NEIU GEOGRAPHY and ENVIRONMENTAL STUDIES

COMPARISON OF CHEMICAL AND HYDROGEOLOGIC PROPERTIES OF GROUNDWATER EXTRACTED FROM HOLLOW-STEM AUGER AND DIRECT PUSH MONITORING WELLS

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ABSTRACT

Some governmental agencies are hesitant to allow Direct-Push Technology as a viable option for groundwater monitoring because it is a new technology that is relatively untested and unproven. This research paper is a field comparison of the chemical and hydrogeological properties of groundwater extracted from paired Direct-Push (DP) and Hollow-Stem Auger (HSA) monitoring wells. This paper compares water table elevations, Benzene, Toluene, Ethyl benzene, total Xylenes (BTEX) concentrations and hydraulic conductivity values of the two well installation methods at a glacial till site in Des Plaines, Illinois. Three well sets (one of each well type in each set) were installed at a site with known groundwater contamination from an underground storage tank (UST). Results were statistically analyzed using a direct correlation analysis to produce representative *r* values, then compared to critical r values for the appropriate degrees of freedom. The results of the study show that there is no statistical difference in the measurement of water table elevations ($r = 0.998$) or sum of BTEX constituents ($r = 0.755$) from the well types. There were other factors other than well type that accounted for some of the variation in samples. The well sets were not located directly parallel to the leading edge of the groundwater plume—in one well set the DP well was closer to the plume, and in the other well set the HSA well was closer. Hydraulic conductivity values were an order of magnitude less in the DP wells than the HSA wells, however this may be corrected if more sophisticated development methods are used.

INTRODUCTION

The protection of water (and more specifically groundwater in this paper) has become more than an economic and political battle in recent decades. It was once thought that there is an endless supply of water, a commodity that can be bought and sold at will. This sentiment has long since passed, where some potable water supplies are now depleted, inaccessible or contaminated. Water resources need to be protected as not only a commodity, but as a resource. Luna Leopold, a leading water resource management expert, suggests that “a new philosophy of water is needed—one based on geologic, geographic, and climactic factors as well as on the traditional economic, social and political factors” (Excerpt from Environmental Geology, 1997).

The protection of our valuable water resources has to evolve into a balance between ecology and economics. There have not been the complex water resource issues in the past as there are today. A clean supply of water is something most North Americans take for granted, but do not realize how vulnerable it really is.

The regulation and protection of water has become a major issue in California, Nevada, and almost surprisingly, Illinois. These areas and many others are facing water supply issues that are fast coming to the forefront of environmental protection. Only today are we realizing that these issues need to be addressed before it is too late.

Groundwater is the source of drinking water for almost half of the United States population (Kram et al, 2001). More specifically, the Chicago region in the eighteenth and nineteenth centuries used groundwater at much higher rates of consumption than today (Jaffe, 2001). The overuse of the Chicago aquifers has drastically lowered the elevation of the groundwater, making them unusable for many years until water levels start to rise again. Lake Michigan now serves as a large generator of water to many communities, but where there is no infrastructure extending beyond some suburbs, groundwater is the source of water for many communities. Protecting this valuable, finite resource is of concern for any environmentalist.

Groundwater constitutes approximately 98% of the Earth's available freshwater (Schwartz and Zhang, 2003). The "containers" that hold groundwater are called aquifers, and have the ability to transport water from below the surface up to the ground surface for human consumption. Since water is held so easily with subsurface soils, it can be safe to assume that other liquids can be held in aquifers as well.

Water is commonly referred to as the "universal solvent," meaning water is able to dissolve many, many chemicals within its oxygen and hydrogen atomic structure. Dissolved chemicals held within the water molecules can be transported as easily as the water itself. Some chemicals of concern are petroleum-based chemicals because many of them can be transported by water very easily. For example acetone can dissolve in water in a one-to-one ratio, meaning for every water molecule in a known volume, there is an equal amount of acetone molecules (Fetter, 1999). Why are these chemicals of concern? Many of the organic, benzene-ring based chemicals are human carcinogens, where at high levels of concentration are detrimental to human and ecosystem health. Industrialized nations rely on petroleum products as their main source of energy, relying on petroleum that is created naturally by decomposed organic matter. Petroleum products (oil, coal and natural gas) are confined in the Earth's crust in total equilibrium with its surrounding geology.

Humans are now able to alter the balance between the stored coal, oil and gas by disrupting the subsurface strata to extract the petroleum products for human consumption. The problem with the consumption of petroleum is that humans are very messy. We do not always clean up our mess, and when a petroleum product is spilled contaminating groundwater, major efforts are needed to clean it up.

There are a multitude of potential non-point sources for groundwater contamination. Major contributors to the groundwater contamination problem are leaking underground storage tanks (LUSTs). LUSTs are a common source of petroleum and hazardous chemical contamination in groundwater due to the migration of contaminants along permeable flow paths in subsurface soil units. In 1997, the U.S. Congress has addressed 30 potential sources of groundwater contamination (Fetter, 1999, USEPA 1977). Of the broad categories of potential groundwater contamination listed, the United States Environmental Protection Agency (USEPA) lists underground storage tanks (USTs) as a high priority for groundwater contamination (Fetter, 1999). **Appendix A** is a summary of the regulation and procedural requirements of the Illinois Leaking Underground Storage Tank Program.

When an Underground Storage Tank (UST) is known to leak, there are necessary steps taken to determine if the release of petroleum has contaminated the soil and/or groundwater—and if it will affect human health or the environment. One of the steps is to install monitoring wells surrounding the UST location to observe and sample the groundwater for petroleum contamination.

Until recently there have been three major categories of drilling methods used to install groundwater monitoring wells: Hollow-stem auger, Rotary Drilling, and Cable-Tool Drilling. Of these three, Hollow Stem Auguring (HSA) is the most common in LUST groundwater site investigations (Fetter, 1999).

STATEMENT OF THE PROBLEM

A fourth technology called Direct-Push technology has become the source for much research and debate. The technology is cheaper, faster and more efficient in shallow groundwater site investigations than HSA drilling techniques. It appears that this new technology may be able to ease budgetary constraints in some Federal, State and local environmental programs, but needs to become better accepted for its technical merit.

Since it is a new technology, governmental agencies are hesitant to allow these types of monitoring wells in the investigation of groundwater contamination because the technology is unproven (Alvarez et al, 2002). A 2001 Illinois Environmental Protection Agency (IEPA) Fact Sheet describes that "…(Direct) Push-Driven technology is an emerging technology and, as it evolves, the application of this technology will likely change." In Illinois, Direct-Push technology is not accepted in regulation as the sole drilling method in some groundwater investigations. The technology in other states is becoming a generally accepted site investigation method (McCall, 2002). Even without state governmental approval, Direct-Push technology has been in use for over a decade through non-governmental investigations with proven success.

Direct-Push drilling involves using percussion hammers and static vehicle weight combined with hydraulic cylinders to advance drilling rods to specific depths (McCall, 2002). The rods can be used to collect soil samples from the rods that are pulled up from the subsurface. Once all the rods are removed from the apparatus, PVC plastic monitoring well pipes can then be fed down through the open, cased borehole to its required depth. The rods are then removed from the hole, leaving behind the completed well. A complete description of the Direct-Push installation methods is discussed in the Methods section of this report.

Conventional Hollow-Stem Auger drilling uses the same methodology, where PVC piping is fed into a hollow borehole, however large diameter augers are drilled into the subsurface (rather than being pushed into the ground). This produces large amounts of displaced soil brought up to the surface that need to be discarded. In most cases the soil is contaminated, so the soil is placed into 55-gallon drums to await off-site disposal. This is where some of the benefits of Direct-Push drilling are seen.

If no soil is sampled before the well is installed, Direct-Push monitoring wells do not produce soil cuttings. By comparison, Hollow-Stem Auger monitoring wells produce approximately one 55-gallon drum of spoiled soil for each 5 meters (15-feet) of drilling—based on personal field experience. In Illinois, the cost to dispose of contaminated soil produced from the installation of monitoring wells is from $150 to $500 per 55-gallon drum—again based on personal field experience. Usually four to six monitoring wells are installed in each groundwater investigation, therefore the costs for soil drum disposal itself ranges from $600 to $3,000.

The drilling equipment used in Direct-Push monitoring wells can also be much more versatile, efficient and cheaper than Hollow-Stem Auger drilling equipment. An HSA drilling machine can be large and cumbersome at smaller sites, not very efficient in narrow spaces. Geoprobe® model Direct-Push drill rigs are sometimes smaller than a mid-size car and can enter into a garage to install wells inside buildings.

Time efficiency is another key factor in which Direct-Push wells are more efficient. The less time field personnel and driller are out at a site provides more time to analyze the data and less cost to the person paying for the investigation. Personal experience has shown that the time needed to install HSA monitoring wells is in the range of 1.5 - 3 hours per well. By comparison, DP wells can usually be installed in less than 1 hour. Drilling costs for DP technology can be much less than conventional drilling methods.

Since DP drilling technology appears to be more cost-effective and efficient than HSA drilling technology, if the two methods correlate in their representation of ground-water sample results taken from LUST sites, more and more State and Federal environmental regulatory agencies will be willing to accept the DP method with the same regard as the HSA method.

This research paper serves as a comparison of the chemical and hydrogeological properties of groundwater extracted from Hollow-Stem Auger (HSA) and Direct-Push (DP) monitoring well installation methods. The two monitoring well types were installed at different locations surrounding a former leaking UST system in Des Plaines, Illinois.

SCOPE

A total of three (3) HSA monitoring wells and three (3) DP monitoring wells were installed surrounding a former leaking underground storage tank hydrocarbon release, approximately 1 meter from each other. The resulting configuration of wells produced three wells sets; one DP well and one HSA well in each set.

Refer to **Figure 1** for the location of the monitoring wells. The three sets of monitoring wells were designated:

1. **DP-1 and MW-3**
2. **DP-2 and MW-2**
3. **DP-3 and MW-5**

Where, DP = Direct-Push monitoring well and MW = HSA monitoring well.

