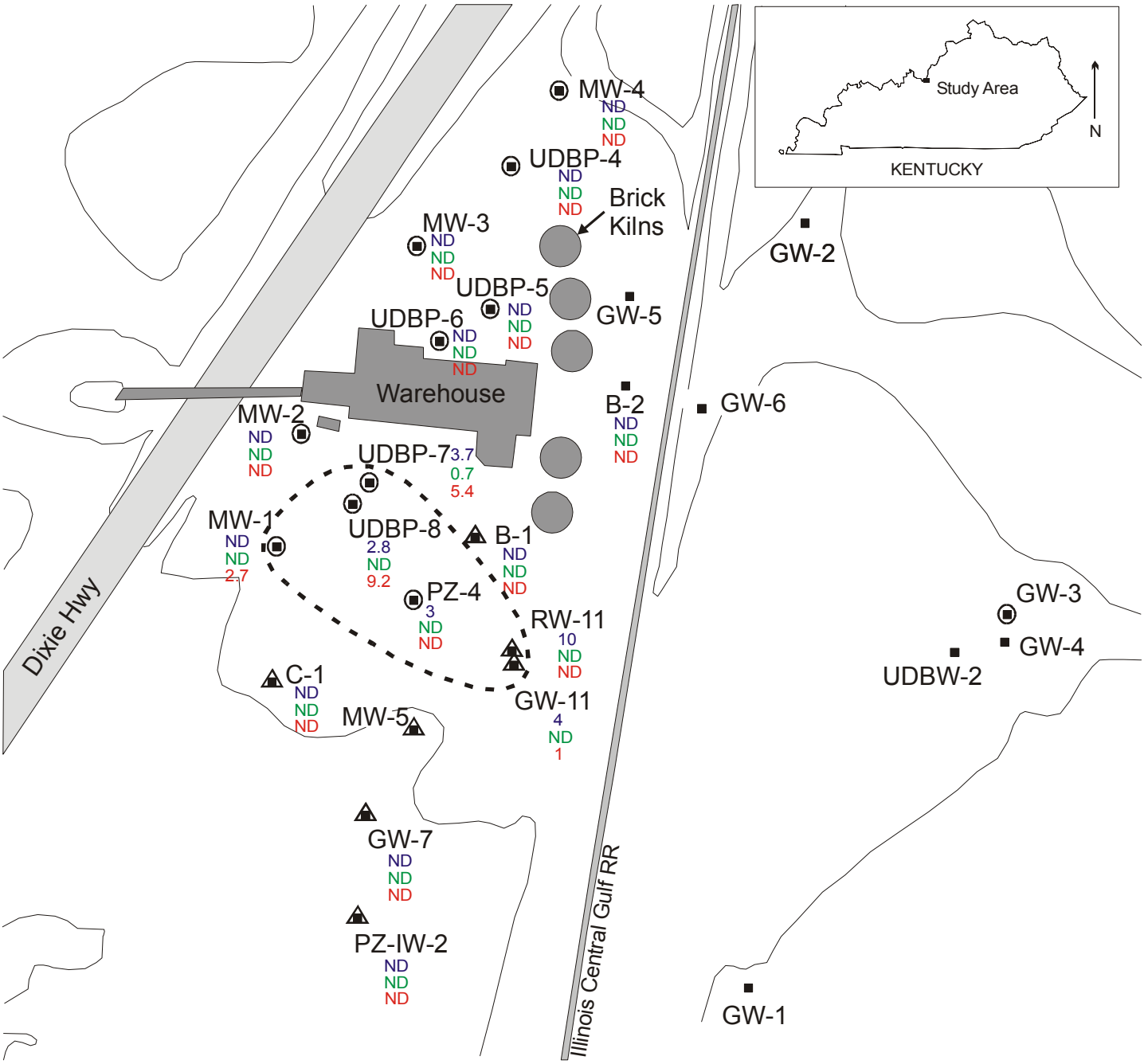


Figure 4-5. Non-biologically produced degradation product concentrations.

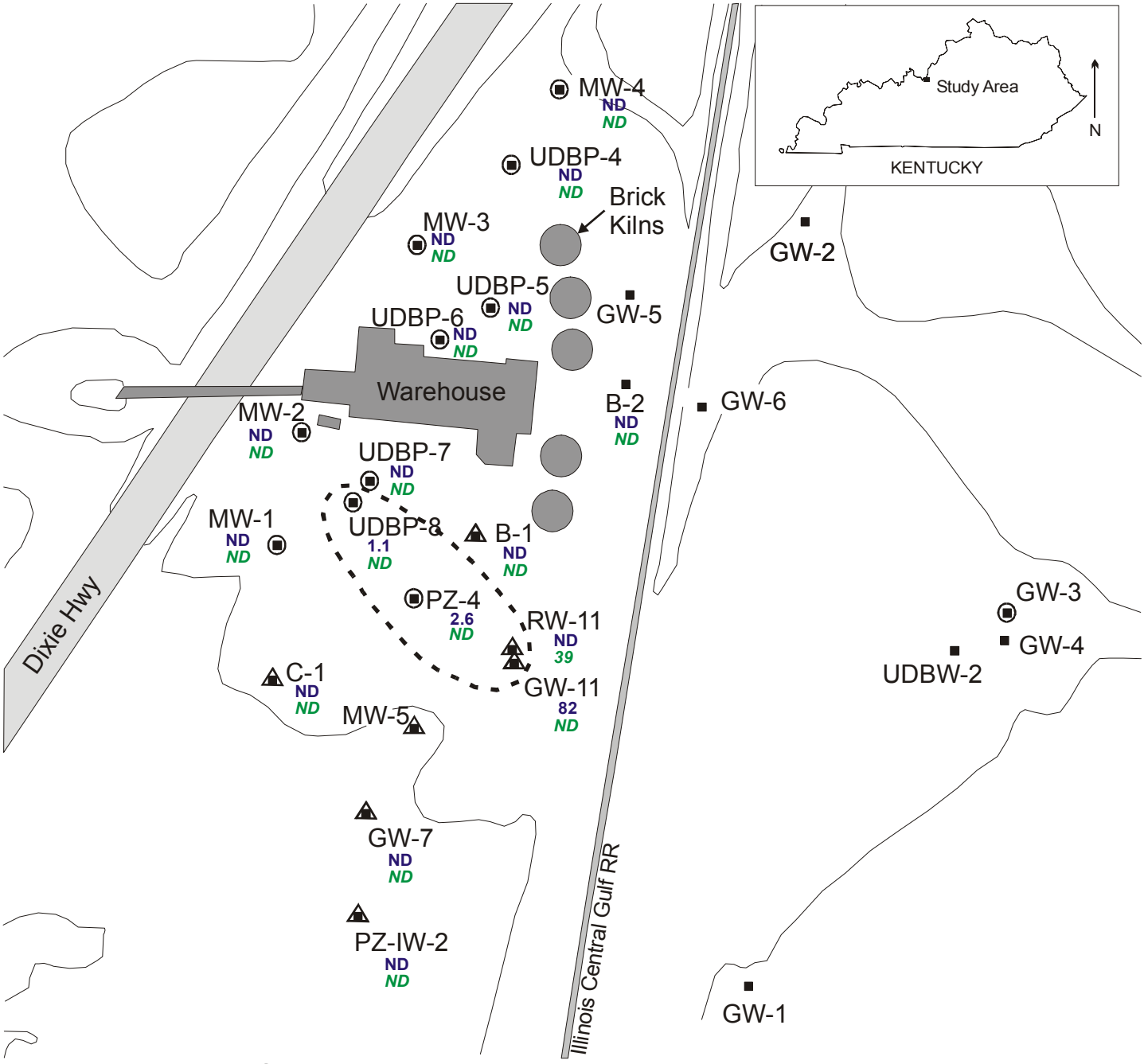


Figure 4-6. Chloroethane and vinyl chloride concentrations.

