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December 2, 2010

Mary Setnicar
Deputy Branch Chief
Land and Chemicals Division {L-8J}
U. S. Environmental Protection Agency
Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3590

Subject: **LR-8J**
Clinton Landfill No. 3 Chemical Waste Unit, Clinton, Illinois
Response to Comments submitted to the USEPA on
July 22, 2010 by KPRG and Associates, Inc.

Dear Ms. Setnicar:

On behalf of Clinton Landfill, Inc. (CLI), Shaw Environmental, Inc. (Shaw) is submitting this response to address comments submitted by KPRG and Associates, Inc. (KPRG) to the United States Environmental Protection Agency (USEPA) in a correspondence dated July 22, 2010. The correspondence submitted to the USEPA is believed to be based on KPRG's review of the permit application submitted to the USEPA for the development of a Chemical Waste Unit (CWU) at the Clinton Landfill No. 3, located in DeWitt County, Illinois.

The following information responds to each of the comments submitted by KPRG to the USEPA in the July 22, 2010 correspondence. This submittal consists of this letter response and respective figures and attachments.

INTRODUCTION

Clinton Landfill, Inc. maintains that the Application for the development of a Chemical Waste Unit at the Clinton Landfill No. 3 provides long-term protection of the environment, and meets or exceeds the stringent design and performance standards contained in State and Federal landfill regulations. The submittal by KPRG fails to provide evidence to the contrary. KPRG and Associates, Inc. have been provided sufficient time to prepare their submittal, as is demonstrated by the 17-page report to the USEPA. But those 17 pages provide no new data or analyses and fail to demonstrate any of their claims are valid. Overall, the assertions made by KPRG appear to be intentionally misleading, inappropriate, and incendiary, relying on scare tactics in an attempt to turn the community and the USEPA against the proposed facility. Some claims are made by KPRG that could be considered unethical, such as accusing the Applicant of exploiting the groundwater software for the benefit of the Applicant. These claims demonstrate that KPRG does not understand the basic facts of the environmental fate of PCBs, nor the facility's design and performance standards contained in State and Federal landfill regulations.

It is also unclear what documents KPRG reviewed to form their opinions. At the beginning of their submittal to the USEPA, KPRG indicates that they reviewed the permit application submitted by CLI. But on the second page of the submittal, at the beginning of the introduction, KPRG mentions performing a technical review of the geologic and hydrogeologic portions of applications filed for the Clinton Landfill No. 3 expansion. A Shaw 2005 document is referenced by KPRG in numerous comments detailed below, even though the Application was not submitted to the USEPA until October 2007.

Based on the discussion above, it is hard to determine what KPRG reviewed, but it does appear that KPRG did not review the design of the landfill which may explain their lack of knowledge in reviewing the groundwater model. The 17-page report was stamped by a professional geologist but a professional engineer did not stamp and sign the report, possibly indicating that only the geologic and hydrogeological portions of the Application were reviewed which would be a significant omission and error in KPRG's review. The groundwater modeling software (MIGRATE) used by the Applicant incorporates numerous landfill design components into the groundwater model. MIGRATE was actually developed and designed for the sole purpose of modeling landfills and incorporates engineered systems and the local hydrogeologic conditions. MIGRATE has been used at the majority of permitted landfills in Illinois. The attacks by KPRG on the groundwater modeling software and the Illinois Environmental Protection Agency's (IEPA) groundwater modeling protocols and regulations, points to KPRG's inexperience with landfill design, modeling of landfills, and permitting landfills in Illinois. Indeed, Federal regulations don't even require sophisticated modeling such as MIGRATE.

Regardless of their attacks to the groundwater modeling, KPRG ignores the basic fact that the mobility of PCBs is so low that computer modeling is not even required to demonstrate, to those knowledgeable regarding the environmental fate and transport of PCBs, that the facility is safe. KPRG and Associates, Inc. makes disingenuous claims that the site's hydrogeologic conditions are "pre-conceived" to be favorable to facility development. However, it is KPRG that ignores the Illinois State Geological Survey's conclusion that groundwater within the Mahomet Aquifer, which is separated from the bottom of the landfill by the engineering liner system and more than 150 feet of glacial clays, receives very little surface recharge in the site vicinity. KPRG's claims, which are based on absolutely no data, directly refute a study by the Illinois State Geological Survey (ISGS), as well as the reviews conducted by the IEPA and Dr. Craig Benson, an internationally renown authority on environmental engineering and landfills.

Due to concerns related to KPRG's lack of modeling experience, a licensee inquiry (for MIGRATE) was made to GAEA Technologies Ltd. (sole distributor of MIGRATE) to see if KPRG owns a copy of MIGRATE and whether or not they are a licensed user. GAEA Technologies Ltd. informed Shaw that KPRG does **not** own a copy of MIGRATE and that KPRG is **not** a licensed user of MIGRATE. Therefore, KPRG would not have been able to review the input and output files, recreate the model runs, or understand the basic operation of MIGRATE. All of KPRG's comments would appear to be based on preconceived and untested opinions versus actual use of MIGRATE (or any other model) for groundwater modeling of the Site.

The design provided within the Application includes the latest landfill design concepts which have been demonstrated to be protective of the environment. Unique to the proposed facility are the number and extent of safeguards employed. In many cases, the stringent design and performance standards contained in State and Federal landfill regulations have been exceeded. Additionally, the proposed design works in conjunction with a suitable location and favorable site geology and hydrogeology to assure that the public health, safety, and welfare will be protected.

RESPONSE TO COMMENTS

The following provides comments or opinions stated by KPRG (in italic) and the respective Applicant response.

Executive Summary

1) *The application for Clinton Landfill Number 3 gained IEPA approval based on simulations created by a program that is very limited in its capabilities. The simulations, and data and analysis provided to the USEPA, largely ignored these limitations except to the extent the limitations were exploited for the benefit of the Applicant. Most notable of these failures is the lack of calibration, absence of fundamental hydrogeologic data, and lack of evaluation of lateral migration.*

Applicant's Response: This comment is disingenuous. KPRG and Associates, Inc. is critical of the modeling software (MIGRATE) that was used at the Site for the Groundwater Impact Assessment (GIA), but it is clear based on comments below that KPRG does not know how to read or interpret the output files generated by the software or even the input parameter tables provided in the text of the GIA. MIGRATE is a well documented model that is approved for use by the IEPA and, as a result has extensive use in modeling landfills in hydrogeologic environments similar to the one at the Site. MIGRATE was developed by Dr. Kerry Rowe, who is recognized as one of the top experts in the world regarding landfill design and contaminant transport. KPRG and Associates, Inc. appears to be critical of the software due to their lack of knowledge and/or they are purely biased against the idea of the permitting of the CWU, rather than their understanding of the software and IEPA regulations.