A concentrated effort was made to place each set of wells equidistant to the hydrocarbon release in an attempt to mitigate concentration gradients between the monitoring wells. Every attempt was made to keep the experiment a controlled experiment. If the hypothetical concentrations of the contaminants were kept the same, the sampling methods from each well type were the same, the laboratory analytical methods used to analyze the samples were the same, and the screen depths and lengths of the monitoring wells were the same, then the only independent variable was the well type. If the results of the study are comparable between the two well types, it can be concluded that it does not matter if a DP or HSA well is installed in a shallow water table groundwater investigation—with respect to the data gathered in this study.

As it stands today, some regulatory agencies are hesitant to allow direct-push technology for groundwater investigations. If the Direct-Push technology can further gain acceptance into regulatory agency methods of procedures, there can be a huge cost and time savings to property owners investigating their hydrocarbon release.

OBJECTIVE

The objective of the study was to determine whether DP monitoring wells will produce results statistically similar to the more conventional HSA monitoring wells. The following hydrogeologic and chemical parameters of groundwater were analyzed:

1. Water table elevations,
2. Hydraulic conductivity (in cm/sec), and
3. The chemical detection of Benzene, Toluene, Ethyl benzene and total Xylenes (BTEX) concentrations in the collected groundwater samples.

REVIEW OF PREVIOUS WORK

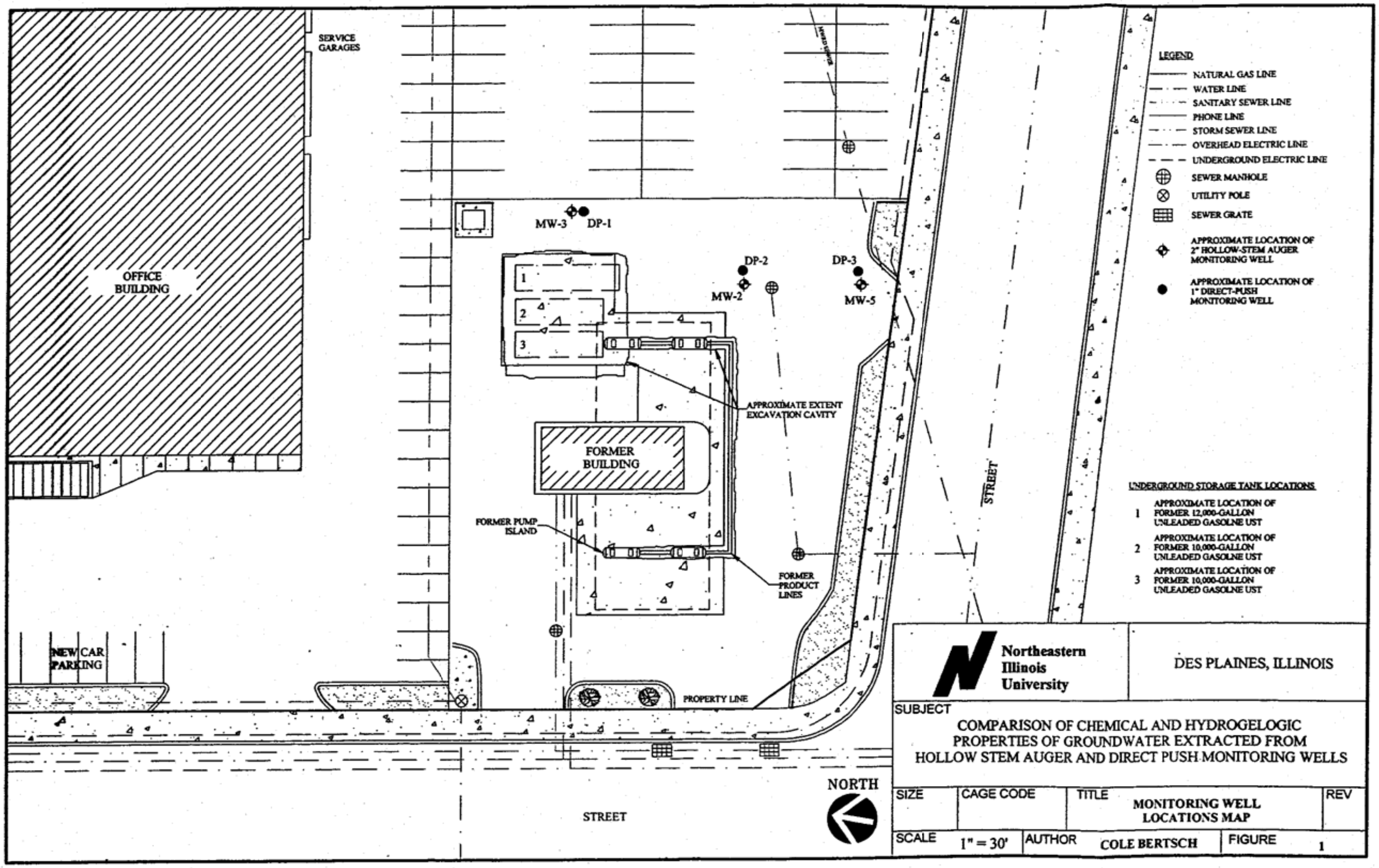
Hollow stem auger monitoring wells are the conventional well installation technique for the detection of petroleum contamination in shallow subsurface aquifers (Schwartz, 2003). Direct-push technology has become a popular, cost-effective method in environmental site investigations, however its use has been more closely associated with soil investigations. There have been three published papers documenting the comparisons between HSA and DP monitoring well installations:

1. Work completed by British Petroleum (BP) in conjunction with the USEPA Regions 4 and 5 has shown how direct-push groundwater monitoring wells can display accurate characteristics of groundwater (Alvarez et al. 2002). Groundwater samples from sets of wells at four different sites were analyzed for: geochemistry parameters, hydraulic conductivity testing, BTEX, MTBE and Naphthalene concentrations. The conclusions from the study indicated that:

- Groundwater levels measured in conventional versus direct-push monitoring wells are nearly identical.
- For BTEX measurements, there is no difference between the concentrations measured in samples from direct-push and conventional monitoring wells across three of the four sites.
- The mean hydraulic conductivity from the conventional wells is 4.4 times greater than from the direct-push wells, suggesting a systematic error or problem. The consistently lower hydraulic conductivity in the direct-push wells are believed to be due to poor well development of the direct-push wells.

2. The US Navy conducted a comparison study on the detection of the chemical Methyl-tert-Butyl-Ether (MTBE) at the Port Hueneme, California Naval Base (Kram et al, 2001). A total of 12 well sets were analyzed for MTBE concentrations, resulting in very similar results between the HSA and DP monitoring wells.
3. The company that makes the most popular model of Direct Push drill rigs—Geoprobe—conducted a study comparing DP to HSA wells in Smokey Hills Valley, Kansas (McCall, 2002). The study area is located in an alluvial depositional environment, with many strata of silts, sands and gravel. The results of the study indicated that there were no differences in the analyzed water table elevations, pH, specific conductance, turbidity and chlorinated Volatile Organic Compound (VOC) data from the two well designs.

The research from these three sources serve das a foundation for this study. The previous studies were all conducted in alluvial or outwash deposits of higher permeable soils. This study tried to focus on



Northeastern Illinois University

DES PLAINES, ILLINOIS

SUBJECT
COMPARISON OF CHEMICAL AND HYDROGELOGIC
PROPERTIES OF GROUNDWATER EXTRACTED FROM
HOLLOW STEM AUGER AND DIRECT PUSH MONITORING WELLS

SIZE	CAGE CODE	TITLE	MONITORING WELL LOCATIONS MAP	REV
SCALE	1" = 30'	AUTHOR	COLE BERTSCH	FIGURE 1

the clayey till environments of northern Illinois.

STUDY AREA

The site is a former gasoline service center located in Des Plaines, Cook County, Illinois. The site is located in the Third Principle Meridian of Township 44, Range 44 and the SW quarter of Section 44. The site formerly contained three (3) unleaded gasoline USTs in the northeast corner of the property area, which were removed in 2002. The USTs were known to have a hydrocarbon release, and the site was entered into the Illinois LUST program to remediate the release. This study site was chosen as a representative area because there was known groundwater contamination in previously installed monitoring wells.

The site and the adjacent area are within Des Plaines, Illinois, a city in the near northwest suburbs of Chicago. Topographically, the site is relatively flat, with a slight grade to the south and east. The area was previously leveled for commercial and residential purposes. There are no surface bodies of water in the immediate vicinity of the site, however the Des Plaines River is located approximately 170 meters east.