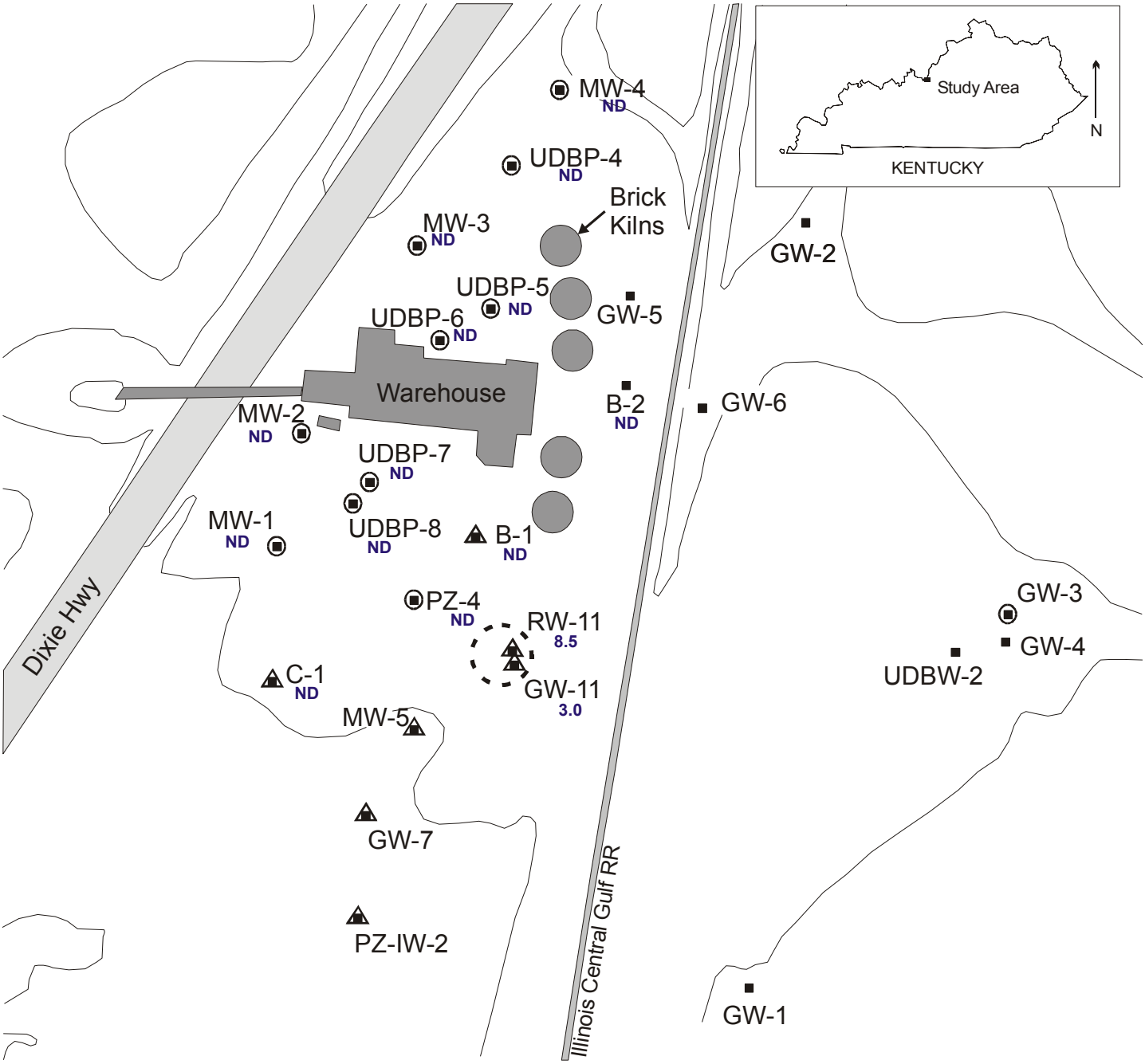


Figure 4-7. Ethene concentrations.

5. DISCUSSION

Results are discussed in the context of the data gaps described in Section 1.

5.1 Data Gap 1—Effect of Seasonal Recharge.

Assessing the seasonal fluctuation in contaminant concentrations is very important to the selection of the appropriate remedy for this site. By comparing water level measurements and contaminant concentrations from October 1999 to July-August 2000, this effect can be evaluated. Results indicate that water levels throughout the site increased from October to July-August 2000 (Table 3-2). TCE, *cis*-1,2-DCE, and 1,1-DCA concentrations also increased throughout the site during this period of time. These results probably indicate that contaminant concentrations fluctuate seasonally and are consistent with a conceptual model in which an increase in recharge in the spring months results in a remobilization of contaminants in the FGA and an increased flux to the CGA.

The seasonal fluctuations in recharge also affected the redox conditions at the site. In general, conditions in July-August 2000 (wet period) were less reducing than in October 1999 (dry period). This indicates that increased recharge at the site results in less reducing conditions, most likely due to the infiltration of oxygenated surface water through the FGA.

Both of these factors indicate that the rate of ARD of chlorinated ethenes and ethanes will vary seasonally. During relatively wet periods, increased precipitation results in increased infiltration of oxygenated recharge. This increased recharge results in less reducing conditions. At the same time, rising water levels result in a remobilization of residual FGA contamination. The increased contaminant concentrations and less reducing conditions result in less biodegradation and an increased flux of contaminants to the CGA. During dry periods, a decrease in precipitation results in less recharge and water levels drop. Conditions become more reducing and contamination remaining in the groundwater is rapidly degraded. The magnitude of this effect on ARD reactions will need to be determined through additional sampling timed to changes in seasonal recharge.

5.2 Data Gap 2—FGA Conditions

This data gap contained three components: 1. The extent of FGA contamination, 2. The extent of the dechlorination zone, and 3. The extent of source degradation. Groundwater and Gore-Sorber⊇ data were used to evaluate the extent of FGA contamination. Results indicate the presence of remaining source contamination in the form of TCE in the GW-11/RW-11 area (TCE and *cis*-1,2-DCE concentrations were equivalent to approximately 700 σg/L TCE at RW-11) (Table 5-1). Results also indicate the presence of another potential source area in the eastern portion of the site at GW-4 and UDBW-2. The presence of ethene in the GW-11/RW-11 area indicates an active dechlorination zone in this area. As described in Section 5.1, seasonal fluctuations result in a flux of TCE and *cis*-1,2-DCE to the CGA at concentrations above MCLs. TCE and *cis*-1,2-DCE are present at concentrations equivalent to approximately 140 σg/L TCE at C-1, UDBP-7, and UDBP-8 (Table 5-1). The rates of these transformation reactions are likely affected by the changing redox conditions as described above. The presence of *cis*-1,2-DCE in the UDBW-2/GW-4 area indicates that biodegradation is probably occurring in that area. However, CA and/or VC were not detected, suggesting that dechlorination is not proceeding to completion. The fate of contaminants in this area is not known at this time.

5.3 Data Gap 3—Conditions Along GW-11 → MW-3

October 1999 data indicated that transport of contaminants from the GW-11 source area appeared to be in the direction of MW-3, rather than toward MW-2 as previously proposed (Figure 1-2) (Martin et al., 2000) (Appendix C Figures C-1 – C-3). For this reason, additional data were necessary east of the kilns to define the eastern plume boundary. Results of July-August 2000 sampling indicate that the eastern boundary of the plume is west of B-2 and GW-5. Results also indicate a component of flow that must be toward MW-5 and C-1 as evidenced by the relatively high levels of TCE and other contaminants at these locations (as illustrated in Figure 4-2). These results indicate that the basic flow and transport properties at the site are not well understood. Additional data collection activities (i.e. tracer test) may be necessary in order to address this problem.

5.4 Data Gap 4—Aerobic Degradation in the CGA

This data gap called for the monitoring of additional locations to the north and west of MW-3 and UDBP-4 in order to determine the fate of degradation products beyond the site boundary. Suitable locations were not located, and UDBW-3, an existing well that was sampled October 1999, could not be sampled July-August 2000 due to access difficulties. For this reason, adequate data were not collected to address this data gap.