As discussed in the introduction above, KPRG does not own a copy of MIGRATE and KPRG is not a licensed user of MIGRATE. Therefore, KPRG would not have been able to review the input and output files, recreate the model runs, or understand the basic operation of MIGRATE. All of their comments would appear to be based on preconceived opinions versus actual use of MIGRATE for groundwater modeling of the Site.

It is unclear whether or not KPRG understands that the Federal Toxic Substances Control Act (TSCA) regulations do not require a GIA and that the GIA was required under 35 Ill. Admin. Code Section 811.317 and 812.316. Therefore, the GIA was developed and executed following State regulations and IEPA Guidance Document LPC-PA2.

As mentioned above, KPRG accuses the Applicant of exploiting the groundwater software for the benefit of the Applicant. Clinton Landfill, Inc. and Shaw Environmental, Inc. find this accusation disturbing, especially based on what appears to be KPRG's lack of knowledge with regards to the modeling software and required regulations and misleading and incorrect hydrogeological comments that will be discussed later in this response.

The hydrogeological investigation was developed and performed in accordance with the requirements of 35 Ill. Admin. Code, Sections 811.315, 812.314, and 812.315 and Federal TSCA regulations. The hydrogeological investigation meets and exceeds all State and Federal regulations.

2) *Additionally, site specific, reasonable and meaningful hydrogeologic data is lacking. The perceived hydrogeology is just that - perceived. The evaluation assumes much but is based on little more than inapplicable speculation. What is necessary is a more detailed review in light of known geologic and hydrogeologic systems at the site. This accurate understanding must then be applied to a three-dimensional groundwater model. The evaluation of the model must be expanded both in terms of time and distance. Failure to perform this most basic evaluation will result in a failure to identify potential threats to human health and the environment.*

Applicant's Response: This comment is erroneous. As pointed out in the Applicant response to Comment No. 1, the hydrogeological investigation meets and exceeds all State and Federal regulations. The IEPA performed a thorough review of the hydrogeological investigation and agreed with the findings and issued a permit for the Site based upon not only what was included in the application, but years of groundwater monitoring which confirms the hydrogeologic conditions. The hydrogeological investigation is composed of over 1,000 pages of information and data that includes numerous boring logs, cross-sections, private water well logs, geotechnical information, slug testing, potentiometric maps, and etc. Clinton Landfill, Inc. has over twenty years of groundwater monitoring data for the facility, and has excavated and constructed landfill cells in the clays at the Site and found them to be as identified in the hydrogeological investigation.

As pointed out in Applicant response to Comment No. 1, the GIA was developed and executed following State regulations and IEPA Guidance Document LPC-PA2. The IEPA regulations require the GIA to evaluate predicted concentrations at 1/3 the distance to the zone of attenuation (ZOA)(33.3 feet), 2/3 the distance to the ZOA (66.6 feet), and at the ZOA (100 feet). Expanding the evaluation further away from the CWU, as suggested by KPRG, seems illogical since potential impacts from the CWU would first be identified closer to the landfill footprint rather than farther away.

Based on KPRG's comment, it is hard to determine whether or not they are looking at the right report, because it has been proven that the hydrogeological investigation and groundwater modeling are not lacking, as made evident by the IEPA approval.

Introduction

3) *KPRG's project team performed a technical review of the geologic and hydrogeologic portions of applications filed for the Clinton Landfill No. 3 expansion in DeWitt County, Illinois. This review focused on the application for a chemical waste disposal facility within the footprint and airspace of the proposed expansion of the Landfill No.3 facility. Our review has identified several issues that should be of concern to, and be considered by, the United States Environmental Protection Agency (USEPA) in reviewing the pending application. The following sections describe the proposed site and landfill characteristics, and detail concerns identified in our review.*

Applicant's Response: As discussed in the introduction section above, it is unclear what documents KPRG reviewed to form their opinions. At the beginning of their submittal to the USEPA, KPRG indicates that they reviewed the permit application submitted by CLI. Based on this comment it appears KPRG may have only performed a technical review of the geologic and hydrogeologic portions of applications filed for the Clinton Landfill No. 3 expansion. A

Shaw 2005 document is referenced by KPRG, even though the Application was not submitted to the USEPA until October 2007.

KPRG and Associates, Inc. may not have reviewed the design of the landfill which may explain their lack of knowledge in reviewing the groundwater model. The 17-page report was stamped by a professional geologist but a professional engineer did not stamp and sign the report, possibly indicating that only the geologic and hydrogeological portions of the Application were reviewed which would be a significant omission and error in KPRG's review.

Conceivably, KPRG believes the waste will be disposed of in an unlined hole in the ground.

Site Geology

4) *The glacial sediments also provide the pathways for migration of landfill contaminants away from the landfill in gaseous and/or liquid form. They contain the water resources that are used by individual households and by public water supplies to meet personal, agricultural and industrial needs (Shaw 2005, Appendix E.3 and Shaw 2009, Attachment 1). They provide the storage capacity and migration pathways that allow precipitation to renew water resources. The glacial sediments provide a limited capacity to mitigate and absorb damage induced by human activities at or near the surface.*

Applicant's Response: This comment is misleading. Based on this comment and KPRG's 17-page report, it seems that their understanding of the glacial sediments at the Site is that they are composed of silt, sand, and gravel. Clay is only mentioned once in their report when discussing migration through clay liners. The fact is that the major component of the glacial sediments below the Site is clay. It appears that during KPRG's technical review of the geologic and hydrogeologic investigations, they missed or skipped portions of the text that discussed the clay present at the Site. This could explain their concerns related to the geologic and hydrogeologic investigation.