GEOLOGY

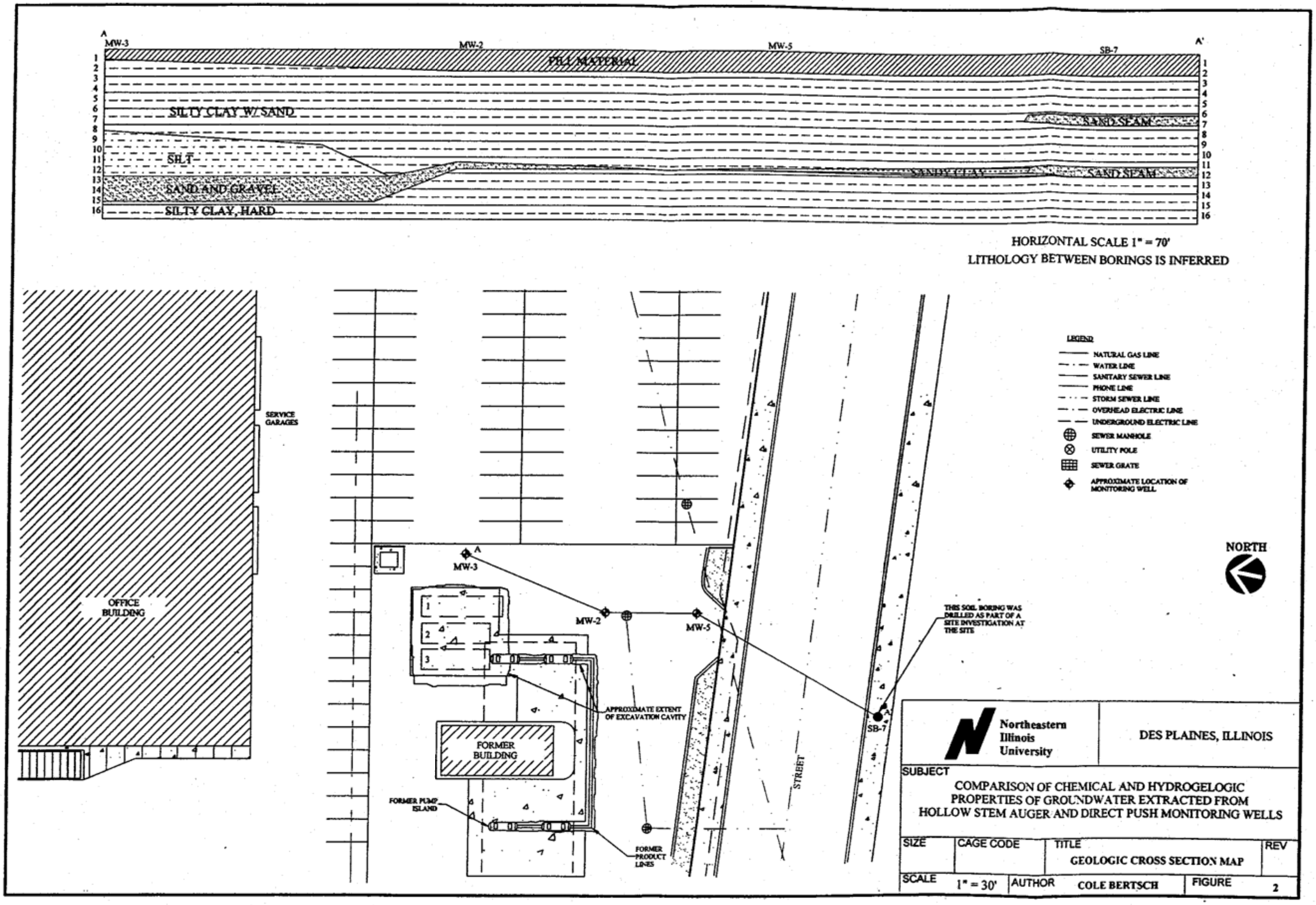
The geology of the site is typical of the Mackinaw Member of the Henry Formation. The Henry Formation usually consists of silt, sand and gravel glacial outwash from outlet rivers of glacial lakes (ISGS, 2003). The general stratigraphy consists of varying depths of Richland Loess silt, underlain by less than 6.5 meters of sands and gravel with local beds of silts, underlain by relatively impermeable glacial till. More specifically, the Mackinaw Member consists of sands and gravel, generally well sorted and evenly bedded; there are mainly glacial till deposits in valleys, where this site is located. The glacial drift thickness at the Des Plaines site is between 30-60 meters, underlain by undifferentiated Silurian aged dolomite bedrock.

This site was chosen because it had known groundwater contamination during site investigation activities conducted in 2003 and 2004. A total of seventeen soil borings were drilled to 5 meters below surface grade for that study. The general site lithology consists of clay fill material to a depth of 1 meter, underlain by moist, silty sandy clay to a general depth of 3 meters. This impermeable layer is underlain by 0.5 to 2 meters of variable sand and silt. This permeable layer is underlain by hard, grey, silty clay to a completion depth of 5 meters. A generalized geological cross section is presented in **Figure 2**.

HYDROGEOLOGY

Analysis of the local geology in the area suggests that the upper, shallow glacial till strata contains some saturated, permeable layers that produce water for Des Plaines River recharge. There is a saturated soil layer at approximately 2.3-4.3 meters below surface grade, within the more permeable silts and sands of the upper glacial till. This layer appears to be more of an aquitard layer; permeable and able to transmit water, but not at the capacity for human consumption.

Based on available groundwater elevations from a total of ten monitoring wells installed at the site, it appears that the general groundwater flow direction is to the southeast across the site, towards the Des Plaines River.



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SIZE	CAGE CODE	TITLE		REV
		GEOLOGIC CROSS SECTION MAP		
SCALE	1" = 30'	AUTHOR	COLE BERTSCH	FIGURE 2

FIELD METHODOLOGY

Myself, Cole Bertsch performed all field, statistical and analysis activities for this study. A private environmental well drilling company (Enviro-Dynamics, LLC of Hobart, Indiana) performed the drilling operations. On July 14, 2004, a total of three (3) DP monitoring wells (DP-1, DP-2 and DP-3) and one (1) HSA monitoring well (MW-5) were installed. The other two HSA monitoring wells (MW-1 and MW-3) were already installed as part of the initial LUST groundwater investigation.

WELL INSTALLATION

Both the conventional Hollow-Stem Auger (HSA) monitoring wells and the Direct-Push (DP) monitoring wells were installed with a D-66 Geoprobe® rig unit with a dual-capacity (direct push and auger) design. The wells were constructed in general accordance with ASTM standards D5092 and D6742 (ASTM, 1994). Before the wells were emplaced, continuous soil sampling from the soil column was conducted and analyzed to determine the appropriate screen interval and depth of the wells. The encountered geology (described in the Hydrogeology Section of this report) determined that a 3 meter (10 foot) screen was the most applicable screen interval to intercept the shallow aquifer water table so as to provide the greatest likelihood of detecting groundwater contamination. The depth of each of the six (6) wells was 4.57 meters (15 feet) below surface grade. The total screen interval is therefore 1.57 – 4.57 meters below surface grade.

Each of the DP and HSA monitoring wells were issued with a 3 meter length, 0.25mm (0.010 inch) PVC slotted screen. The 0.25mm slot in the screen was chosen to limit large diameter soil and sand particles from entering the well. The screen interval of the wells allowed for the collection of representative groundwater samples from the saturated soil unit most conductive to the migration of contaminants.

2.5cm (1 inch) and 5cm (2 inch) OD well material PVC casing and well screen materials were used—since they are inert to the petroleum products present at the site, and they will maintain the integrity of the borehole.

Conventional Monitoring Well Installation

The conventional monitoring wells were constructed with a hollow-stem auger using 5cm diameter PVC flush-threaded 0.25mm slot screen, and 5cm solid PVC casing. The bottom of the screened interval was capped with a threaded PVC bottom cap, and the top of the solid casing closed with a lockable expansion plug-type cap.

Drilling began by first removing the probe rods from the open borehole after soil sampling activities. The D-66 Geoprobe® rig then drilled 19cm (7.5 inch) OD hollow-stem augers to a depth of 4.57 meters in each of the HSA wells.

The 5cm PVC screen and casing was placed within the open hollow-stem augers. As the well was constructed, the augers were slowly extracted from the borehole, where a silica sand filter pack was added to the annular space of the PVC screen and casing.

Clean, inert, quartz #4 filter silica sand was placed in the borehole annular space to approximately 0.6 meters above the top of the screened interval. The remainder of the borehole annular space was filled with bentonite chips to a point just below the surface. Bentonite is a clay mineral that is relatively impermeable, expandable, and does not react with or in any way affect the samples from the well. This seal helps prevent contamination of groundwater samples and the groundwater regime from inter-connection with the surface. A gravity pour method (of sand and bentonite) was used to ensure there were no gaps in the formation.

A flush mounted well box with a bolt down cover was installed into concrete surrounding the top of the wells. Each well was equipped with an expandable casing plug. A flush-mounted steel protective cover was emplaced in the concrete to protect against tampering and damage from vehicular traffic or other activities associated with expected site use.

Soil cuttings were placed into labeled 55-gallon drums and removed from the site by a special waste hauler. The excess well material waste was discarded in an on-site waste receptacle.

Direct-Push Well Installation

The direct-push monitoring wells were constructed with steel probe rods using 2.5cm diameter PVC flush-threaded 0.25mm slot screen, and 2.5cm solid PVC casing. The bottom of the screened interval was capped with a threaded PVC bottom cap, and the top of the solid casing closed with a lockable expansion plug-type cap.

Drilling began by first removing the probe rods from the open borehole after soil sampling activities. The D-66 Geoprobe® rig then pneumatically pushed 8.25cm (3.25 inch) outside diameter OD probe rods to a depth of 4.57 meters in each of the DP wells.

The 2.5cm PVC screen and casing was placed within the hollow, steel probe rods. As the well was constructed, the rods were slowly extracted from the borehole, where a silica sand filter pack was gravity poured into the annular space of the PVC screen and casing.

Clean, inert, quartz #4 filter silica sand was placed in the borehole annular space to approximately 0.6 meters above the top of the screened interval. The remainder of the borehole annular space was filled with bentonite chips to a point just below the surface. Bentonite material is relatively impermeable, expandable, and does not react with or in any way affect the samples from the well. This seal helps prevent contamination of groundwater samples and the groundwater regime from inter-connection with the surface. A gravity pour method (of sand and bentonite) was used to ensure there were no gaps in the formation.

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The DP method of well installation does not produce soil cuttings. There was no waste to discard except for the excess of well materials. This waste was discarded in an on-site waste receptacle.

WELL DEVELOPMENT

Each of the wells were developed on July 14, 2004 to allow free entry of groundwater, minimize turbidity of the sample, and minimize clogging. After well installation, the HSA monitoring wells (MW-1, MW-3 and MW-5) were developed by bailing out several well volumes of water using a disposable HDPE hand bailer and nylon cord. The DP monitoring wells (DP-1, DP-2 and DP-3) were developed by bailing out multiple well volumes of water using a micro hand bailer and thin fishing line. By purging the water, the bailer creates a surge effect on the sand pack of the well, allowing for the free interconnection of water between the sand pack and the saturated formation. A visual-manual approach was used to determine the completion of development activities. The monitoring well set of MW-5 and DP-3 were dry after they were installed on July 14, 2004. The two wells were developed on July 26, 2004.

WELL ELEVATION SURVEY

An elevation survey was conducted using manual survey level instrument and measuring rod techniques upon completion of the well installation activities. An arbitrary benchmark of 30.00 meters was established. The top of PVC pipe well casing and top of the steel protective covers were measured for each well in relation to the arbitrary benchmark of 30.00 meters.