Table 5-1. Equivalent TCE and 1,1,1-TCA concentrations calculated from TCE and *cis*-1,2-DCE and 1,1,1-TCA and 1,1-DCA concentrations, respectively.

Wells	TCE σg/L	*cis*-1,2-DCE σg/L	Total mol/L	Equivalent TCE σg/L	1,1,1-TCA σg/L	1,1-DCA σg/L	Total mol/L	Equivalent 1,1,1-TCA σg/L
FGA & FGA Sand								
B-2	0	0	0	0	0	0	0	0
GW-11	0	0.6	6 E-09	1	0	1.9	2E-08	3
RW-11	65	470	5E-06	702	0	48	5E-07	65
GW-7	0	0	0	0	0	0	0	0
PZ-IW-2	0	0	0	0	0	0	0	0
B-1	0	2	2E-08	3	0.5	0	4E-09	1
C-1	14	65	8E-07	102	11	33	4E-07	55
PZ-4	19	89	1E-06	140	4.8	22	3E-07	34
CGA	—	—	—	—	—	—	—	—
MW-1	0.7	21	2E-07	29	1.4	8.4	10E-08	13
MW-2	1.1	11	1E-07	16	2.7	5.7	8E-08	10
MW-3	4	35	4E-07	51	5	11	1E-07	20
MW-4	8	6	1E-07	16	0.8	0	6E-09	1
UDBP-4	6	8	1E-07	17	1	2	3E-08	4
UDBP-5	0	0	0	0	0	0	0	0
UDBP-6	4	26	3E-07	39	6	7	1E-07	15
UDBP-7	16	93	1.08E-06	142	4.1	22	2.53E-07	34
UDBP-8	12	93	1.05E-06	138	3	23	2.55E-07	34

6. CONCLUSIONS

Results of both the October 1999 and July-August sampling activities generally support the hypothesis that natural attenuation via ARD of chlorinated ethenes and ethanes is taking place in the FGA. These results were used to develop the following specific conclusions with regard to geochemical conditions and contaminant fate and transport at the Distler Brickyard Site.

- Two potential source areas exist at the site: 1) The GW-11/RW-11 area and 2) The GW-3/UDBW-2 area. At RW-11, TCE and *cis*-1,2-DCE are present at concentrations equivalent to approximately 700 σg/L of TCE (Table 5-1). While the complete dechlorination pathway of TCE to ethene occurs in the GW-11/RW-11 area, the biodegradation rate is affected by seasonal recharge fluctuations and is insufficient to prevent migration of TCE to the CGA. TCE migrates to the CGA at concentrations as high as 19 σg/L and *cis*-1,2-DCE is as high as 93 σg/L. The ARD reactions could be limited by a lack of electron donor in the GW-11/RW-11 area. The presence of *cis*-1,2-DCE in the GW-3/UDBW-2 area indicates that dechlorination occurs in this area. However, due to the lack of adequate data in this area of the site, the fate of contaminants from the GW-3/UDBW-2 area is not known at this time. It is also not possible with existing data to evaluate the relative strength of this source in order to predict whether or not it poses a long-term threat to groundwater.

- Redox conditions in the FGA and in the CGA from the GW-11/RW-11 source area to UDBP-7 and UDBP-8 are iron-reducing. The remainder of the CGA is aerobic.

- An active dechlorination zone exists in the GW-11/RW-11 area as indicated by both October 1999 and July-August 2000 data.

- Seasonal fluctuations in recharge affect redox conditions, contaminant concentrations, ARD reactions, and the local groundwater flow directions.

7. REMAINING DATA GAPS

The following items represent remaining data gaps for the site. These data gaps need to be considered when implementing a final remedy.

- **GW-3/UDBW-3 Source area.** The nature and extent of this potential source area needs to be assessed to determine the potential threat it poses to groundwater. Also, the groundwater flow and transport pathways from this source into the CGA need to be determined to evaluate what action, if any, is necessary in this area.

- **Magnitude and timing of recharge fluctuations.** An understanding of the magnitude and timing of fluctuations in recharge is necessary to determine the highest contaminant concentration that can be produced from the GW-11/RW-11 source area. This has important implications for the selection of a natural attenuation remedy.

- **Local gradient and groundwater flowpaths.** A large gap in the conceptual model for this site is an understanding of the basic groundwater transport flowpaths within and from the FGA, and how these flowpaths are affected by seasonal recharge fluctuations. Addressing this issue is key to the implementation of any remedy at this site.

8. POTENTIAL FINAL REMEDIAL RESPONSE ACTIONS

The goal of the final remedial response action for the Distler Brickyard Site is to prevent the migration of chloroethenes and ethanes, thus preventing contamination of the CGA aquifer. A review of available technologies was performed in order to select those that might be feasible in this particular hydrogeologic system. The technologies that were evaluated include: pump-and-treat, low permeability barriers, surface caps, surfactant/cosolvent flushing, soil vapor extraction, chemical oxidation, monitored natural attenuation (MNA), MNA with FGA source removal, and MNA with enhanced ARD. As described previously in this report, the migration of contaminants in this system is complicated by the seasonal changes in recharge and variable saturation of potential source area(s). For this reason, potential technologies must be effective under these variable conditions. Also, the generation of an additional waste stream is an undesired result. Pump-and-treat, low permeability barriers, surface caps, surfactant/cosolvent flushing, soil vapor extraction, and chemical oxidation were not selected for further evaluation because they involve the generation of secondary waste streams which would likely require additional treatment and disposal. MNA, MNA with FGA source removal, and MNA with enhanced ARD are recommended as potential technologies that may be effective at this site and are described below.

The following sections provide brief descriptions of possible remedial technologies that could be implemented at this site. Once a technology has been selected, a detailed design document will be prepared to support the field implementation. Potential final remedial responses include a monitored natural attenuation program either with or without additional action targeted at the source area(s). A description of each remedy, along with pros and cons and the expected outcome for each remedy, is summarized in Table 8-1.

1. **Monitored natural attenuation (MNA).** Natural attenuation via intrinsic ARD in the source area(s) and dilution, dispersion, and aerobic degradation in the downgradient portion of the CGA is used to address current contamination.

2. **Monitored natural attenuation (MNA) with targeted source action.** MNA can be used in the CGA as described above; however, in these scenarios, active remedies are targeted at the FGA source area(s). Active approaches to source area remediation might include:

    2a. **FGA Source Removal.** Remaining source contamination in the FGA can be remediated through the physical excavation of contaminated aquifer material.

    2b. **Enhanced ARD in the FGA.** A low-cost and long-term remedy designed for low permeability materials can be used in the FGA to address remaining source contamination. The ideal technology would be in situ (no groundwater extraction) and would require minimal maintenance once installed.

8.1 Monitored Natural Attenuation

In this remedy, natural attenuation processes (dilution, dispersion, and degradation) are relied upon to reduce concentrations of VOCs to acceptable levels. In this scenario, MNA would be implemented for remediation of both FGA and CGA contamination. The following issues need to be considered in order to implement an MNA remedy for this site:

- A determination of the location and strength of source areas at the site and the magnitude of resultant downgradient contamination produced by each.

- A thorough understanding of the groundwater flow and transport system.

- Modeling predictions to ensure that VOC concentrations are lowered to acceptable levels before reaching the nearest point of beneficial use.

- Development and implementation of a long-term monitoring strategy.

If suitable for this site, MNA has many potential benefits over traditional engineered technologies as described in Table 8-1; however, because a source of contamination remains, the timeframe for remediation will be relatively long.

8.2 MNA with Source Action

This section describes approaches in which MNA is used in combination with an additional action targeted at specific source areas. In these scenarios, the targeted source action removes the flux of VOCs to the CGA, resulting in a shorter remediation timeframe compared to MNA alone. Two possible source actions were considered: physical source excavation and source degradation through enhanced ARD.