The hydrogeologic setting at the CWU is ideal for a modern landfill. Review of boring logs below the facility indicate that there is at least 150 feet of in-situ clay between the landfill liner system and the Mahomet Aquifer (See Figures 1 and 2). The clayey deposits beneath the site have existed for over 10,000 years (much longer than recorded human history) and act as an aquitard. An aquitard is defined as a water-saturated sediment or rock whose permeability is so low it cannot transmit any useful amount of water. Therefore, the clayey deposits will act as a permanent barrier and supplement protective design features of the landfill by restricting contaminant movement from the landfill in both vertical and horizontal directions. The presence of this extremely thick and massive clay is why the ISGS identified this site as having one of the best hydrogeologic settings for a landfill in the State (See Figure 3).

The isolation of the Mahomet Aquifer from surficial recharge, in the region near the Site, is also documented by a recent article by the ISGS (Hackley, Panno, and Anderson, July/August 2010). The article summarizes that, the chemical and isotopic results for the Mahomet Aquifer in the western (region where the Site is located) and northeastern regions indicate that these areas of the aquifer are relatively isolated from the surficial recharge and have been influenced by the infiltration of older groundwater from bedrock units with greater dissolved ion concentrations (See Attachment 1). The article goes on to state that, "it appears the most of the Mahomet Aquifer is well protected from surficial contamination".

KPRG and Associates, Inc. discuss how glacial sediments provide a limited capacity to mitigate and absorb damage induced by human activities at or near the surface. Once again, it seems that either KPRG: 1) has ignored the fact that the site is underlain by glacial clay that was compacted by glaciers which were thousands of feet thick, 2) lacks a fundamental understanding of glacial environments, and/or 3) has sacrificed professional integrity for the sake of contract from an opponent to the facility. Clay is known to be one of the best natural barriers to damage induced by human activities at or near the surface. Clay also has an extremely high ability to mitigate and absorb contamination introduced by human activities.

While the CWU's redundant liner and leachate collection systems will prevent landfill leachate from migrating to the underlying aquifers, extremely conservative modeling demonstrates that PCBs would not migrate to underlying aquifers even if the proposed liner systems do not exist. This is due to the inherent immobile nature of the PCBs which would cause them to bond strongly to the clay and not travel through the clays which underlie the landfill. Put simply, the clay directly below the liner would act like an impenetrable barrier to the PCBs.

The ability of the natural clay to absorb the PCBs can be demonstrated by using a simple conservative groundwater model that assesses how PCBs in leachate, sitting directly on top of the 3-foot recompacted engineered clay liner (constructed out of the native clays at the site), would move vertically through the proposed clay liner. Such a model was performed for the proposed site and was provided in Attachment 2 of the CLI February 2009 submittal to the USEPA. The model is based on the assumption that leachate will contain 500 ppm PCBs. This is extremely conservative since data from PCB permitted landfills demonstrate that leachate PCB concentrations are likely more than 100,000 times less than this assumed concentration. Regardless, even at this concentration (500 ppm), the PCBs groundwater model assessment demonstrates that PCBs will not migrate out of the 3-foot recompacted clay liner even after 1,000 years. This model does not even consider the geosynthetic liner system or the 150 feet of in-situ clay beneath the recompacted clay liner which further demonstrates that the CWU will never negatively impact the Mahomet Aquifer.

Once again, a Shaw 2005 document is referenced by KPRG, even though the Application was not submitted to the USEPA until October 2007. It is interesting that KPRG references Attachment 1 of the Shaw 2009 document which was submitted for CLI by Shaw in February 2009. Attachment 2 of this same document contains the model discussed in the previous paragraph, yet KPRG never mentions this model or the results contained in the text. Either they missed this groundwater model provided to the USEPA, agree with the results, or chose to ignore the results that demonstrate PCBs will not migrate out of the 3-foot recompacted clay liner even after 1,000 years.

It is hard to believe that an environmental consulting firm like KPRG does not know that clay is a large component in glacial materials in the Midwest and that these clays have the capacity to mitigate and absorb damage induced by human activities at or near the surface (as documented in numerous published articles and supported by the model provided in Attachment 2 of the CLI February 2009 submittal to the USEPA). Overall, the assertion made by KPRG appears to be intentionally misleading, inappropriate, and incendiary.

5) *Illinoian sediments were weathered, altered and eroded during the many millennia between the Illinoian and Wisconsinan glacial epochs. Weathering, cracking and the presence of significant sands within the Wisconsinan and Illinoian sediments facilitate significant*

movement of groundwater. This is verified in the vicinity of the site by the presence of many domestic water supply wells that produce water from these units (Shaw 2005, Appendix E.3).

Applicant's Response: This comment is deceptive. While there are sand seams within the glacial tills at the Site, the sands certainly could not be described as significant. The sands are an important part of the detection monitoring system and any slight change in groundwater quality in the sands would be intercepted and detected by the monitoring system. The monitoring wells that surround the facility will be 50 feet from the waste boundary. The closest water well to the CWU is over 1,000 feet away and located at the CLI office. The closest water well not owned by CLI is over a half of a mile away from the CWU.

As stated above, CLI has over twenty years of experience at the facility and has excavated and constructed landfill cells in the clays at the Site. Clinton Landfill, Inc. has found the sand seams to be discontinuous and easily dewatered. Dewatering activities at Clinton Landfill No. 2, have shown that only monitoring wells in close proximity to the dewatering activities and at a specific elevation are affected (water levels in the wells are lowered) when these discontinuous sands are excavated. The fact that dewatering activities only affect certain monitoring wells at the facility and not all of the monitoring wells and that the sand seams are so readily dewatered, shows that the sand seams at the Site are not extensive and that the clay is not fractured and allowing significant movement of groundwater.

This conclusion is further supported by the ISGS identifying this site as having one of the best hydrogeologic settings for a landfill in the State and Hackley, Panno, and Anderson, July/August 2010 indicating that this area of the Mahomet Aquifer is relatively isolated from surficial recharge.

If the sands seams in the glacial tills were significant and not discontinuous, there would be no need to access the Mahomet Aquifer for potable drinking water.

<u>Site Hydrogeology</u>

6) *These local aquifers are sometimes fed directly by precipitation but are also usually recharged with precipitation that infiltrates from the surface through fractures and weathered zones within the fine-grained glacial sediments and through interbedded organic and peat layers. Occasionally private wells will penetrate to gravel and sand units within the glacial sediments below the Illinoian-aged sediments and into the Mahomet Aquifer.*

Applicant's Response: See Applicant response to Comment No. 5.