GROUNDWATER ELEVATIONS

Static groundwater elevations in each well were determined and recorded prior to each of the four sample collection events. First, static water level measurements were measured using a Solinst electrical tape depth to water meter. The water meter was decontaminated after moving from one well to another, to avoid cross-contamination. Standard surveying techniques were used to derive groundwater elevations. A groundwater elevation of the monitoring wells was determined by subtracting depth to water of each well to the arbitrary elevation of the top of the PVC casing. For example, the following is how the November 15, 2004 groundwater elevation for DP-1 was conducted:

$$GW_e = TOC_e - D_w$$

Where, GW_e *is groundwater elevation,* TOC_e *is top of casing elevation, and* D_w *is the depth to water measurement*

$TOC_e = 30.78m$
$D_w = 2.60m$

Therefore, $GW_e = 28.18$ *meters*

GROUNDWATER SAMPLING ACTIVITIES

A total of four sampling events were conducted as part of this study. The well set of DP-3/MW-5 was sampled during the first two events, but based on the wells being outside of the groundwater plume, these two wells were not sampled in the remaining two events.

A static water level was first recorded for each well. The wells were then purged of three well volumes to remove water in the well that is not indicative of in-situ conditions. The volume of water removed from each well was calculated by the following equation:

$$V = \pi r^2 h \times 3$$

Where, r is the radius of the well screen and h is the height of water in the well.

Each HSA monitoring well was sampled using a disposable HDPE, and each DP monitoring well was sampled using a disposable HDPE micro-bailer. For each well, a new set of materials and supplies was used. New latex sample gloves were worn for all sampling tasks to help prevent cross contamination between the groundwater samples. In each sampling event, two 40ml vials were filled with representative groundwater samples from each well.

The samples were preserved on ice until they were submitted to an independent environmental laboratory. First Environmental Laboratories of Naperville, Illinois analyzed the samples according to “Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,” SW-846 and EPA Method 5030/8260B. The samples were entered into a Gas Chromatography/Mass Spec-trometer (GC/MS) and the output readings were recorded in parts-per-billion (ppb) units. The samples were each analyzed for Benzene, Toluene, Ethylbenzene and Total Xylenes (BTEX) parameters.

HYDRAULIC CONDUCTIVITY TESTING

In lieu of conducting pump tests on each of the monitoring wells to calculate the hydraulic conductivity of the water-bearing formation, a bail-down slug test was performed. Slug tests result in data considered to be less representative than those in a pump test (Schwartz and Zhang, 2003), but are only used as a method to determine the correlation of data between the two well types, not the formation itself.

A slug test is a method of determining the hydraulic conductivity of a geological unit using an observation well. The slug tests conducted for this study used the following methodology:

1. The initial depth to water was measured using a Solinst® electrical tape.
2. A volume of water was removed from the well using an HDPE bailer/micro-bailer.
3. Upon final removal of water, the electrical tape was sent down the well to measure the instantaneous change in water level.
4. The water levels were then measured at defined intervals of time until the water level returned to 90 percent of its original position, or until 45 minutes had elapsed.

The data acquired in the field was entered into the AQTESOLVE® Version 3.01 groundwater modeling program. The program was developed by HydroSOLVE, Inc. AQTESOLVE® has the capability to convert field data into graphical form on semi-log graph paper. This enables the program to match the data to establish slug test equations.
The Bouwer-Rice (1976) curve-matching solution for confined aquifers with a partially penetrating well was used to transform the data into hydraulic conductivity values (in cm/sec).

STATISTICAL METHODS

The overall objective of this study is to determine if, based on the gathered data, that direct-push monitoring wells yield comparable groundwater parameter results to hollow-stem augured monitoring wells.

The statistical method chosen to apply the acquired data is a *correlation* analysis. A correlation analysis serves to ask two questions: (1) Are the two variables related in some consistent and linear way, and (2) What is the strength of the relationship (Hampton, 1994).

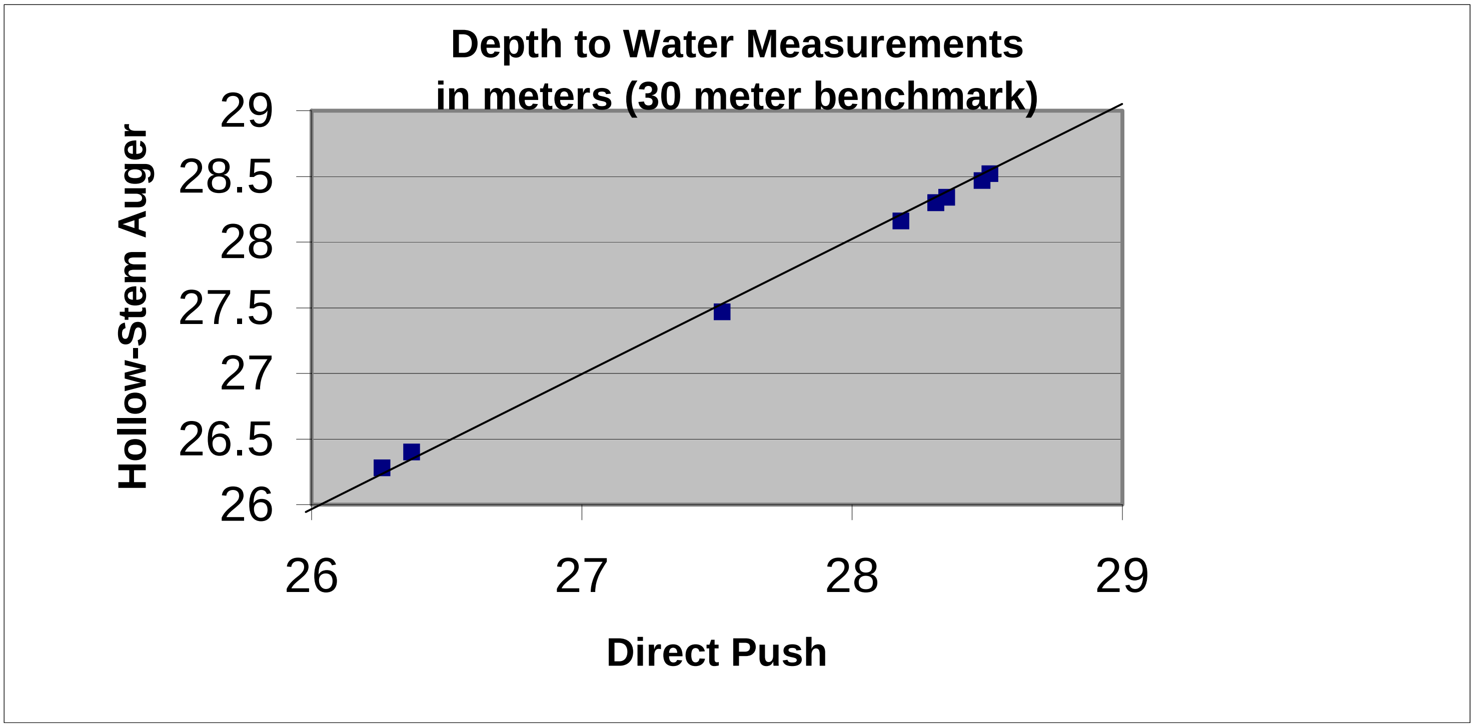
The correlation analysis was oerformed using the methodology outlined in Introduction to Biological Statistics (Hampton, 1994). The first step in the correlation analysis is to determine if the data set meets the requirements for correlation. The following assumptions of the data are made:

1. *The sample of paired (x,y) data is a random sample.* The data in this study is a population data set, not a sample of the population, therefore the data qualifies.

2. *The pairs of (x,y) data have a normal distribution.* The data set does have a normal distribution.

The next step is to plot the data into a scatterplot graph to determine if there is a linear relationship between the data—to satisfy the first objective of a correlation analysis. The graphs in **Figure 3** represent the scatterplots for the analyzed parameters.

The following figures are read by comparing the x axis to the y axis. The x axis is represented by the Direct Push monitoring well data, and the y axis is represented by the Hollow Stem Auger monitoring well data. The displayed data can then be compared between the two well types by observing how far the points are off of the middle line. If the data points are close to the line, then it can be qualitatively interpreted that there is correlation between the two well types.