8.2.1 Physical Source Removal

In this option, contaminated aquifer material is physically excavated and removed, thus removing the source of contamination from the system. The primary benefit of this remedy is that a source of VOC contamination no longer remains. This eliminates the flux of contamination to the CGA, resulting in a shortened remediation timeframe compared to MNA without source removal. While this technology would involve the generation of a secondary waste stream, it is presented here because it is a relatively simple technology whose effectiveness is not compromised by the variable saturation conditions of this system. The primary drawbacks of this remedy are that it requires a field mobilization and management of excavated soil, both of which represent significant costs.

8.2.2 Enhanced ARD

In this option, contamination is destroyed in situ by natural biodegradation processes. The results described in this report indicate that natural biodegradation of VOCs is occurring in the GW-11/RW-11 area. The goal of this remedy is to enhance this natural process, resulting in increased transformation of contaminants. The natural biodegradation is enhanced through the use of an electron donor. In order to be successful in this particular system, the electron donor must be cost-effective, easily delivered to the subsurface, and slowly degraded – thus providing a long-term source of amendments for ARD and requiring minimal maintenance.

Research has been conducted on various electron donors that support enhanced ARD of TCE. Examples of electron donors tested to date include propionate, butyrate, lactate, benzoate, molasses, glucose, ethanol, methanol, and hydrogen (Bouwer and McCarty, 1983; Freedman and Gossett, 1989; and many others). Recently, research has been conducted on the use of polymeric organic materials (POMs), such as corn crop residue, unrefined chitin, and wood shavings, as possible amendments to support ARD (Sinziana et al., in press). The use of POMs for this purpose has many advantages. First, the POM degrades slowly and does not require active maintenance. Second, the slow rate of POM degradation should support the microbial population that performs ARD and minimizes competition from other organisms, such as methanogens. Third, the POM provides both an electron donor and nutrients for microbial growth, eliminating the need to supply nutrients separately. Finally, the POM is an ideal material for bioremediation, because it is generally composed of agricultural byproducts normally considered waste. Therefore, it is inexpensive and readily available.

Table 8-1. Summary of potential remediation technologies.

Technology	Description and Requirements	Pro	Con	Expected Outcome
MNA	No additional engineered remediation strategy – relies on natural mechanisms to reduce contaminant concentrations. Requires characterization to identify source areas and natural attenuation mechanisms. Requires long-term monitoring program.	Requires no additional engineered system or above-ground infrastructure (except monitoring wells). Requires no regular maintenance. Contamination is remediated in situ, so human contact with contaminated groundwater is avoided.	Requires characterization to identify and quantify natural attenuation mechanisms. May require modeling to predict the effectiveness of natural attenuation mechanisms. Requires long-term monitoring program. May require additional wells to support characterization and monitoring program. Timeframe for remediation is longer than MNA with source action.	Contamination will be remediated in situ via natural processes. Remedial timeframe is relatively long – will depend on source strength, timing and magnitude of recharge, and the efficiency of ARD reactions.
FGA Source Removal and MNA	Chloroethene/ane source material in the FGA is physically removed. This stops the flux of contamination to the CGA. Contamination remaining in the CGA is remediated via natural attenuation processes.	The source material is removed from the system. The removal of source material will shorten the remediation timeframe compared to MNA with no source removal.	Requires management of excavated soil, which could represent a significant cost. Requires additional characterization to delineate location of source areas. Requires a field mobilization to remove source material, which could represent a significant cost. MNA will require modeling, additional wells (possibly), and a long term monitoring program, as described above.	The source material is removed from the system, resulting in a shortened remediation time frame compared to MNA alone.
Enhanced ARD in the FGA and MNA	Natural ARD is enhanced using an electron donor. This results in complete degradation of	Results in complete degradation of contamination without off-site migration	This technology has not previously been tested in the field.	The electron donor results in enhanced ARD. Contamination is degraded before it

Table 8-1. (continued).

Technology	Description and Requirements	Pro	Con	Expected Outcome
	degradation of contamination. ARD is enhanced using a slow-release electron donor emplaced in the FGA source area. Contamination remaining in the CGA is remediated via natural attenuation processes.	off-site migration. The remediation timeframe is shortened compared to the unenhanced case. Electron donor is long-lasting and requires no above-ground delivery system, so maintenance costs are low. The electron donor responds to recharge fluctuations, providing amendments for ARD when they are necessary. Because the flux of contamination to the CGA has been stopped, MNA will be necessary only until existing contamination is remediated. External funding may be available for the deployment of this technology.	This technology will require additional characterization and possibly additional monitoring wells to monitor the process. The process will be monitored extensively in the beginning to ensure that it is operating successfully and to optimize the system. MNA will require modeling, additional wells (possibly), and a long term monitoring program, as described above. However, the timeframe will be shorter and the MNA monitoring network will be smaller than for MNA alone.	migrates off-site.

Initial laboratory experiments with POMs have indicated that the POMS supply the necessary fatty acids, alcohols, and hydrogen necessary for ARD of chloroethenes and ethanes. Experiments are currently underway to determine if the POM actually enhances ARD of chloroethenes as expected (Brennan, personal communication). The use of this particular POM technology (chitin) has not been previously tested under field conditions.

The conceptual design for deployment of the POM in the field is presented in Figure 8-1. The POM is ground into a slurry which is either hung in monitoring wells using some sort of permeable bag or is emplaced directly into the source area using a direct-push technology. The POM is installed both upgradient and surrounding the source area. Once emplaced, the POMs release electron donor in the form of fatty acids that stimulates microbial activity and results in the development of a reducing environment that is favorable for ARD. Because there is adequate electron donor present, chloroethenes and ethanes are completely degraded to ethene and/or ethane in this ARD zone before moving downgradient.

This approach is well suited to the Distler Brickyard Site. The low hydraulic conductivity in the FGA makes injection of liquid amendments technically challenging. The use of a solid phase amendment, such as the POM, avoids this problem. The POM is emplaced directly into the formation where it is needed. Also, the variable saturation of the FGA also makes the use of a traditional liquid electron donor difficult. As previously discussed, rising water levels remobilize chloroethene and ethane contamination. At the same time, ARD reactions are slowed due to the increased flux of oxygenated rainwater to the FGA. For these reasons, injections of liquid electron donor must be timed to recharge events in order to provide electron donor when it is needed. The use of the POM provides benefit over liquid electron donors in this area. The POM supplies electron donors during times of saturation, when they are needed, prolonging the life-span of the POM. Because of the advantages the POM provides over conventional liquid electron donors, this approach may be a successful remediation technology for the Distler Brickyard Site.

The deployment of enhanced ARD using POMs at the Distler Brickyard Site would require the following activities. First, as described in Section 8.1, the groundwater flow system must be better characterized. This will be required for any of the remedies outlined in this report. Second, extent of the GW-11/RW-11 source must be better delineated. This is necessary to ensure that the source area is completely enclosed by the POM. Also, additional monitoring wells may be necessary immediately downgradient of the GW-11/RW-11 to monitor the efficiency of ARD reactions in the source area. For the same reason, frequent monitoring will likely be required in the initial testing stages of the deployment. Additional laboratory and field-testing will be required to develop the strategy for deployment of this technology at the Distler Site. As with any remedy, continued monitoring of downgradient CGA wells will be required for some period of time to ensure that concentrations in groundwater are below acceptable levels before reaching the nearest beneficial use.

If allowed by the EPA and the state of Kentucky, the Distler Site would be used as a research site to test the performance of the POM technology in the field. The implementation would likely be through a collaborative research effort between INEEL, the University of Illinois, and the USGS. This research would be funded through external sources, such as the National Science Foundation or the U.S. Department of Defense Small Business Innovation Research or Small Business Technology Transfer Programs.