7) *The natural water table surface in the glacial sediments is unconfined and expected to form a subdued replica of the land surface. It will lie below the land surface in topographically high areas and decrease away from those areas to the elevation of Salt Creek. The water table provides the driving force, or potential, for groundwater flow. Under that potential, groundwater flow within the glacial sediments will come from areas of higher topography to areas of lower topography, primarily through pathways of higher conductivity. Groundwater typically recharges in areas of higher topography and discharges to streams or surface water bodies in areas of lower topography. At this site, the shallow flow direction is generally north to south, consistent with the surface topography toward Salt Creek to the south.*

Applicant's Response: Clinton Landfill, Inc. agrees with these statements and has determined that the southern end of the facility is down-gradient and that groundwater flowing in this direction would be intercepted by the monitoring wells that surround the facility. With the groundwater flowing southward, any slight change in groundwater quality would be intercepted and detected by the monitoring wells located just 50 feet from the waste boundary.

Additionally, with the groundwater discharging towards Salt Creek, which is located more than 1,500 feet south of the CWU, vertical movement of groundwater is minimal, adding further protection to the Mahomet Aquifer. This minimal vertical movement of groundwater or surficial recharge to the Mahomet Aquifer was discussed by Hackley, Panno, and Anderson, July/August 2010.

It is also extremely important to realize that CLI owns the land between the CWU and Salt Creek and that no water wells are located in that area.

8) *The base of Clinton Landfill No. 3 will be excavated into the glacial sediments to elevations as low as 665 ft-msl. The base of the excavation approximately coincides with the bottom of the Wisconsinan sediments and the top of the Illinoian sediments. The excavation at this level puts the basal liner(s) and the lower portions of the sidewalls of the landfills below the uppermost encountered water during the drilling of boring EX-14 which was recorded at approximately 672 ft-msl. and also below the heads recorded after well completion at location EX-14 (approximately 678 ft-msl) which screens the major water bearing strata at and near the base of the excavation over most of the footprint of the landfill.*

Applicant's Response: Clinton Landfill, Inc. agrees that the facility will likely be an inward gradient landfill with groundwater moving into the landfill in the unlikely event a hole was to develop in the liner. We note that the floor of the adjacent Clinton Landfill No. 2 is at Elevation 636 ft-msl and lower. This is about 30 feet lower than that planned at the CWU. Clinton Landfill, Inc. has developed and operated Clinton Landfill No. 2 over the past two decades without any difficulty or evidence of impacts to groundwater.

The fact that KPRG chose to use one of the monitoring wells with the highest water levels and located at one of the furthest locations from the CWU, points to KPRG's intent to "cherry-pick" the data and not look for reasonable data while evaluating the facility. Numerous wells are located in close proximity of the CWU that would have provided water levels in this area of the facility.

9) *Diffusion of contaminants through the liner will inevitably occur. The permit application contains no evaluation of the magnitude of contaminant diffusion through the liner system during the operating and post-closure period. The groundwater impact assessment considers diffusion only post-closure (i.e., the time at which the leachate collection system is turned off), assuming a "clean" system at the start of post-closure.*

Applicant's Response: This comment is false. Diffusion was considered from day one of the operating life of the landfill and continued 100 years after the operating life of the facility. This is shown in the input tables for the groundwater model, which were provided with the October 2007 Application (See Attachment 3). Additionally, diffusion was discussed in the text of the GIA and any hydrogeologist with groundwater modeling experience could look at the output files provided for the GIA and see that diffusion was incorporated into the models from the beginning of the operating life for the facility.

Based on this comment, either KPRG is unqualified to review any groundwater modeling or KPRG is purposefully trying to mislead the USEPA and the public.

10) *It is not until after the post-closure, leachate extraction and monitoring periods that the full potential for release of contaminants from the landfill into groundwater will develop. The Operating Plan takes great care to show that leachate head on the Chemical Waste Unit will be maintained at less than 12-inches during the operating life of the landfill. Leachate collected in the sumps will be removed for offsite disposal. Although the Closure and Post-Closure Care Plan suggests the landfill will be cared for "perpetually", there is no requirement for continued collection and removal of contaminated leachate after closure. Groundwater inflow through the liner and infiltration through the cap will begin to saturate the waste once the leachate collection system ceases to be operated. Leachate formed from the contact and interaction of this water and waste will saturate the waste to an equilibrium level, the level at which the amount of water flowing into the landfill equals the amount of leachate leaking from the landfill. The application includes no evaluation of the timing, magnitude or impact of these equilibrium releases. Consideration of the final equilibrium condition was not part of the permitting process and was not considered by the Illinois Environmental Protection Agency (IEPA). Therefore, evaluation of equilibrium releases will only be done if required by USEPA.*

Applicant's Response: This comment is false. As shown in Attachment 3, outward vertical Darcy velocities are incorporated into the groundwater models from day one of the operating life of the landfill and continued 100 years after the operating life of the facility. The groundwater models assumed that the landfill was leaking from day one, so calculating an equilibrium point (as discussed by KPRG) and then applying an outward gradient would be less conservative. Additionally, the vertical Darcy velocity was discussed in the text of the GIA and any hydrogeologist with groundwater modeling experience could look at the output files provided for the GIA and see that an outward gradient scenario was incorporated into the models from the beginning of the operating life for the facility.

Based on this comment, either KPRG is unqualified to review any groundwater modeling or KPRG is purposefully trying to mislead the USEPA and the public.

Evaluation

<u>Adequacy of the Site Characterization</u>

11) *This sequence is critical because the ultimate criterion for evaluation of a landfill application is the acceptance by IEPA of the facility's computer simulation assessments of the groundwater impacts (GIA). This is the computer projection of landfill impacts 100 feet laterally from the waste boundary 100 years after closure. It is the summary demonstration by the applicant that the landfill will not damage its surroundings beyond a level that is acceptable under the statutes and regulations. Construction of a calibrated, three-dimensional, numeric groundwater model is required in order to adequately investigate and interpret performance of the facility over the long term.*

Applicant's Response: See Applicant response to Comments No. 1 and 2.

Additionally, as clearly pointed out in Applicant responses to Comments No. 9 and 10, KPRG is unqualified to review any groundwater modeling or KPRG is purposefully trying to mislead the USEPA and the public. Regardless of whether or not KPRG is unqualified or being misleading, their comments should be given only minimal consideration while the USEPA reviews the facility.