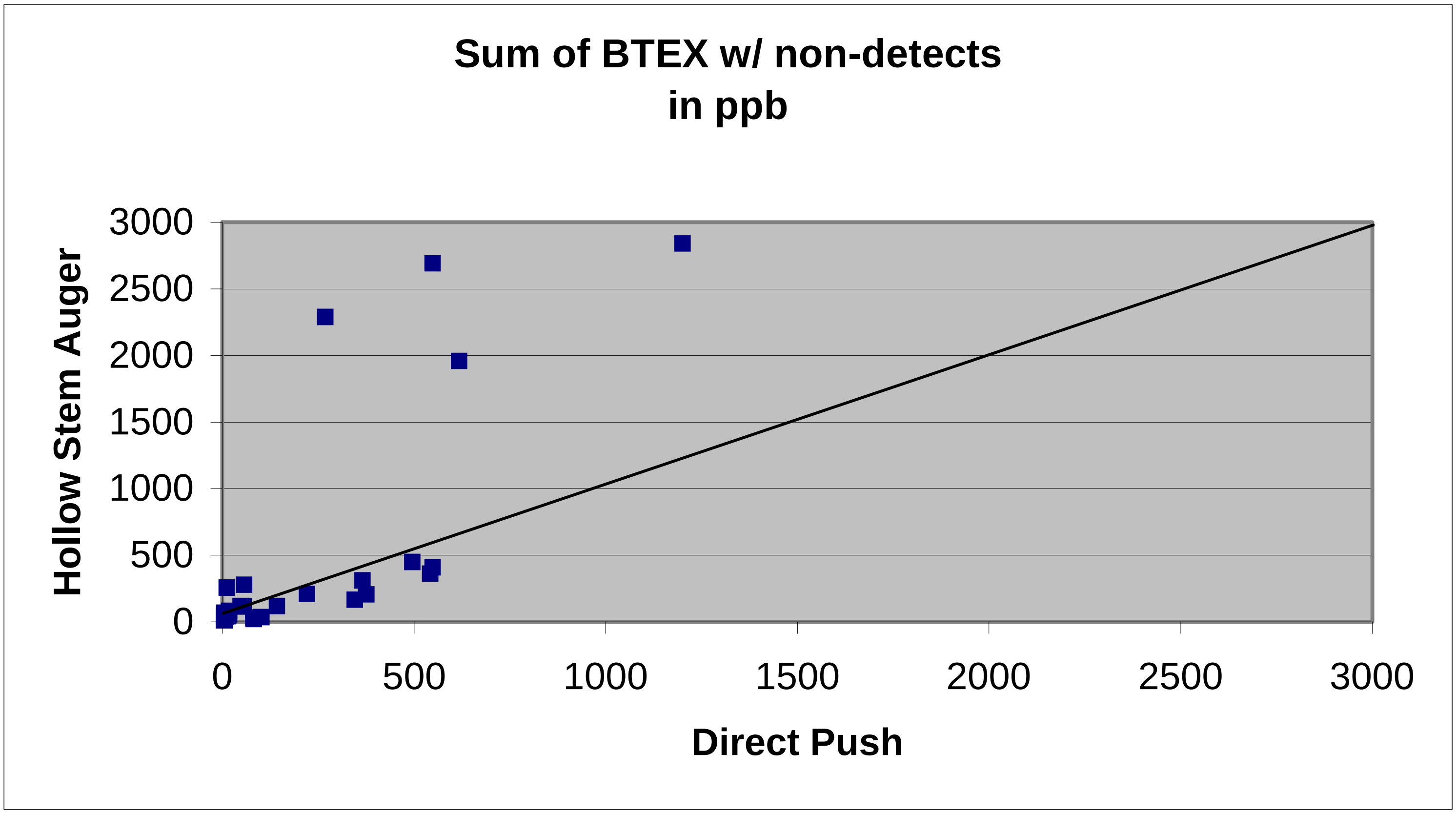


Figure 3 – Summary of the scatterplot diagrams

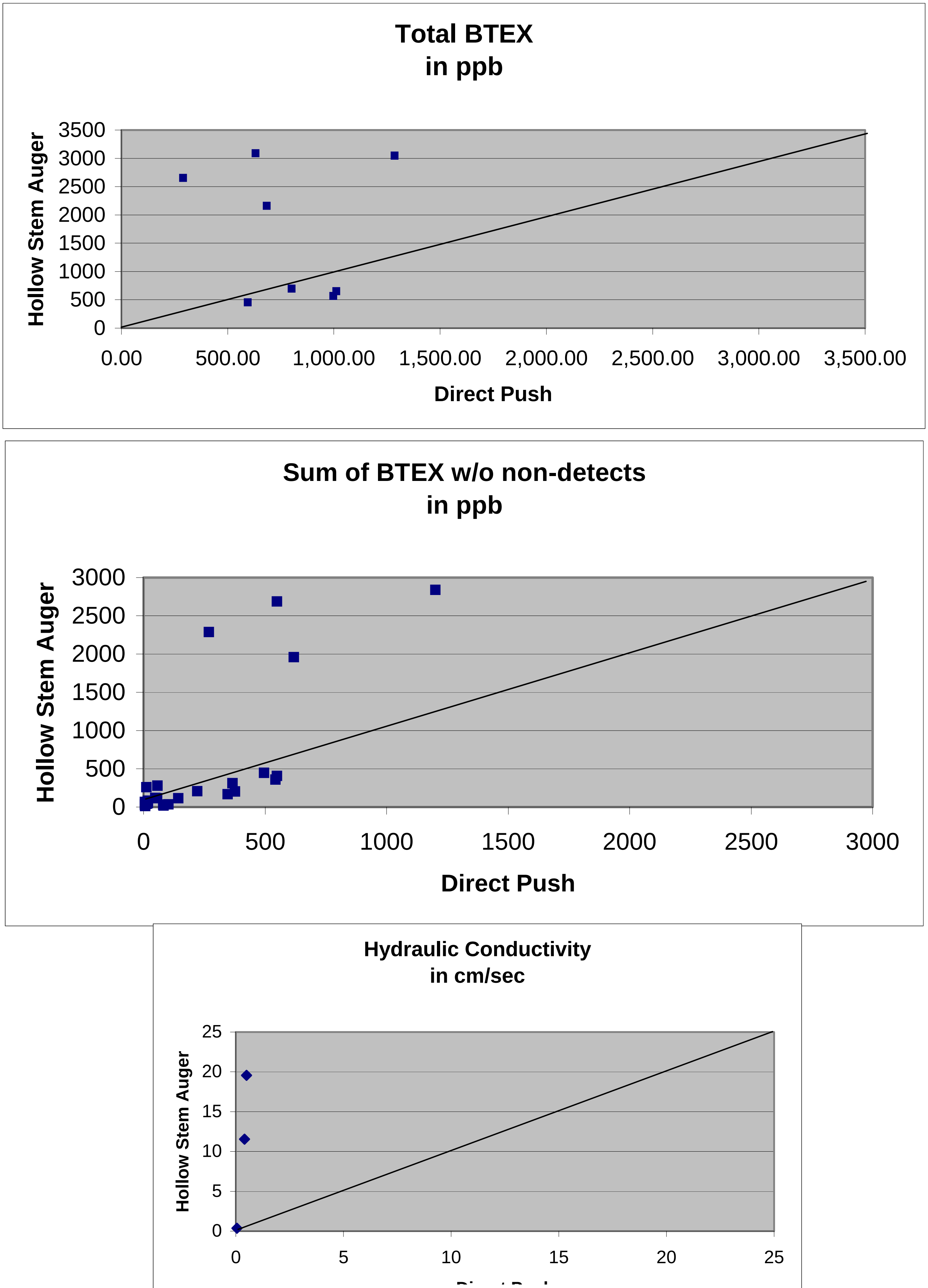
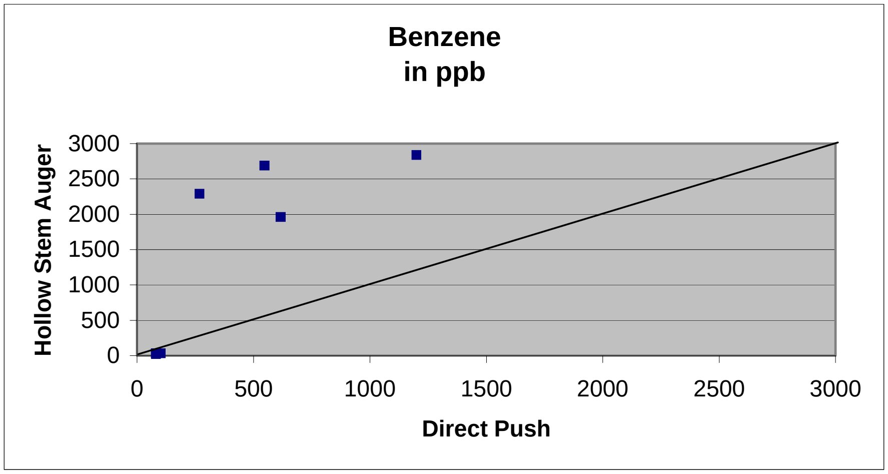
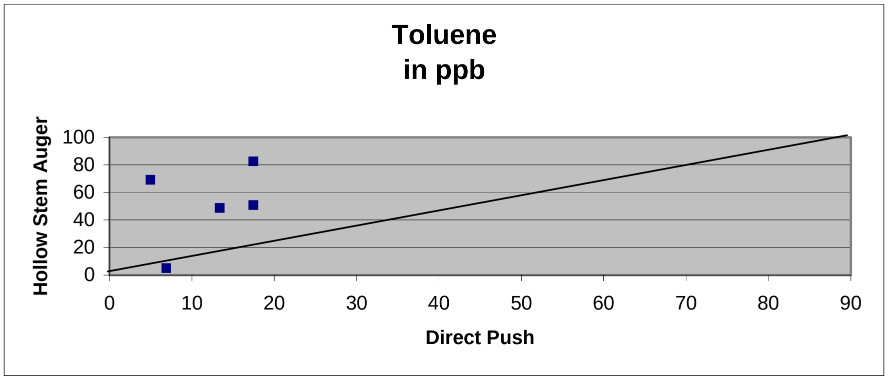
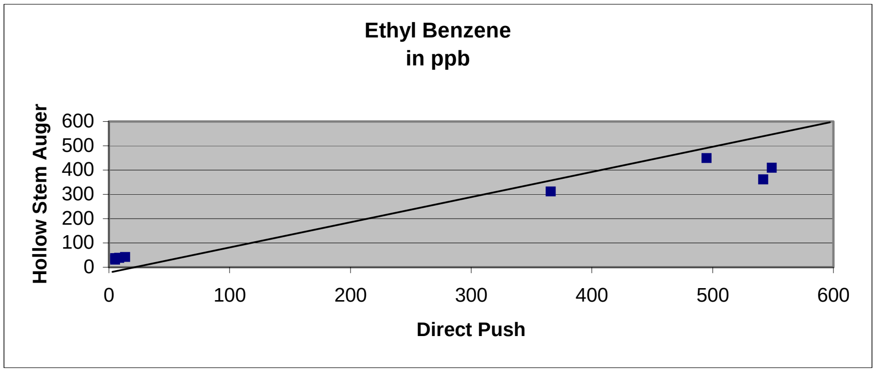


Figure 3 continued – Summary of the scatterplot diagrams







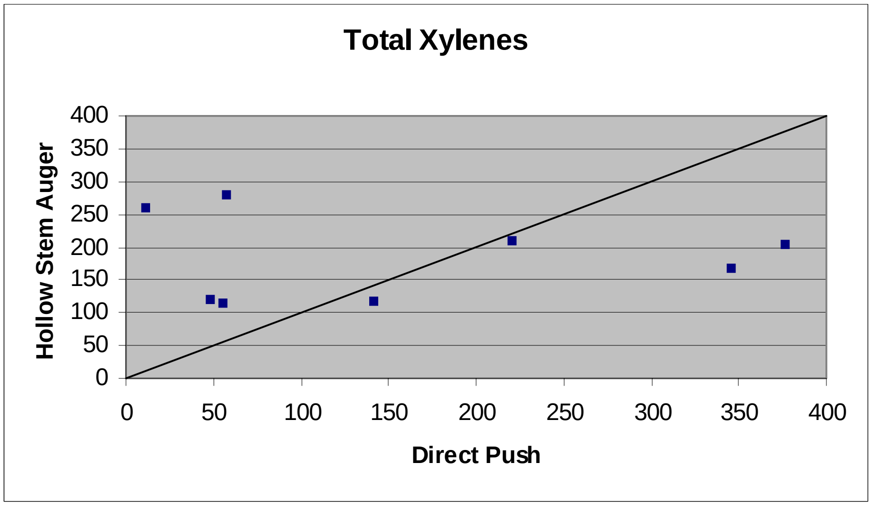


Figure 3 continued – Summary of the scatterplot diagrams

The interpretation of there being a linear relationship between the data is not the final step because the analysis of scatterplots is subjective. To statistically verify the linear relationship, or lack thereof, is to test the strength of the linear relationship.