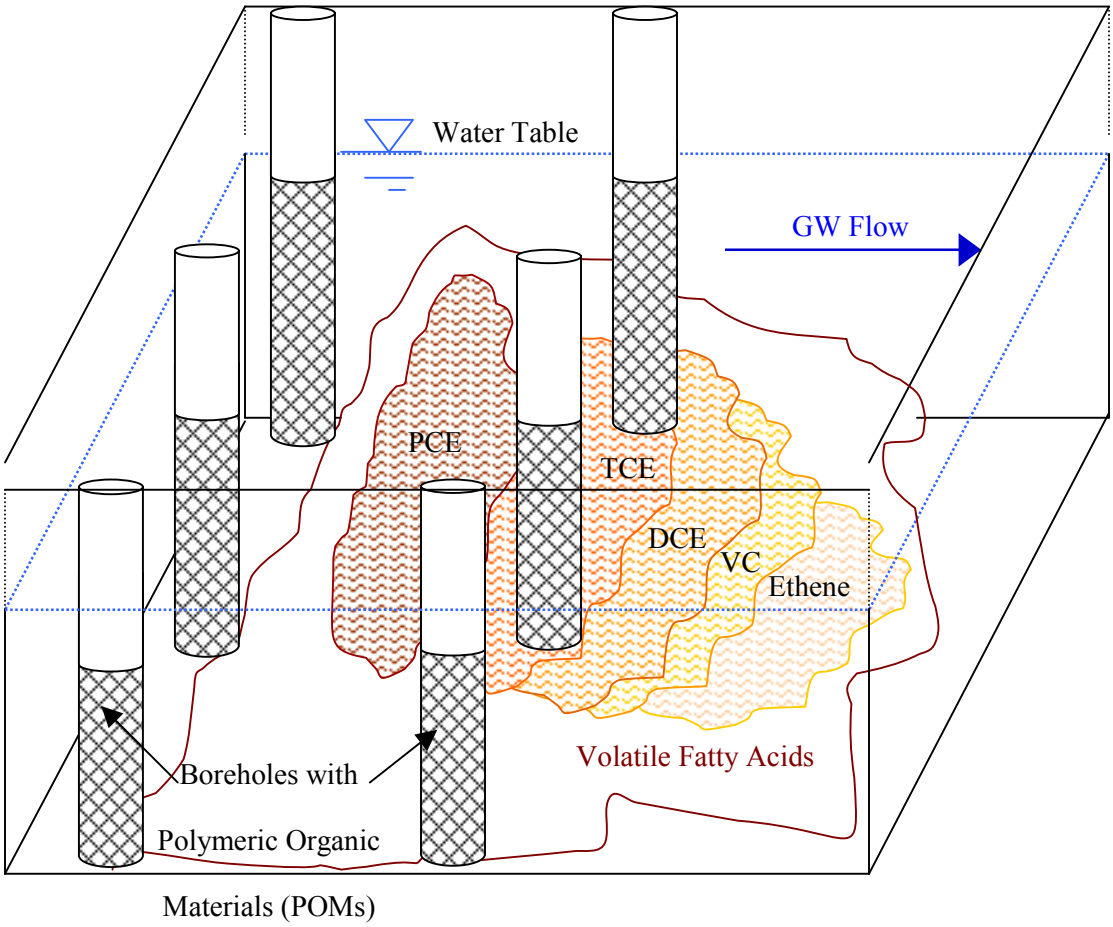


Figure 8-1. Conceptual field deployment strategy for enhanced ARD using POM (Sinziana et al., in press).

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Appendix A

Monitoring Well Installation Logs and Completion Diagrams

Appendix B

July-August 2000 Data Summary Tables

Table B-1. Oxidation-reduction parameters.

Wells	Dissolved Oxygen mg/L	Total Nitrate/Nitrite mg/L	NO_2^- mg/L	NO_3^- mg/L	Fe (II) mg/L	Sulfate mg/L	Methane σg/L
FGA & FGA Sand							
B-2	0.47	ND	0.034	NA	0.97	89	22
GW-11	0.44	ND	0	NA	6.25	79	58A
RW-11	2.85	ND	0.101	NA	0.04	50	11
GW-7	0.24	—	0.035	NA	0.72	—	—
PZ-IW-2	0.97	—	0.166	NA	1.31	—	—
B-1	2.15	0.65	0.82	NA	0.35	59	5.4A
C-1	6.9	0.94	0.14	0.8	0	67	4.4
PZ-4	3.2	0.05	0.098	NA	0.34	73	16
CGA							
MW-1	5.26	0.34	0.064	0.276	0	59	ND
MW-2	4.04	0.46	0.037	0.423	0.31	61	ND
MW-3	3.92	0.96	0.043	0.917	0.5	52	0.34J
MW-4	5.57	2.6	0.03	2.57	0.23	73	4.2
UDBP-4	2.12	1.8	0.007	1.793	0.1	50	0.17J
UDBP-5	1.98	0.86	0.142	0.718	0	49	0.98J
UDBP-6	2.5	0.79	0.62	0.17	0.05	48	0.22AJ
UDBP-7	0.13	ND	0.088	NA	3	50	0.42J
UDBP-8	0.07	ND	0.18	NA	4.7	73	1.5

A = Average J = Approximate ND = Not Detected NA = Not Applicable

Table B-2. Volatile organic compounds in groundwater. All data in σg/L.

Wells	PCE	1,1,2-TCA	1,1,1-TCA	TCE	1,1-DCA	cis-1,2-DCE	1,2-DCA	trans-1,2-DCE	1,1-DCE	CA	VC	Ethene	Ethane
FGA & FGA Sand													
B-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GW-11	ND	ND	ND	ND	1.9	0.6	1	4	ND	82	ND	3.0A	0.28AJ
RW-11	ND	ND	ND	65	48J	470	ND	10J	ND	ND	39J	8.5	ND
GW-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	—
PZ-IW-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	—
B-1	1	ND	0.5J	ND	ND	2	ND	ND	ND	ND	ND	ND	1.2AJ
C-1	ND	ND	11	14	33	65	ND	ND	ND	ND	ND	ND	1.2J
PZ-4	ND	4.2	4.8J	19	22	89	ND	3	ND	2.6	ND	ND	ND
CGA													
MW-1	ND	ND	1.4J	0.7J	8.4	21	2.7	ND	ND	ND	ND	ND	ND
MW-2	ND	ND	2.7	1.1	5.7	11	ND	ND	ND	ND	ND	ND	ND
MW-3	ND	ND	5	4J	11	35	ND	ND	ND	ND	ND	ND	ND
MW-4	ND	ND	0.8J	8	ND	6	ND	ND	ND	ND	ND	ND	1.0J
UDBP-4	ND	ND	1	6	2	8	ND	ND	ND	ND	ND	ND	ND
UDBP-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
UDBP-6	ND	ND	6	4	7	26	ND	ND	ND	ND	ND	ND	ND
UDBP-7	1.2	1.9	4.1J	16	22	93	5.4	3.2	0.7J	ND	ND	ND	ND
UDBP-8	ND	2.3	3.0J	12	23	93	9.2	2.8	ND	1.1	ND	ND	ND

A = Average J = Approximate ND = Not Detected NA = Not Applicable

Table B-3. Volatile organic compounds detected in Gore-Sorbers. All data in σg per sorber.