12) *The pending application lacks a proper characterization. The sequence for this application began with a presumed understanding of the site upon which the facilities were designed, are being or will be constructed, operated and monitored. Unfortunately it appears that data was forced into a pre-conceived site understanding or ignored when the data did not match this pre-conceived view. The facilities will be monitored by systems that are potentially inadequate to measure impacts. Additionally the applicant used "assumed" input data that varies from being unreliable to being known to represent improbable conditions. Specific examples of insufficiencies, inadequacies, or errors in the application are provided below:*

Applicant's Response: See Applicant response to Comments No. 1 and 2. It is interesting to note that the three separate organizations (the IEPA, Shaw, and PDC Technical Services), which have performed extensive review of the hydrogeological data that has been collected from the site over the past two decades, all came up with the same "pre-conceived" understanding that the site is protective of the environment.

Interpretive Errors and Inadequacies

13) *Inattention to Wisconsonian Sediments - The application ignores the significance of Wisconsonian Age glacial sediments with respect to the facility to be constructed. These sediments include obviously weathered till and sand and peat layers as much as 10 feet in thickness, not insignificant amounts. Although these sediments will be removed within the footprint of the excavation, they are also the sediments that will lie adjacent to the sidewalls of the landfill(s). They contain the water table that will rise and fall seasonally and provide the migration paths for contaminants that diffuse or flow from the landfill(s) laterally into undisturbed strata. These may provide unmonitored preferential pathways for contaminants to migrate.*

Applicant's Response: See Applicant response to Comments No. 5 and 8. Furthermore, KPRG is ignoring the fact that the landfill sidewalls will be lined with 3 feet of recompacted engineered fill and two layers of 60-mil thick high density polyethylene (HDPE) geomembrane. The sidewalls will slope down toward the landfill floor at a steep grade. Any liquids within the landfill will enter the highly permeable leachate drainage layers that will be placed above and between the geomembranes. Because liquids travel the path of least resistance (i.e. highest permeability) under the influence of gravity, all liquids will drain to the landfill bottom (which is below the bottom of the Wisconsinan-aged glacial deposits) and be collected via the engineered leachate collection system.

14) *Failure to Characterize Water Table - Review of the boring logs included with the permit application shows that water-bearing sediments are present well above the screened intervals in the Lower Radnor Sand that is depicted as the uppermost water-bearing unit at the site. Likewise no water table elevation data or water table maps are provided with the application. We have confirmed that your office, the USEPA, was never provided the water table data or water table maps. The groundwater flow direction and velocity at the water table have not*

been characterized. This is a significant deficiency of the permit application. The water table provides the fundamental driving force for groundwater flow and ultimately determines the potential impacts from this facility.

Applicant's Response: See Applicant response to Comments No. 5 and 8.

Additionally, as discussed above, the hydrogeological investigation meets and exceeds all State and Federal regulations. The IEPA performed a thorough review of the hydrogeological investigation and agreed with the findings and issued a permit for the Site. The hydrogeological investigation is composed of over 1,000 pages of information and data that includes, numerous boring logs, cross-sections, private water well logs, geotechnical information, slug testing, potentiometric maps, and etc. Clinton Landfill, Inc. has over twenty years of experience at the facility and has excavated and constructed landfill cells in the clays at the Site and found them to be as identified in the hydrogeological investigation.

15) Improper Interpretation of Fine-sediment Properties - The Landfill's pending application assumes that the laboratory data collected from boring samples of the fine-grained sediments represents the functional hydraulic conductivity of those layers within the glacial sediments under actual field conditions. This assumption is appropriate only to the degree that it a) is realistically likely and b) is supported by all data at the site. Based on knowledge of regional geological/hydrogeologic conditions and application data review, neither condition is met. Hydraulically significant fracturing of glacial tills is the rule, not the exception in the midwest, and water moves faster and at higher volumes than laboratory data would suggests; contrary to the Landfill's assumption hydrogeologic data at the site (gradients, heads and head changes, saturations, field permeability testing, etc.) collectively establish that the fine-grained glacial sediments do not act as impermeable layers significantly inhibiting downward or lateral flow beneath or adjacent to the facility. The large increase in head level recorded in some wells (discussed below) which were not addressed or discussed in the application illustrates the applicant's lack of understanding of fine-grained sediments.

Applicant's Response: See Applicant response to Comments No. 5 and 8.

Clinton Landfill, Inc. also has monitored the groundwater quality surrounding the adjacent Clinton Landfill No. 2 for more than 20 years. The fact that no evidence of impacts to the groundwater surrounding Clinton Landfill No. 2 have been found shows the fallacy of KPRG claims that the shallow and deeper water bearing units are susceptible to contamination by modern lined landfills.

16) Poor Use of Constraints due to Data Depth - A review of the mapped extent of the sands deemed important by the application shows an improper or inaccurate integration of the boring data. In particular, there are instances (e.g., wells EX-IO, EX-26, EX-27, and EX-29) where wells that may have been too shallow to penetrate the Lower Radnor sand are interpreted as the sand having no thickness at that location. An absence of data at a location is not evidence of an absence of the sand. This failure is yet another example of the Landfill's failure to submit an accurate representation of the proposed facility.

Applicant's Response: This comment is incorrect. The geologic and hydrogeologic investigation at the proposed facility was based on over 40 boring locations advanced throughout the Site. Boring locations EX-26, EX-27, and EX-29 all penetrate the anticipated top of the Lower Radnor Till Sand, as the top of the Lower Radnor Till Sand was not encountered (NE) at these locations it was given a NE label. Boring location EX-10 was presented on the Roxana-Robein Member figures and then removed from the Upper Radnor Till Sand figures, but was mistakenly left on the Lower Radnor Till figures. The inclusion of EX-10 on the Lower Radnor Till figures does not change any of the conclusions from the geologic and hydrogeologic investigation or have any effect on the GIA.