Pearson Correlation Coefficient (r)

The strength of a linear relationship is measured by calculating the *Pearson Correlation Coefficient*, or *Linear Correlation Coefficient*, designated *r*. The value of *r* ranges from –1 to +1, where +1 indicates a perfect positive correlation between the two variables, 0 represents no correlation, and –1 indicates perfect negative correlation. The *Linear Correlation Coefficient* was calculated for each of the parameters in the scatterplots displayed in **Figure 3** using the following equation:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\ \sqrt{n(\sum y^2) - (\sum y)^2}}$$

Derived *r* values near 1 indicate a strong linear correlation between the HSA and DP well installation methods, but needs to be statistically verified.

Formal Hypothesis Test

The next step is to perform a *Formal Hypothesis Test* to determine whether the acquired *r* value is statistically significant. This step involves formulating a null hypothesis:

$H_o\!:p = 0$ *(No Linear Correlation)*
$H_o\!:p \neq 0$ *(Linear Correlation)*

These are the two results of a null hypothesis; we either accept the null hypothesis ($H_o\!:p = 0$), or reject the null hypothesis ($H_o\!:p \neq 0$). This study is attempting to reject the null hypothesis and determine that there is a statistically significant correlation between the well methods.

There are several methods to determine if the acquired *r* value is significant. The method chosen was to refer to the table in **Appendix C**, "Critical Values of the Pearson Correlation Coefficient (*r*)." This table gives the minimum values of *r* that permit one to reject the null hypothesis. The table provides a 95% confidence interval for the data. If the calculated value of *r* is equal to or greater than the tabular value for the specified degrees of freedom (n – 2, total sampling events minus 2), the null hypothesis is rejected. It is accepted that the two well types are linearly correlated, based on the available data.

For example, if r = 0.9125 and degrees of freedom = 8, the value obtained from the table in **Appendix C** is 0.632. The *r* value of 0.9125 is greater than 0.632 at the 95% confidence interval with 10 pairs of data. It can be interpreted that if there is *no* linear correlation between the data, there is a 5% chance that the linear correlation coefficient *r* will exceed 0.632. Ninety-five percent of the time there *will* be linear correlation and the *r* value will exceed 0.632.

Coefficient of Determination (r^2)

Now that it can be determined if the correlation is significant or not, the *coefficient of determination*, r^2, is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph. The *coefficient of determination* is the ratio of the explained variation to the total variation.

The *coefficient of determination* is such that $0 \leq r^2 \leq 1$, and denotes the strength of the linear association between *x* and *y*.

For example, if $r = 0.9125$, then $r^2 = 0.833$, which means that 83.3% of the total variation in *y* can be explained by the linear relationship between *x* and *y*. The other 16.7% of the total variation in *y* remains unexplained, attributed to other factors not analyzed in the study.

Microsoft Excel® Statistical Analysis ToolPack was used as the statistical analysis tool for this study. The scatterplots and Pearson Correlation Coefficient determinations were derived from data entered into an Excel® spreadsheet program for the following parameters:

(1) water level measurements,
(2) the sum of BTEX constituents including non-detections,
(3) the sum of BTEX constituents not including non-detections,
(4) Total BTEX concentrations,
(5) Benzene,
(6) Toluene,
(7) Ethyl Benzene,
(8) Total Xylenes and
(9) hydraulic conductivity values.

RESULTS

Before statistical evaluations took place, the gathered data was graphed on scatterplots showing an apparent linear/non-linear correlation (**Figure 3**). The scatterplots were analyzed for each parameter, and based on the apparent existence of a linear correlation, the acquired *r* value and the corresponding critical *r* value, a determination was made on whether to accept or reject the null hypothesis.

A summary of the statistical analysis is displayed in **Table I**.

Water Table Measurements

Reject Null Hypothesis, H_o:p ≠ 0
Linear Correlation evident in data set

The *r* value for the water table elevation measurements was 0.99886, which describes a very significant linear correlation. The r^2 value of 0.997 means that only 0.3% percent of the variations in water table elevation measurements are from factors other than the difference in well type.

BTEX Constituents with non-detects

Reject Null Hypothesis, H_o:p ≠ 0
Linear Correlation evident in data set

The *r* value for the summary of BTEX values including samples with results that were below detection levels was 0.755, which describes a good linear correlation. The r^2 value of 0.570 means that 43% percent of the variations in the detection of BTEX constituents are from factors other than the difference in well type.

BTEX Constituents without non-detects

Reject Null Hypothesis, H_o:p ≠ 0
Linear Correlation evident in data set

The *r* value for the summary of BTEX values not including samples with results that were below detection levels was 0.756, which describes a good linear correlation. The r^2 value of 0.571 means that 42.9% percent of the variations in the detection of BTEX constituents are from factors other than the difference in well type.

Parameter	**Degrees of Freedom**	**Direct Linear Correlation?**	***r* value**	**r^2 Value**	**Critical *r* Value[1]** ***a = 0.05***	**Null Hypothesis**	**Accept / Reject Null Hypothesis**
Water Level Elevations	10	Yes	0.99886	0.997	0.576	0.997 > 0.576	Reject, H_o:p ≠ 0 Linear Correlation
Sum of BTEX constituents with non-detections included	30	Yes	0.755	0.570	0.349	0.755 > 0.349	Reject, H_o:p ≠ 0 Linear Correlation
Sum of BTEX constituents without non-detections	27	Yes	0.756	0.571	0.367	0.756 > 0.367	Reject, H_o:p ≠ 0 Linear Correlation
Total BTEX concentrations	6	Yes	-0.12	-0.01	0.707	-0.12 < 0.707	Accept, H_o:p ≠ 0 No Linear Correlation
Benzene	6	Yes	0.82	0.67	0.707	0.82 > 0.707	Reject, H_o:p ≠ 0 Linear Correlation
Toluene	6	Yes	0.40	0.16	0.707	0.40 < 0.707	Accept, H_o:p = 0 No Linear Correlation
Ethyl benzene	6	Yes	0.98	0.96	0.707	0.98 > 0.707	Reject, H_o:p ≠ 0 Linear Correlation
Total Xylenes	6	No	-0.03	-0.0009	NA	NA	Accept, H_o:p = 0 No Linear Correlation
Hydraulic Conductivity	4	No	0.97	0.94	NA	NA	Accept, H_o:p = 0 No Linear Correlation

Table I – Statistical Results of the comparison of chemical and hydrogeologic properties of groundwater between the Hollow Stem Auger and Direct Push monitoring wells.

[1] a = 0.05 is a 95% confidence interval for a two tailed test
Value obtained from "www-micro.msb.le.ac.uk/2060/rtable.html" and is included in **Appendix C**

Total BTEX Concentrations

Accept Null Hypothesis, H_o:p = 0
Linear Correlation not evident in data set

The *r* value for the summary of Total BTEX values was –0.12, not displaying positive linear correlation. The variations in Total BTEX concentrations are from factors other than the difference in well type, because in the one set of wells the DP wells had the higher concentrations, and in the other set, the HSA wells had the higher concentrations. The explanation for this is described in the Discussion section of this study.

Individual Benzene, Ethyl benzene, Toluene and total Xylenes concentrations

When the BTEX parameters were individually analyzed, there was some variation. Benzene and Ethyl benzene concentrations were statistically significant, while Toluene and total Xylenes concentrations were not. When the sum of the individual concentrations were analyzed (displayed in the BTEX Constituents with non-detects and BTEX Constituents without non-detects sections), the results do display an overall statistical significance.

Hydraulic Conductivity Values

Accept Null Hypothesis, H_o:p = 0
Linear Correlation not evident in data set

Observations of the hydraulic conductivity scatterplot showed that the direct-push conductivity tests were significantly lower than the hollow stem auger conductivity tests. The data did not represent a direct linear correlation, therefore the *r* value is not statistically significant. There are factors other than the difference in well type that affected the results of the hydraulic conductivity values.

DISCUSSION

Overall, the results of the data acquired from the DP and HSA monitoring wells was statistically significant. In most cases there was no statistical difference in the detected parameters between the two well types. This discussion section describes the interpretations and significance of the acquired results.

This study primarily focused on the statistical interpretation of acquired field data. More data provides more accurate results, and more accurate interpretations of the results. The data set for this study was substantially decreased when the initial results of the first round of groundwater samples were analyzed. The well set of MW-5 and DP-3 did not return BTEX concentrations above the laboratory method detection limits. These wells were the furthest from the source of the release of the three well sets, and did not have groundwater contamination. This was unfortunate for the study, but fortunate for the local area in the sense that the groundwater contamination did not spread over a large area. The results from the well set were not included in the statistical analysis of BTEX parameters, but were included in the water table elevation data and hydraulic conductivity data analyses. This resulted in a smaller data set for the study. This had an effect on statistical analysis of the BTEX parameters because the critical *r* values were higher because of the smaller data set.

Comparisons between the two well types in previous studies have had difficulty in keeping the experiment controlled. Either the study had the two well types drilled at different depths, different screen intervals, different filter packs, or placed the wells too far apart from each other. These differences resulted in data not completely representative of actual site conditions.