Well	PCE	1,1,2-TCA	1,1,1-TCA	TCE	1,1-DCA	cis-1,2-DCE	1,2-DCA	trans-1,2-DCE	1,1-DCE
FGA & FGA Sand									
B-2	ND	ND	ND	ND	0.07	0.05	ND	ND	ND
GW-11	0.17	ND	4.15	1.53	3.44	2.92	0.20	0.59	0.47
GW-11 (dupl.)	0.24	ND	1.54	0.94	2.68	2.14	0.09	0.35	0.11
GW-7	ND	ND	0.09	0.02	ND	ND	ND	ND	BDL
PZIW-2	ND	ND	BDL	ND	ND	ND	ND	ND	ND
B-1	0.04	ND	0.77	0.08	0.16	0.46	0.04	0.05	0.31
GW-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
GW-6	ND	ND	ND	ND	ND	ND	BDL	ND	ND
GW-2	BDL	ND	ND	ND	ND	ND	ND	ND	ND
GW-4	0.24	ND	BDL	3.58	ND	0.49	BDL	0.07	BDL
UDBW-2	0.17	ND	BDL	19.8	ND	6.09	ND	0.12	ND
GW-1	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-5	0.19	0.07	6.57	8.60	3.69	6.77	0.30	0.24	0.34
CGA									
UDBP-7	ND	ND	0.14	0.21	0.32	1.32	0.03	0.10	BDL
MW-1	ND	ND	0.26	0.03	0.14	0.21	ND	BDL	BDL
MW-1 (dupl.)	ND	ND	0.28	0.04	0.14	0.23	BDL	BDL	BDL
GW-3	ND	ND	ND	ND	ND	ND	ND	ND	ND
DL	0.03	0.03	0.04	0.02	0.04	0.02	0.02	0.03	0.04

ND = Not detected BDL = Below Detection Limit DL = Detection Limit

Table B-4. Potential electron donors.

Wells	Total Organic Carbon mg/L	Dissolved Organic Carbon mg/L	Ethyl Benzene σg/L	Total Xylenes σg/L
FGA & FGA Sand				
B-2	9.9	9.3	ND	ND
GW-11	20	19A	45J	89
RW-11	17	14	ND	ND
GW-7	—	—	ND	ND
PZ-IW-2	—	—	ND	ND
B-1	9.1	7.4	ND	ND
C-1	18	13	ND	ND
PZ-4	20	14	ND	ND
CGA				
MW-1	14	10	ND	ND
MW-2	12	9	ND	ND
MW-3	8.4	7.9	ND	ND
MW-4	10	8.1	ND	ND
UDBP-4	8	7.6	ND	ND
UDBP-5	8.4	7.7	ND	ND
UDBP-6	6.8A	5.1A	ND	ND
UDBP-7	12	10	ND	ND
UDBP-8	12A	10	ND	ND

A = Average J = Approximate ND = Not Detected NA = Not Applicable

Table B-5. Bioactivity parameters.

Wells	Alkalinity mg/L	Carbon Dioxide mg/L
FGA and FGA Sand		
B-2	347	138
GW-11	349	168
RW-11	374	125
GW-7	NA	123
PZ-IW-2	NA	140
B-1	257	86
C-1	475	NA
PZ-4	411	168
CGA		
MW-1	381	104
MW-2	370	113
MW-3	316	88
MW-4	316	72
UDBP-4	286	77
UDBP-5	279	112
UDBP-6	300	109
UDBP-7	322	127
UDBP-8	388	132

Table B-6. Biological nutrients.

Wells	Ammonia mg/L	Total Phosphorus mg/L
FGA and FGA Sand		
B-2	0.17	0.18
GW-11	0.13	0.029
RW-11	ND	0.17
GW-7	—	—
PZ-IW-2	—	—
B-1	0.12	1.6
C-1	ND	3.2
PZ-4	0.091	1.8
CGA		
MW-1	ND	0.02
MW-2	ND	0.02U
MW-3	ND	0.3
MW-4	ND	1.1
UDBP-4	ND	0.1
UDBP-5	0.052	0.6
UDBP-6	ND	0.096A
UDBP-7	ND	ND
UDBP-8	0.094A	0.098A

Table B-7. Chloride concentrations from October 1999 and July 2000.

Wells	Chloride October 1999 mg/L	Chloride July 2000 mg/L
FGA and FGA Sand		
B-2	—	1.9
GW-11	2.6	2.5
RW-11	—	14
B-1	—	3.9
C-1	—	80
PZ-4	—	13
CGA		
MW-1	14A	30
MW-2	16	12
MW-3	100	12
MW-4	—	2.9
UDBP-4	41	4.3
UDBP-5	—	4.2
UDBP-6	—	10
UDBP-7	120	4.6
UDBP-8	140	11

A = Average

Appendix C

October 1999 Contour Plots

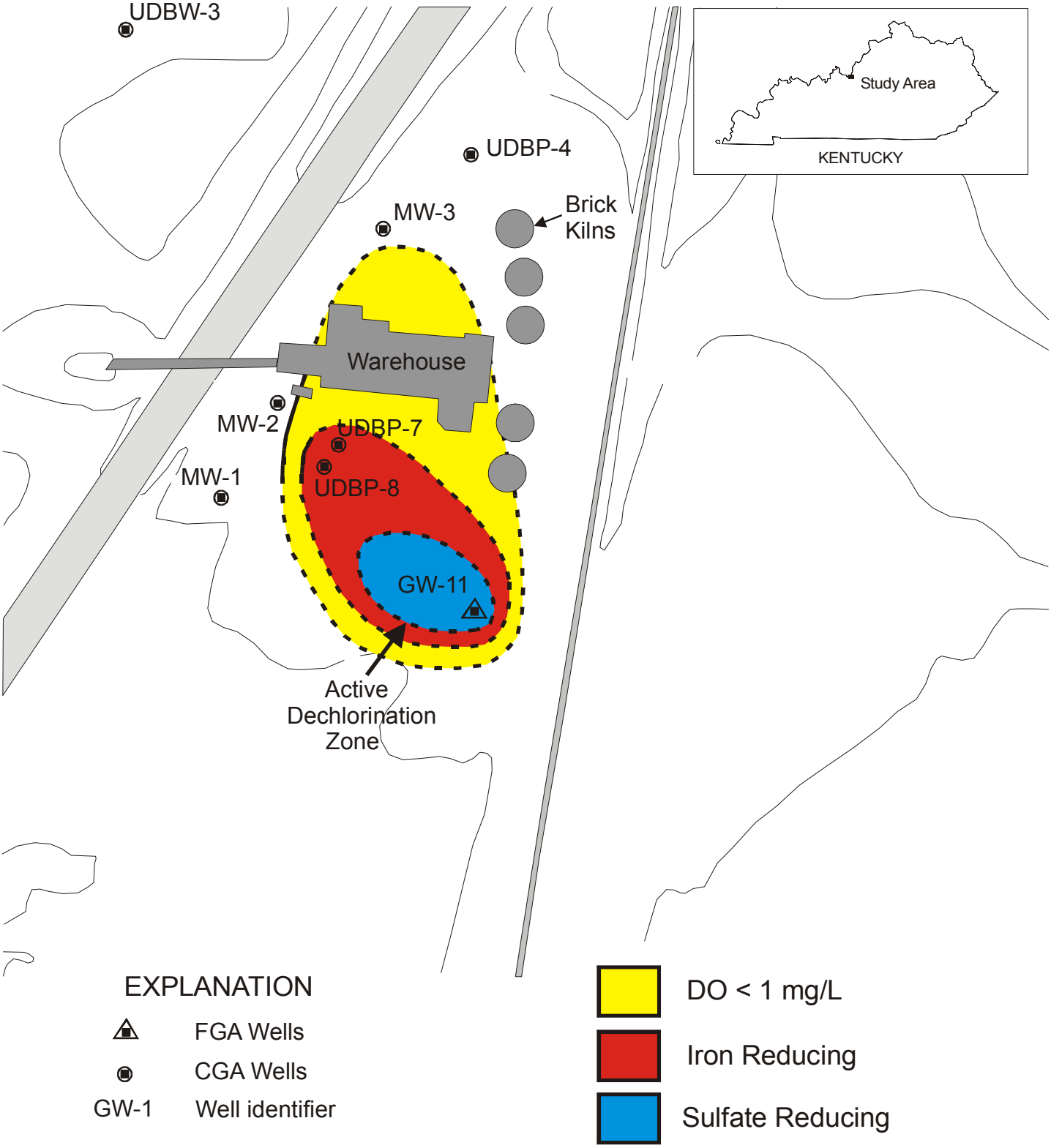

Figure C-1. Redox conditions October 1999.