17) *Inconsistent Interpretation of Flow Systems - The flow of groundwater in the application is represented as isolated flow within separate, discrete aquifer layers. Contrary, the flow is interpreted as two-dimensional (i.e., strictly within the isolated layers). This ignores the significance of the vertical gradients documented in the data (both upward and downward), seasonal variations, systematic head changes related to site operations, thickness variations, areas where aquifers are absent, and correspondence between head levels in deeper aquifers and the shallowest saturation (first water) at a boring location. One extreme example of the Landfill's interpretation that is inconsistent with the site data is the mapping of potentiometric surfaces within aquifers as moving water directly across boundaries where the aquifers pinch out. If flow is restricted to occurring within the aquifer, there can be no flow across the zero line (Shaw 2005, Figures 812.314-19 and 812.314-27). Either the flow direction is wrong, or the map of the limits of the aquifer is wrong. Either way, the Landfill's failure to properly identify groundwater conditions will result in multiple subsequent errors in the application including but not limited to the not being able to properly detect or secure contaminants from migrating from the landfill.*

Applicant's Response: This comment is misleading. As discussed in Comment No. 5, the sand seams at the Site are not extensive and the clay is not fractured and allowing significant movement of groundwater. However, to be conservative in developing the Site conceptual model, these discontinuous sand seams are assumed to be interconnected and potential migration pathways. The other option would be to assume the sand seams are discontinuous and not consider them when evaluating the Site.

18) *Inappropriate Interpretations of Permeability Testing - The interpretation of the slug test data acquired at the site is in consistent with the recovery character observed for the tests. Spot-checking the solution shown on the graphs does not reproduce the value reported. The recovery curves for the slug tests are characteristic of curves from a multi-porosity, multi-permeability system, like a combined system of permeable sand and fractured fine-grained tills. The curves are not consistent with a sand aquifer contained within non-permeable bounding beds. Therefore, any results from the evaluation of slug test data must be disregarded or at the very least discounted.*

Applicant's Response: This comment is disingenuous. KPRG and Associates, Inc. do not provide any examples of slug tests where they believe they may be seeing curves from a multi-porosity, multi-permeability system, like a combined system of permeable sand and fractured fine-grained tills. While there are no examples to respond to specifically, the Applicant response to Comment No. 5 does discuss the point that the clay at the Site is not fractured and is not allowing significant movement of groundwater.

The comment, "*any results from the evaluation of slug test data must be disregarded or at the very least discounted*", is just another example of KPRG making a statement and not providing any facts to support their opinion. As clearly pointed out in earlier Applicant responses to

Comments, KPRG purposefully makes statements to mislead the USEPA and the public in an attempt to turn the USEPA and public against the proposed facility.

19) *Insufficient Evaluation of Head Data - Review of the groundwater head data supplied with permit application (see graph of heads below) shows that all monitoring wells located along the west and northwest boundaries of the Clinton Landfill (e.g., wells EX-7, EX-12S, EX12-D, EX-I3, EX-I7, and EX-19) for which head data was reported experienced rapidly rising heads commencing in late 2005 and 2006 while the remaining monitoring wells remained nearly static. This is an unusual occurrence that is completely unaddressed in the permit application. To identify the cause of the increase in heads, readily available aerial photographs of the site were reviewed. It was observed that what appear to be storm water retention ponds, associated with construction on adjacent portions of the Clinton Landfill, had been constructed near the west and north perimeters of the permit area. If these ponds are the source of water causing the localized rise in heads, the glacial sediments when the proposed Chemical Waste Unit are capable of readily transmitting groundwater in a flow system that is significantly different than that described in the permit application. This casts doubt on the entire site characterization and resulting GIA in the Landfill application.*

Applicant's Response: This comment is erroneous. The comment made by KPRG is essentially based on a jump in water levels near the end of 2005 in two monitoring wells, EX-7 and EX-19. KPRG and Associates, Inc. attribute this jump in water levels to storm water retention ponds, associated with construction on adjacent portions of the Clinton Landfill. They discuss reviewing readily available aerial photographs of the site to come up with this conclusion. They go on to mention that this casts doubt on the entire site characterization and resulting GIA in the Landfill application.

If KPRG had taken the time to look at the readily available aerial photographs they mention, they would have noticed that cell construction had been going on near EX-7 and EX-19 at the Clinton Landfill No. 2, prior to the jump in water levels in late 2005. They could have also looked at Geologic Drawings G2 and G3 (See Attachment 2) provided in the Application and noticed that EX-7 and EX-19 are screened in a sand that resides around approximately 640 feet mean sea level (ft. MSL). The depth of cell construction for Clinton Landfill No. 2 was approximately 630 ft. MSL. A reasonable explanation for the jump in water levels at EX-7 and EX-19 is that dewatering activities performed for the construction of Clinton Landfill No. 2 had concluded prior to the jump in water levels at the end of 2005.

The fact that dewatering activities only affected two monitoring wells at the facility points to the fact that the sand seams at the Site are not extensive and that the clay is not fractured and allowing significant movement of groundwater. This is further supported by the ISGS identifying this site as having one of the best hydrogeologic settings for a landfill in the State and Hackley, Panno, and Anderson, July/August 2010 indicating that this area of the Mahomet Aquifer is relatively isolated from surficial recharge.

Based on the strong evidence that the increase in water levels in EX-7 and EX-19 is related to dewatering activities performed for the construction of Clinton Landfill No. 2, KPRG may want to change their conclusion. Hopefully, this will remove any doubt that they have on the site characterization and resulting GIA in the Landfill application.

Monitoring Inadequacies

20) *Directions and Rates of Flow - The hydrogeologic data provided with the application includes a 4-year snapshot of monitoring wells. It is noteworthy that several of the wells showed noticeable -- and in some cases dramatic -- changes in groundwater head which are reflected in changes in the direction and velocity of groundwater flow. Without detailed evaluation and explanation of this, the applicant cannot reasonably infer the range of hydrologic conditions associated with existing or future conditions at the site. From this lack of examination and understanding the USEPA cannot, reasonably assess varying levels of risk to the public health, safety and welfare.*

The groundwater monitoring system proposed for the facility is laid out under the premise that flow rates and directions inferred from the original groundwater head levels are representative of the flow rates and directions that will exist after the Chemical waste Unit is constructed. That assumption is flawed and does not even apply to the existing heads and resulting contemporary flow system. The flow system will change further as a result of the construction of the landfill - it inherently must and has shown that it will change - and the groundwater monitoring system(s) must be laid out in a manner that is consistent with the anticipated new flow regime to successfully document landfill performance.