This study tried to limit the uncontrolled variables in each respect to obtain the most accurate data. Each of the wells were drilled to the same depth, encountered the same geology, had the same screen interval, and were placed 1 meter from each other in each well set. Although the data was statistically significant for a majority of the parameters, there was one variable not completely accounted for.

Initially, the groundwater plume was thought to extend from the former UST cavity east towards the Des Plaines River. Actual site data displayed however that the highest concentrations of contamination were located at the pump island nearest the cavity, extending in a southeast direction. This is significant because the placement of the wells was based on the plume migrating east. Refer to **Figure 1** for the locations of the HSA and DP monitoring wells. Every attempt was made to place the monitoring wells perpendicular to the leading edge of the plume, both wells located in the direction of groundwater flow. Updated site information suggests that the monitoring wells are located along the outer edges of the plume. This is apparent in observing the raw data acquired from the wells. The total BTEX values for the DP and HSA wells were not dependent on well type, rather the distance from the source of groundwater contamination. In the well set that had the DP well with the higher total BTEX value (DP-1), this well was closer to the plume than its paired well (MW-3). In the well set that had the HSA well with the higher total (MW-2), this well was closer to the plume than its paired well (DP-2). Refer to the following table for the concentrations on July 26, 2004:

PARAMETER (in ppm) **Sample Date 7/26/04**	**MW-3**	**DP-1**	**MW-2**	**DP-2**
Benzene	30.7	81.6	2,290	269
Toluene	5.0	5.0	69.0	5.0
Ethylbenzene	410	549	37.1	5.0
Xylenes	205	376	259	11.3

Regardless of the well type, it was apparent that the well closest to the release had the highest BTEX concentrations. The statistical analysis showed that 43 percent of the variation in the BTEX concentrations was from factors other than the well type. This may be one of the factors of variation that produces a difference in the concentrations.

Interpretations of the water table elevation data between the two well types were almost a perfect linear correlation. It is safe to assume based on previous data from other studies, and the data provided from this study that there is no difference in the measurement of water table elevations between the two well installation methods. Regardless of the location of the contamination plume or depth to groundwater, the two methods measured groundwater to a correlation efficiency of 99.7%, where only 0.3% of the variation was from other sources.

The hydraulic conductivity measurements did not have a direct linear correlation between the two well types, indicating that there is a significant difference in the measurement of the velocity of groundwater flow in the wells. An initial observation is that slug tests are best conducted in piezometers or monitoring wells that are not screened across the water table (WDNR, 2003). In LUST investigations, contaminant groundwater sampling of chemicals lighter than water determines that the well should be designed where the well screen is across the water table. This is the only way to yield accurate sample results. The problem with this well design is that a slug test in a water table well will force water into the unsaturated filter pack and possibly the unsaturated native soils, increasing the length of submerged screen. Changing the length of the submerged screen during the test makes the test invalid (Bouwer, 1989).

Because the direct push wells were installed by first soil sampling the borehole with small direct push rods, then inserting larger, 8.25cm steel rods, there was a unit of soil that was compacted against the natural formation. This compaction makes the density of the soil surrounding the well screen less permeable, therefore yields a smaller hydraulic conductivity value. The installation method should have accounted for this and soil sampled with 8.25cm rods initially, thusly removing all the soil in the borehole so compaction is not an issue.

The proper development of the monitoring well before a slug test is conducted is also of utmost importance. The direct-push wells in this study were not developed intensively to create a surge effect because they were bailed by hand with a micro-bailer. Proper development is needed in order to break the potential well skin that may develop from the installation of pre-packed direct-push wells. Henebry, et al (2000) performed research into skin effects and has concluded that the potential error involved with respect to skin effects can be negated with proper development of the well to ensure the native porosity of the surrounding material is kept intact.

Accurate hydraulic conductivity results from the direct-push monitoring wells may potentially be obtained by using more sophisticated well development methods that involve hand pumps or a bladder system. These methods were not used due to time and financial constraints. In addition, the hand bailing method of well development in LUST investigations is the most common approach. In other methods, distilled water is added to the wells, which cannot occur at contaminated sites because the groundwater samples will become diluted and not yield true, representative analytical results.

The hydraulic conductivity results from the Direct-Push monitoring wells were one degree of magnitude lower than the Hollow Stem Auger conductivity results. It was expected that this would occur based on the results of previous studies. Because proper installation methods and alternative development methods are the only way to determine a true conductivity value, and these methods are not commonly used at LUST investigations, there lies the possibility that a mathematical model should be able to account for the lack of development in the Direct-Push wells. The modification could be applied to hydraulic conductivity tests to produce accurate results. This can only occur if there is enough data to support that Direct-Push wells constantly yield lower conductivity results.

CONCLUSIONS

The main conclusion that can be drawn from this study is that the two well types are able to detect chemical and hydrogeological properties of groundwater with a level of consistency that is statistically significant. Although this study has a limited data set, the results can be used to further investigate the relationship between the well types.

This data helps support the claim that when governmental agencies approve or review site investigations that involve Direct-Push technology, there is data that suggests that the two technologies can produce similar results. The results from this study support claims made in several other studies. This study was performed in glacial till material of Illinois, a place where no other comparative study was conducted. Since the results were supportive of a correlation between the installation methods, it is further evidence that the results may compare in a multitude of unconsolidated geologic formations. A larger data set would have made the statistical conclusions easier to make, however the study was limited through time and financial constraints.

With respect to the measurement of water table elevations, this study provides evidence that DP technology is a more cost effective and efficient method of well installation for hydrogeologic groundwater flow studies. The technology is more cost and time efficient, and there is supporting evidence suggesting that the results can be statistically significant. The results of the correlation statistical analysis show that there is almost no difference in the measurement of water table elevations for the two well types. Since DP technology is more cost effective and efficient, this is a quick, easy installation technique that yields accurate elevation data for a hydrogeologic investigation that needs an accurate groundwater flow direction.

The sum of BTEX constituents resulted in a statistically significant value between the paired well types. Although there were some parameters that were not statistically significant in the chemical analysis, this can be attributed to factors other than well type. The total BTEX values for the DP and HSA wells were not dependent on well type, rather the distance from the source of groundwater contamination. In the well set that had the DP well with the higher total BTEX value (DP-1), this well was closer to the plume than its paired well (MW-3). In the well set that had the HSA well with the higher total (MW-2), this well was closer to the plume than its paired well (DP-2).

It was previously known that hydraulic conductivity tests are based primarily on the proper installation and development of the well before the test is performed. These attributes were not accounted for during the testing of the DP wells, therefore the hydraulic conductivity values were skewed towards the HSA wells. A more sophisticated approach is needed to develop the wells before the two installation techniques can be accurately compared. There may be some technical merit to the derivation of a groundwater model to account for the apparent well skin that forms on a DP monitoring well and include it in the analytical hydraulic conductivity calculation. If using DP wells for hydraulic conductivity tests, all mitigating factors should be taken into account before performing the test.

In summation, this study provides some evidence that Direct-Push technology is a useful investigative tool, especially at how the measurement of water table elevation data correlated. Environmental investigations can be aided by the ease and efficiency of data collected by DP wells.

REFERENCES

ASTM, American Society for Testing and Materials, 1994. Method D:5092: Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers: ASTM Standards on Ground Water and Vadose Zone Investigations, Second Edition, West Conshohocken, PA.

ASTM, American Society for Testing and Materials, 1994. Method D:6742: Standard Guide for Selection and Installation of Direct Push Ground Water Monitoring Wells : West Conshohocken, PA.

Alvarez, G., and Victor Kremesec. "Monitoring Well Comparison Study: An Evaluation of Direct-Push Versus Conventional Monitoring Well." 2002, *BP Corporation / U.S. EPA OUST*.

AQTESOLV for Windows–V.3.01, 2000. Developed by Glenn M. Duffield, HydroSOLVE, Inc.

Bouwer, H and C. Rice. 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells." *Water Resources Research*, 12: pg. 423-28.

Bouwer, H. 1989. The Bouwer and Rice Slug Test - An Update. *Ground Wate*r, Volume 27, Number 3, pp. 304-309.

Fetter, William. 1996. *Contaminant Hydrogeology.* 2nd Edition. Upper Saddle River, NJ: Prentice Hall Publications.

Fetter, William. 1999. *Applied Hydrogeology*. 4th Edition. Upper Saddle River, NJ: Prentice Hall Publications

Freeze, R. A., and Cherry, J. A., 1978. *Groundwater*. Prentice-Hall, Englewood Cliffs, NJ.

Hampton, Raymond. 1994. *Introductory Biological Statistics,* William C Brown Publishing

Henebry, Brent, and Gary Robbins. "Researching the Influence of Skin Effects on Hydraulic Conductivity Determinations in Multilevel Samplers Installed with Direct Push Methods." *Ground Water,* 2000, 38, no.6: pg. 882-886.

Hvorslev, M. J., 1951. Time lag and soil permeability in groundwater observations. *U. S. Army Corps of Engineers Waterways Experiment Station Bulletin*, 36.

Illinois Environmental Protection Agency, IEPA. Division of Land, LUST Section. Available at: www.epa.state.il.us

Illinois Environmental Protection Agency, IEPA, 2001. *Use of Push-Driven Technology* (Fact Sheet), http://www.epa.state.il.us/land/cleanup-programs/push-driven/pushdriven.pdf , Accessed, November, 2004.

Illinois State Geological Society. *Illinois Surficial Geology and Elevation Data*. Springfield, IL: ISGS, 2003. Database on-line. Available from http://www.isgs.uiuc.edu/nsdihome/webdocs/st-geolq.html. Accessed 13 November, 2003.

Jaffe, Martin, 2001. *Water Supply Management Options for Northeastern Illinois*, Available at: http://www.uic.edu/cuppa/upp/people/faculty/jaffe/1.htm , UIC, Accessed in November, 2004

Keller, Edward, *Introduction to Environmental Geology*. 2nd Edition. Prentice-Hall Publishing, pp. Chapter 9; Water Resource and Pollution.