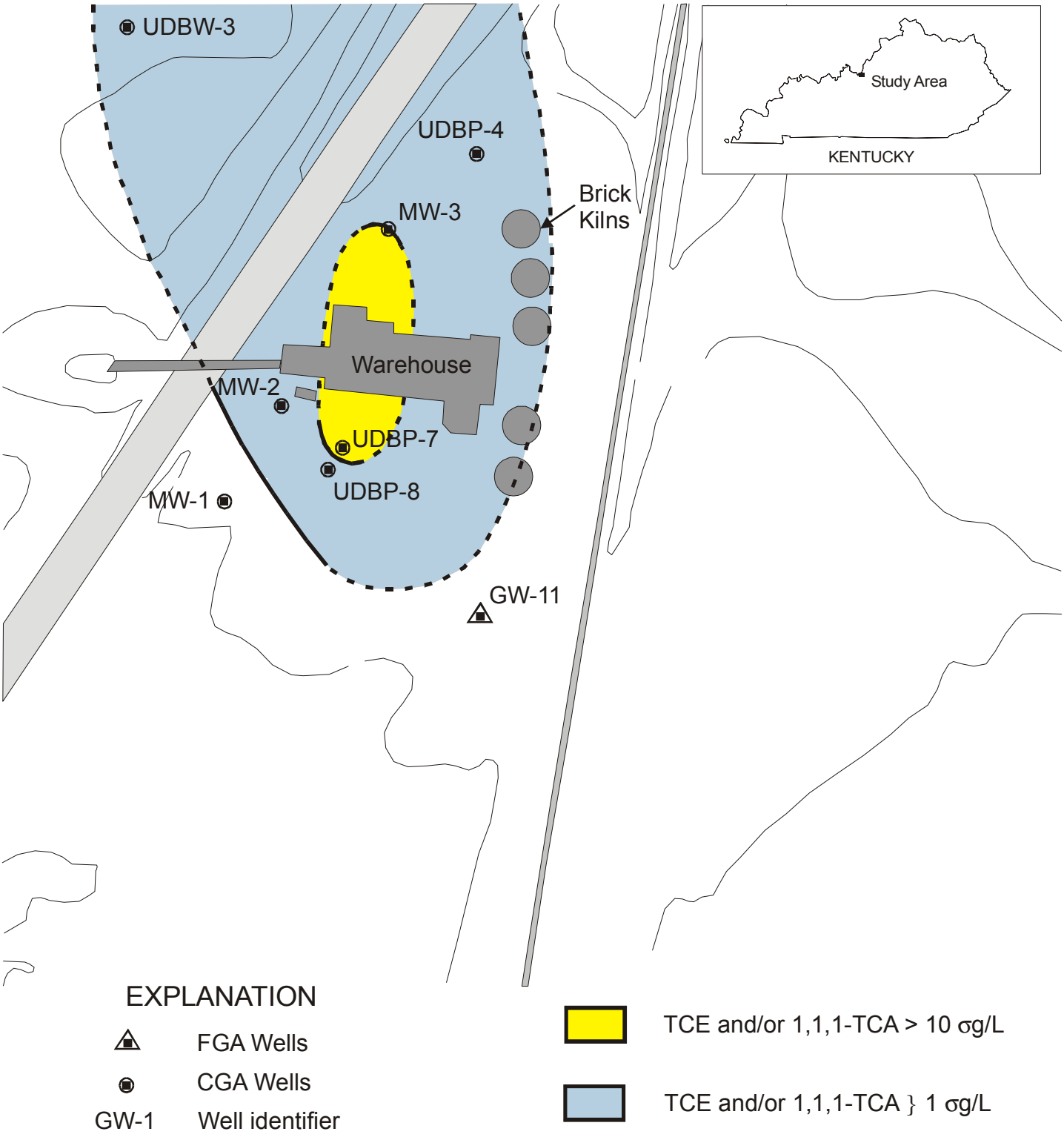

Figure C-2. TCE and 1,1,1-TCA concentrations October 1999.

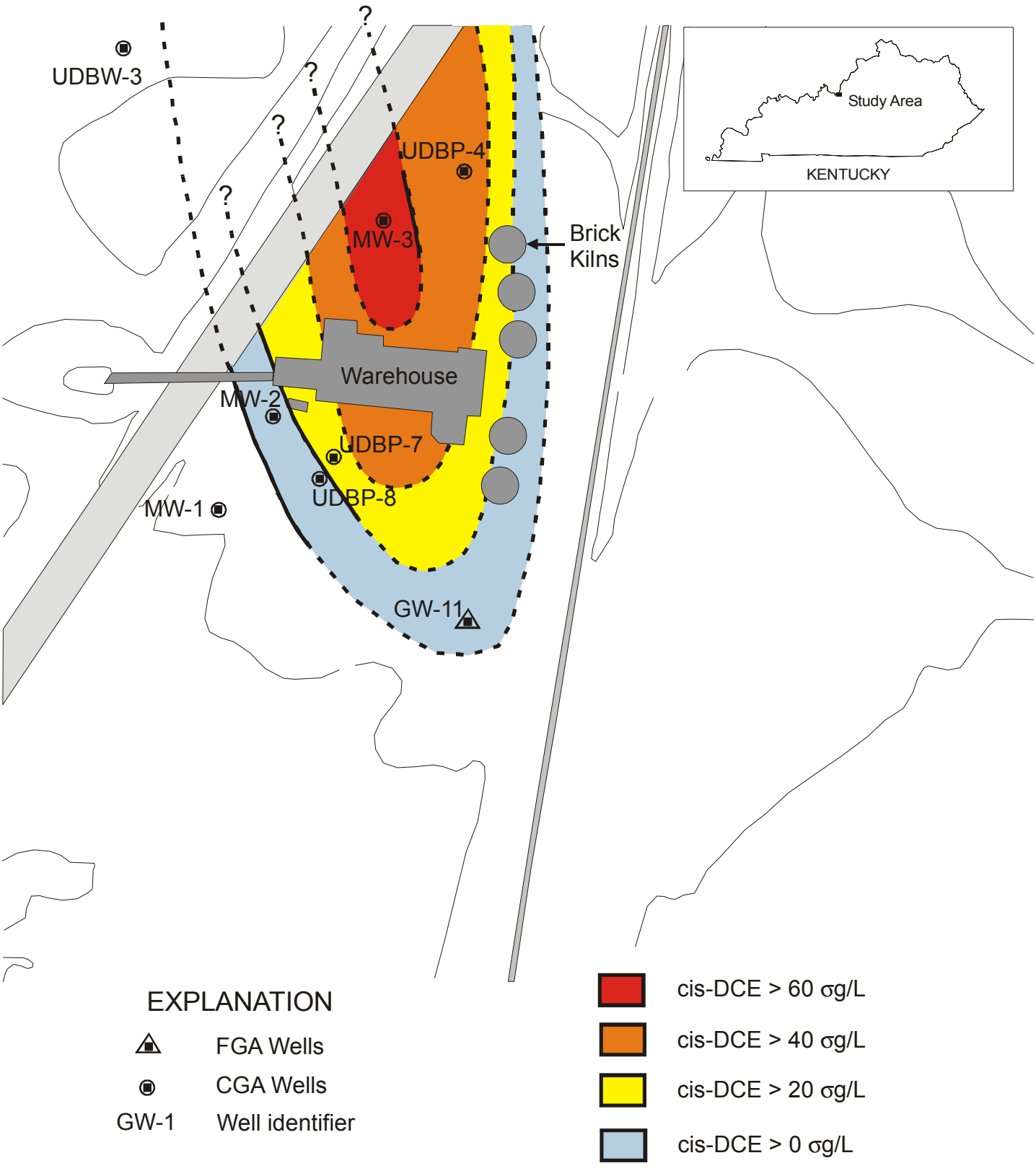

Figure C-3. Biodegradation product *cis*-1,2-DCE concentrations October 1999.