Quantifying the extent, location and magnitude of flow regime changes that will result from the expansion to the degree necessary to design a groundwater monitoring network capable of demonstrating protection of the public health safety and welfare, requires a full 3-D numerical groundwater flow model calibrated to existing conditions and verified to transient seasonal variation or, if available, earlier historic data. The application suggests two material changes to the existing flow system (from construction) that would be expected at this site. The first is change to the lateral flow patterns in response to the insertion of the landfill mass into the horizontal flow system in the unconsolidated sediments. The second are the changes to the vertical component of the flow system that will occur as a result of depriving additional (landfill and Chemical Waste Unit footprints) acres of their existing recharge. These were not considered in the application and are discussed below.

In comparison to the existing unconsolidated sediments, the volume of the landfill mass encased in the basal liner would function as a barrier to horizontal groundwater flow. A low-permeability barrier inserted into a horizontal groundwater flow system has an impact directly analogous to dropping a boulder into a flowing stream. Water that previously could flow through the aquifer volume now occupied by the landfill either cannot flow or must find a new path around the obstacle. Like the boulder, the landfill will create a bow wave with divergent flow upgradient (upstream) and there will be convergent shadow downgradient (downstream) of the landfill.

Vertical flow at this site is demonstrably important to understanding conditions and monitoring post-construction conditions. With the exception of the well cluster located nearest Salt Creek, the hydrogeologic data with the application provide evidence of predominantly downward vertical gradients across most of the existing facility and the expansion areas. The hydrogeologic characterization in the application completely fails to assess the significance of this downward driving force, the magnitude of the downward flow in response to it, its significance to the overall flow of groundwater under the proposed landfill, and its implications *upon monitoring the post-construction hydrogeologic system that will control contaminant migration.*

The full, properly designed and calibrated, three-dimensional numerical groundwater model suggested above, including a GIA evaluating the final equilibrium condition after post-closure, would appropriately evaluate this potential deficiency and the ability of the proposed monitoring system to adequately detect releases into the groundwater flow system that has been modified by construction of such an extensive barrier to existing groundwater flow. Insisting upon such modeling and evaluation would allow USEPA to make an informed determination that is based upon demonstrated performance and sound scientific principles - rather than simple acceptance of hopeful projections and assumptions by the applicant.

Applicant's Response: As discussed in the Applicant response to Comment No. 7, CLI agrees with KPRG that groundwater is moving from North to South. Clinton Landfill, Inc. has determined that the southern end of the facility is down-gradient and that groundwater flowing in this direction would be intercepted by the monitoring wells that surround the facility. With the groundwater flowing towards the south, any slight change in groundwater quality would be intercepted and detected by the monitoring wells located 50 feet from the southern edge of the CWU.

Additionally, with the groundwater discharging towards Salt Creek vertical movement of groundwater is minimal, adding further protection to the Mahomet Aquifer. This minimal vertical movement of groundwater or surficial recharge to the Mahomet Aquifer was discussed by Hackley, Panno, and Anderson, July/August 2010.

The "shadow effect" described by KPRG may slightly reduce water levels below the facility but it will not overcome the groundwater gradient from North to South. KPRG and Associates, Inc. may have developed their concerns based on a fractured clay system that does not exist at the Site. As discussed in Applicant response to Comment No. 5, the clay below the Site is not fractured and surficial recharge is minimal.

The slightly lower water levels that may occur due to the "shadow effect" (if it did occur) below the facility would only reduce groundwater flow below the Site, making the GIA more conservative. Actually, the potentiometric maps generated for Clinton Landfill No. 2 have not shown any reduction in groundwater gradients from North to South (See Attachment 4). This indicates that the lined landfill is not creating a "shadow effect" and further supports the fact that surficial recharge at the Site is minimal.

Most importantly, groundwater flow is monitored quarterly and reported to the IEPA on an annual basis. The requirements of 35 Ill. Admin. Code, Section 813.304 requires the Applicant to review the groundwater flow patterns and to conduct a new GIA if Site conditions vary from that upon which the previous GIA was based. Therefore, any potential changes that may be observed in the future will be incorporated into a new GIA. Clinton Landfill, Inc. has monitored groundwater flow directions surrounding Clinton Landfill No. 2 for more than 20 years and has not detected any significant change even though Clinton Landfill No. 2 extends about 30 feet deeper than the CWU will. Therefore, at this point CLI does not expect any significant changes but if changes do occur CLI will submit a new GIA to the IEPA.

Based on the comments made by KPRG, they are clearly not familiar with the State regulations, are not familiar with the extensive monitoring that has been conducted at the site for more than two decades, and do not understand that a new GIA would be required if Site conditions changed.

21) *Verification of HELP Simulations - The Site Location Application presents considerable detail about expected leachate generation rates derived from use of the Hydrologic Evaluation of Landfill Performance ("HELP") model. The HELP results are presented by the permit applicant without any calibration and without a monitoring program that provides verification of the assumptions and simulated results. Careful monitoring and reporting of the volume and chemistry of leachate produced in the Chemical Waste Unit, would provide near real-time verification whether the landfill is or is not performing to the planned specifications. Departure from the HELP performance projections would allow design modification and/or remedial actions to be taken proactively, before a more significant contamination problem develops.*

In order to take advantage of the opportunity to monitor actual landfill performance, model simulations of monthly leachate generation in the Chemical Waste Unit should be submitted for both the operating and closed conditions. The USEPA should also require monthly reporting of the volume of leachate pumped. Comparison of HELP-predicted rates to the actual leachate generation rates would indicate whether individual cell liner and cover systems are functioning as assumed in the HELP simulations.

Applicant's Response: This comment is flawed. The HELP model was developed in a joint effort by the USEPA and United States Army Corps of Engineers (USACE) as a quasi-two-dimensional hydrologic model for conducting water balance analyses of landfills and other solid waste containment facilities. The equations used in the HELP model were calibrated based on empirical data collected over many years. Additionally, the HELP model has been used for over the past 15 years at landfills across the nation and shown as a good predictor of leachate generation. The HELP model was not used in the application as an indicator of landfill liner performance.

Comparison of HELP-predicted rates to actual leachate generation rates would **not** be an indicator of the liner performance since leachate generation rates are driven by the following factors: area of active filling area, location of filling activities, and time of year, **not** performance of the bottom liner system. As discussed on Page 3-9 of Section 3 of the October 2007 USEPA Permit Application, the landfill liner design will contain a redundant leachate collection system which will serve as an early indicator of the performance of the top liner.