Kram, Mark, Dale Lorenzana, Joel Michaelsen and Ernest Lory. 2001. "Performance Comparison: Direct-Push Wells versus Drilled Wells.", *Naval Facilities Engineering Command (NFESC), Technical Report TR-2120-ENV*.

Leopold, Luna, 1997. Excerpt from: Keller, Edward, *Introduction to Environmental Geology*. 2nd Edition. Prentice-Hall Publishing, pp. Chapter 9; Water Resource and Pollution.

MacDonald, J.A. and Kavanaugh, M.C. "Restoring Contaminated Groundwater: An Achievable Goal?" American Chemical Society. *Environmental Science and Technology. Vol. 28*., No. 8. 1994.

McCall, Wesley, at al. 1997. "Field Comparison of Direct-Push Prepacked Screen Wells to Paired HSA 2" PVC Wells." *HazWaste World*, SuperFund Conference XVIII, Washington, DC.

McCall, Wesley. "Groundwater Monitoring Gets a Direct Push." *Environmental Protection,* 2002, Vol. 13, no. 8: p. 49.

Michigan State University, Center for Integrative Toxicology, Available at: http://www.iet.msu.edu/regs/state/illinois/illiundertank.htm , Accessed November, 2004.

Microsoft Office Excel, 2003.

Ogata, Akio. 1970. *Theory of Dispersion in a Granular Medium*. U.S. Geological Survey Professional Paper *411-I*, p. 134.

San Diego State University Geology Department. *Darcy's Law*, Available at:. http://www.geology.sdsu.edu/classes/geol351/darcys.htm Accessed November, 2004

Schwartz, Franklin and Hubao Zhang, 2003. *Fundamentals of Ground Water*. New York: John Wiley & Sons, Inc.

Schwarzenbch, R.E., Gschwend, P.M., and Imboden, D.M. 1993 *Environmental Organic Chemistry*, John Wiley & Sons, New York, pg. 681

Sonderegger, John, Willis Weight, 2001. *Manual of Applied Field Hydrogeology.* McGraw – Hill, New York, NY.

University of Leicester – Microbiology. Database on-line. Available at: http://www-micro.msb.le.ac.uk/2060/rtable.html, Accessed November, 2004.

U.S. EPA, 1990. *Assessing UST Corrective Action Technologies: Early Screening of Cleanup Technologies for the Saturated Zone*, EPA/600/2-90/027, Risk Reduction Engineering Laboratory, Cincinnati, OH.

U.S. EPA. 1977. *The Report to Congress-Waste Disposal Practices, and Their Effects on Ground Water.* Washington, DC, 512 pp.

WDNR (Wisconsin Department of Natural Resources), 2003. *Guidance on Natural Attenuation For Petroleum Releases.* Bureau for Remediation and Redevelopment. Appendix A, pg 8

APPENDIX A

Current Illinois Underground Storage Tank Regulations

It is the concern of the Illinois Environmental Protection Agency (IEPA) and other governmental regulatory agencies to regulate and protect Illinois' land, air and water for its residents.

A key component to the protection of groundwater is to enforce governmental regulations on the operation, use, management and remediation of Underground Storage Tank (UST) systems. Illinois regulations support the protection of human health and the environment through a set of codes. Under Illinois' Underground Storage Tank Program, all USTs must be registered and established guidelines must be followed to ensure the protection of human health and the environment. The rules govern the design, construction, installation and operation of regulated underground storage tanks, rules designed to prevent the release of petroleum and other hazardous substances. The rules also require that leaking tanks be reported, and tank closure site assessment reports and tank closure reports must be filed. Appropriate actions must be taken to address risks at sites that are contaminated by leaking USTs.

The Illinois Office of the State Fire Marshal (OSFM) is responsible for the regulations that cover the daily operation and maintenance of UST systems. If a release occurs, tank owners or operators must notify the Illinois Emergency Management Agency (IEMA), which then notifies the IEPA.

The regulations cover any one or combination of underground tanks (including underground pipes and equipment) that contain specific chemicals identified as regulated substances. A regulated substance is either petroleum (including crude oil or petroleum-based substances derived from crude oil) or a hazardous substance identified in Section 101(14) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980.

The UST regulations require owners or operators of new and existing UST systems to set up a system that can reliably detect a spill or leak from the entire tank and any portion of the connected underground piping that routinely contains a regulated substance. When this system indicates a spill or leak has occurred, owners or operators must notify the IEMA within 24 hours.

Leaking Underground Storage Tanks

LUSTs are regulated under Title 35 of the Illinois Administrative Code, Part 731: Underground Storage Tanks (UST); Part 732: Petroleum Underground Storage Tanks; Public Act 92-0554; and, Part 742: Tiered Approach to Corrective Action Objectives. The regulations authorize the IEPA to: review and evaluate technical plans and reports; require corrective action when a LUST threatens human health or the environment; and issue "No Further Remediation" letters once the LUST program requirements and cleanup objectives have been met.

The Part 732 and Public Act 92-0554 regulations apply to owners and operators of petroleum UST systems when there is a confirmed spill or leak. Part of the regulations require that a site investigation to be completed at a site with a known leak of contaminants into the soil or groundwater. Drilling into the soil at specific locations around the contamination can provide valuable data into the nature, concentration and extent of the released contaminants.

Sources: MSU Centre for Integrative Toxicology, summarized from www.epa.state.il.us

APPENDIX B

Summary of Analytical Results - Groundwater

PARAMETER **Sample Date** **7/26/04**	**MW-3**	**DP-1**	**MW-2**	**DP-2**	***MW-5***	***DP-3***
Benzene	30.7	81.6	2,290	269	*< 5.0*	*< 5.0*
Toluene	5.0	5.0	69.0	5.0	*< 5.0*	*< 5.0*
Ethylbenzene	410	549	37.1	5.0	*< 5.0*	*< 5.0*
Xylenes	205	376	259	11.3	*< 5.0*	*< 5.0*
Total BTEX	650.7	1,011.6	2,655.1	290.3	*20*	*20*

PARAMETER **Sample Date** **8/2/04**	**MW-3**	**DP-1**	**MW-2**	**DP-2**	***MW-5***	***DP-3***
Benzene	34.6	102	2,690	548	*< 5.0*	*< 5.0*
Toluene	5.0	6.9	82.6	17.5	*< 5.0*	*< 5.0*
Ethylbenzene	362	542	39.1	8.5	*< 5.0*	*< 5.0*
Xylenes	168	346	279	57.3	*< 5.0*	*< 5.0*
Total BTEX	569.6	996.9	3,090.7	631.3	*20*	*20*

PARAMETER **Sample Date** **11/15/04**	**MW-3**	**DP-1**	**MW-2**	**DP-2**
Benzene	31.3	80.6	2,840	1,200
Toluene	5.0	5.0	50.7	17.5
Ethylbenzene	450	495	42.2	13.4
Xylenes	210	221	115	55.1
Total BTEX	696.3	801.6	3,047.9	1,286.0

PARAMETER **Sample Date** **11/22/04**	**MW-3**	**DP-1**	**MW-2**	**DP-2**
Benzene	20.7	82.4	1,960	618
Toluene	5.0	5.0	48.7	13.4
Ethylbenzene	312	366	31.2	5.0
Xylenes	118	142	120	47.9
Total BTEX	455.7	595.4	2,159.9	684.3

Note: Analytical results are expressed in parts-per-billion (ppb).
Values from MW-5 and DP-3 were not included in the study for BTEX parameters

APPENDIX B

Summary of Monitoring Well Survey Data

MONITORING WELL	GROUND SURFACE ELEVATION	TOP OF CASING ELEVATION
MW-3	30.89m	30.80m
DP-1	30.89m	30.78m
MW-2	30.46m	30.37m
DP-2	30.49m	30.42m
MW-5	30.56m	30.47m
DP-3	30.59m	30.50m

Note: Measurements are in meters relative to an arbitrary site benchmark of 30.00 meters

Summary of Water Table Elevation Data

MONITORING WELL	7/26/04	8/2/04	11/15/04	11/19/04	11/25/04
MW-3	28.34m	28.30m	28.16m		
DP-1	28.35m	28.31m	28.18m		
MW-2	28.52m	28.47m	28.30m		
DP-2	28.51m	28.48m	28.31m		
MW-5	26.28m	27.47m	26.40m		
DP-3	26.26m	27.52m	26.37m		

Summary of Hydraulic Conductivity Data

MONITORING WELL	HYDRAULIC CONDUCTIVITY In cm/sec
MW-3	$6.205\text{x}10^{-5}$
DP-1	$1.569 \text{ x } 10^{-6}$
MW-2	$3.661 \text{ x } 10^{-5}$
DP-2	$1.278 \text{ x } 10^{-6}$
MW-5	$1.154 \text{ x } 10^{-6}$
DP-3	$1.785 \text{ x } 10^{-7}$

APPENDIX C

Critical Values of the Pearson Correlation Coefficient *r*

Level of Significance (p) for a Two-Tailed Test				
df (n-2):	0.10	**0.05**	0.02	0.01
1	0.988	**0.997**	0.9995	0.9999
2	0.900	**0.950**	0.980	0.990
3	0.805	**0.878**	0.934	0.959
4	0.729	**0.811**	0.882	0.917
5	0.669	**0.754**	0.833	0.874
6	0.622	**0.707**	0.789	0.834
7	0.582	**0.666**	0.750	0.798
8	0.549	**0.632**	0.716	0.765
9	0.521	**0.602**	0.685	0.735
10	0.497	**0.576**	0.658	0.708
11	0.476	**0.553**	0.634	0.684
12	0.458	**0.532**	0.612	0.661
13	0.441	**0.514**	0.592	0.641
14	0.426	**0.497**	0.574	0.623
15	0.412	**0.482**	0.558	0.606
16	0.400	**0.468**	0.542	0.590
17	0.389	**0.456**	0.528	0.575
18	0.378	**0.444**	0.516	0.561
19	0.369	**0.433**	0.503	0.549
20	0.360	**0.423**	0.492	0.537
27	0.311	**0.367**	0.430	0.471
30	0.296	**0.349**	0.409	0.449
35	0.275	**0.325**	0.381	0.418

Source: http://www-micro.msb.le.ac.uk/2060/rtable.html