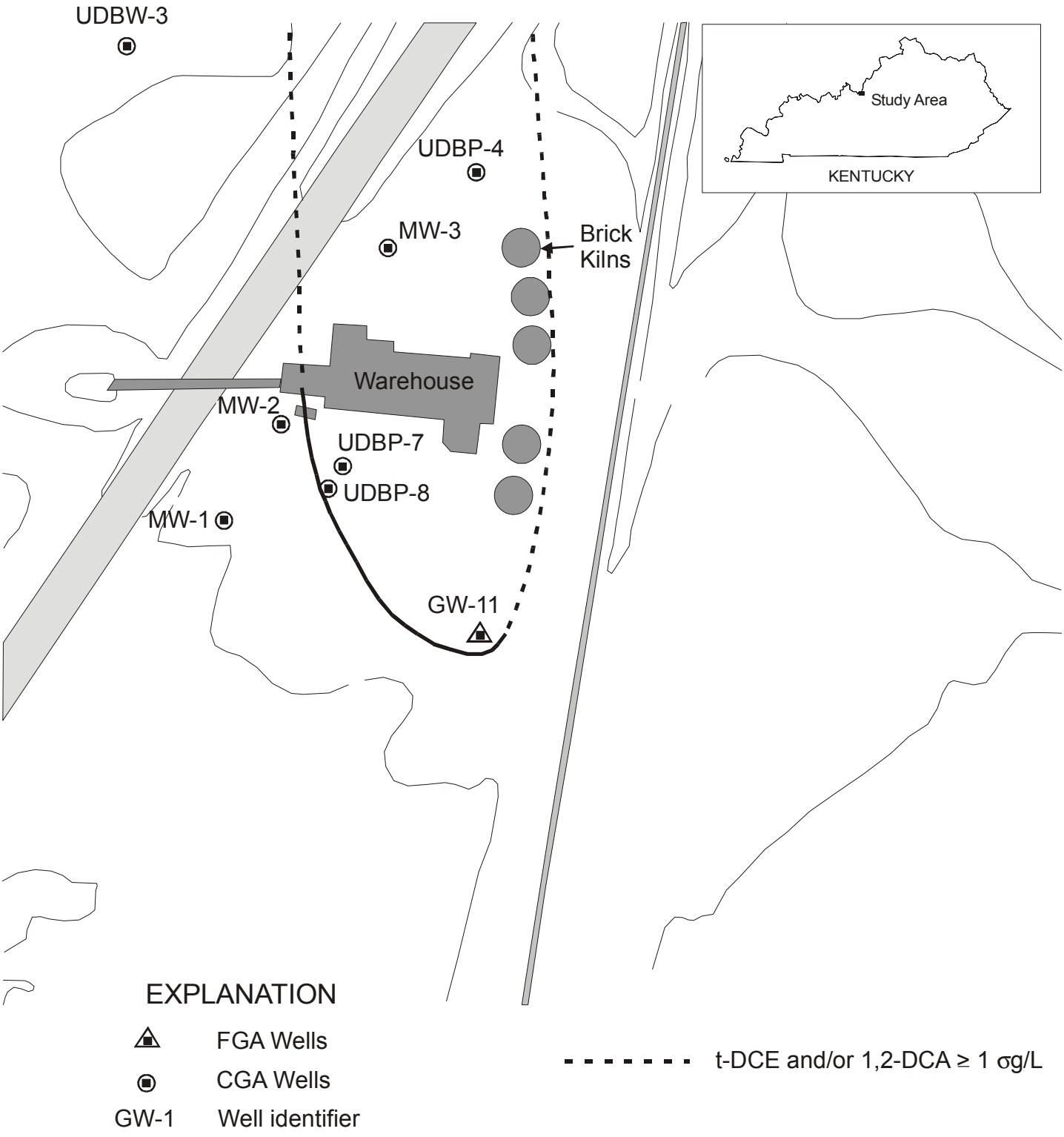

Figure C-4. Non-biologically produced degradation products *trans*-1,2-DCE and 1,2-DCA concentrations October 1999.

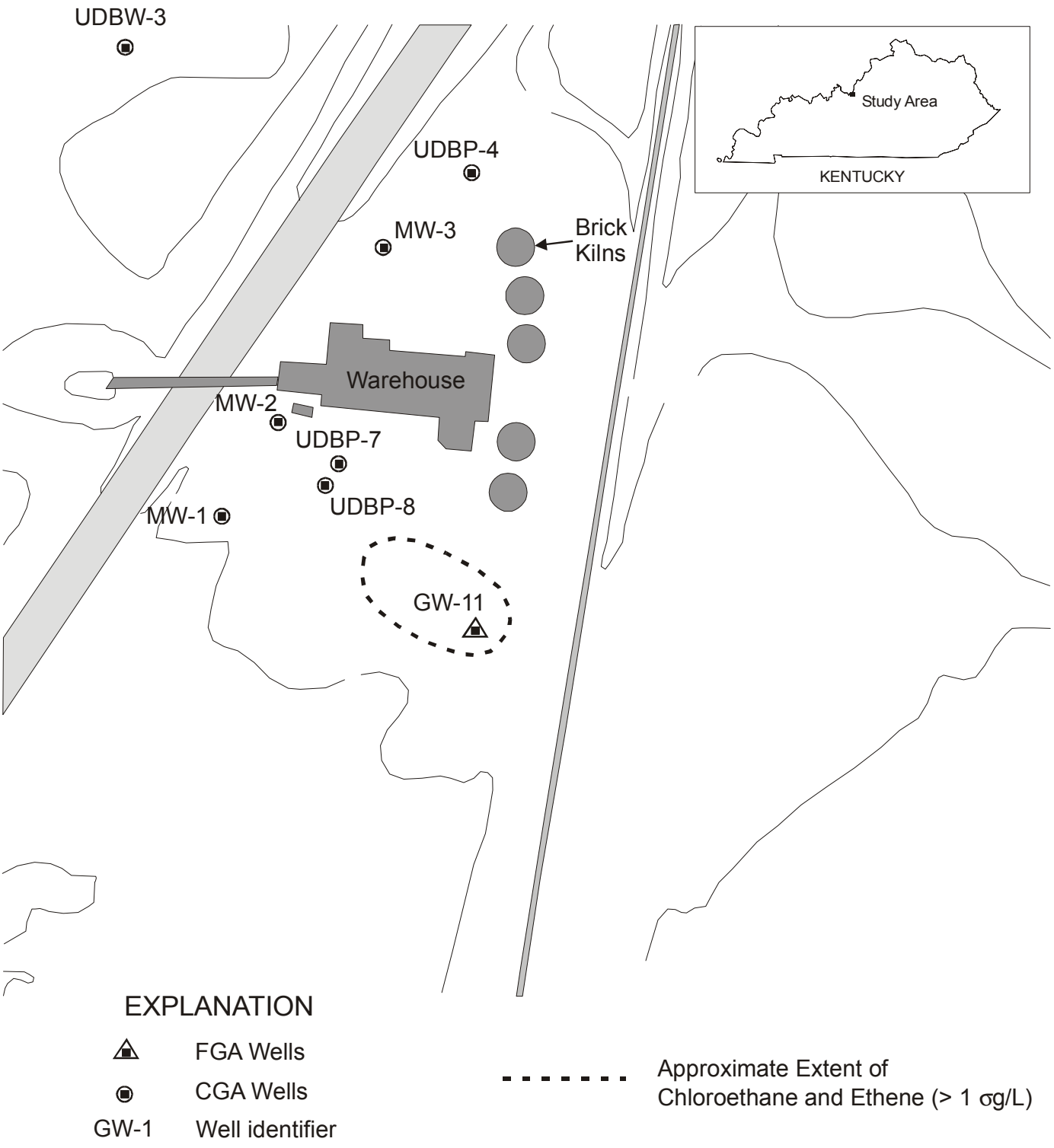

Figure C-5. Chloroethane and ethene concentrations October 1999.