22) *Leachate Production and Internal Head Monitoring - The Environmental Monitoring Plan calls for leachate samples from the Chemical Waste Unit to be collected and analyzed on a monthly basis during site operation. This monitoring should be expanded to include the post-closure period as well. Tracking the chemistry of leachate, in parallel with fluid production described above would allow regulators to identify unexpected changes that signal breeches or construction flaws in the landfill liner or cover systems and allow for timely implementation of remedial measures.*

The Landfill applicant should also install piezometers within the Chemical Waste Unit in order to assure accurate measurement of leachate elevation. Piezometers would also allow ready *detection of leachate buildup in the landfill if the geotextile fabric and/or filter material in the leachate collection systems became bio-fouled or plugged with sediment during or after the leachate extraction system is operational.*

Applicant's Response: This comment is false. As stated on Pages 7-6, 8-15, and Table 8-4 of the October 2007 USEPA permit application, leachate will be monitored on a monthly basis during the entire post-closure care period. Furthermore, the leachate drainage system has been designed with multiple factors of safety, accounting for the possibility of partial clogging due to biological activity, chemical precipitation, and sediment. The designed system adequately ensures that the head on the liner system will be maintained less than 12 inches, as required by State and Federal regulations.

23) Perimeter Monitoring - Effective perimeter monitoring can only occur if the monitoring occurs at locations and times where contamination will occur. As discussed above, the monitoring locations currently planned at depths below the landfill invert are located not based on the flow system that will exist after the facility is in place. Perimeter monitoring must also be installed laterally along the sides of the landfill to verify no unacceptable leakage from the sidewalls. This monitoring must include groundwater pathways in saturated sediments and soil gas pathways in unsaturated sediments.

Applicant's Response: See Applicant response to Comment No. 20.

Furthermore, subsurface gas will be routinely monitored at locations within 100 feet of the CWU perimeter in accordance with the facility's IEPA permit.

24) Sub-Landfill Monitoring - The post-construction site will virtually eliminate recharge over the footprint of the landfill(s). However, recharge will continue as it does currently outside that footprint. That change in the distribution and quantity of recharge, coupled with the downward vertical gradients across most of the site, will result in lateral convergence of flow from the flanks toward the facility and downward under it. Perimeter monitoring will simply observe the water moving toward the landfill, not water flowing away from the landfill. As proposed the only contamination that might be observed would be diffusive transport outward that exceeds flow transport toward the landfill. For meaningful monitoring in the significant paths of flow, the operator must also monitor under the landfill, not just around its flanks.

Applicant's Response: See Applicant response to Comment No. 20.

Shaw has worked on hundreds of landfills located throughout the nation. We are not aware of any landfills which monitor groundwater directly beneath the landfill. We find this suggestion to be outrageous, again indicative of the true motives of KPRG's report.

25) Duration of Monitoring - Throughout the period of landfill operation and during the nominal 30-year post-closure care period, the landfill owner is required to maintain and operate the leachate collection system and monitor groundwater to detect releases. Barring catastrophic liner or cover failure or improper construction, continuing operation of the leachate collection system will maintain the inward groundwater gradient discussed in the application.

When the post-closure care period expires, infiltration of groundwater through the liner and precipitation through the cap will continue but leachate will no longer be removed. Leachate *will then, 30-years after site closure, begin to accumulate in the closed cells, initially at the sumps and then flooding progressively higher in the waste and progressively further up the slope of the individual cells away from the sumps. Leachate will saturate the waste to an equilibrium level at which the amount of water flowing into the landfill equals the amount of leachate leaking from the landfill. The process of saturating the waste to the equilibrium point may take additional years depending upon the failure rates of the liner and cover, but saturation of the waste is inevitable. At that equilibrium point in the future, when the potential for significant releases from the landfill is highest, regular sampling of the monitoring wells is no longer required by IEPA. Without additional USEPA-imposed monitoring requirements, the first notice that leachate levels have risen, that outward flow has begun, or that groundwater is being contaminated, will be contamination of an area water supply well or surface water body. Thus, the USEPA should require:*

1) A review of the groundwater flow and monitoring systems at the landfill will be conducted upon closure of the landfill and at 5-year intervals thereafter until equilibrium conditions, both inside and outside of the landfill, are established to verify the monitoring system continues to be capable of detecting a release; and

2) Monitoring of the functioning groundwater monitoring system continues for a minimum of 30-years after equilibrium conditions are verified. Extension of the post-closure care monitoring period in this manner will provide the public a level of assurance that its health, safety and welfare are being protected.

Applicant's Response: This comment is untruthful. Based on the PCBs groundwater model assessment submitted to the USEPA, PCBs will not migrate out of the 3-foot recompacted clay liner even after 1,000 years. This model does not even consider the geosynthetic liner system or the 150 feet of in-situ clay beneath the recompacted clay liner which further demonstrates that the CWU will never negatively impact the Mahomet Aquifer. Additionally, an outward vertical Darcy velocity was applied to the PCBs groundwater model assessment from day one of the operating life of the landfill which assumes the equilibrium point has been reached on day one of operations.

Additional monitoring is not justified by KPRG's comments. Once again it appears that, either KPRG is unqualified to review any groundwater modeling or KPRG is purposefully trying to mislead the USEPA and public.

<u>Evaluation of Impacts to Groundwater</u>

26) Impacts to groundwater were assessed by the permit applicant using the MIGRATE program. The validity of the results of the MIGRATE simulations are not defensible for each of the problems in hydrogeologic characterization that are described above. However, beyond the problems with inputs to the program (identified above), there are other weaknesses to this GIA related to the choice of the program, the design of the simulations, and the conditions being simulated. Even if the above noted characterization problems were eliminated, the simulations run by the permit application would not produce meaningful results due to the following deficiencies:

Applicant's Response: See Applicant response to Comments No. 1 and 2.

27) *Model Cannot Be Calibrated - The model is deterministic. The projections of future concentrations assume the input flow systems are correct; there are no provisions within the model to either verify that or to use the model results to improve the input. The model does not compute flow paths, head values, head gradients, discharge rates, or changes of any of these against which to check observational data. The inability to calibrate MIGRATE robs the user from the opportunity to perform a critical check of validity of model inputs. Without calibration, there can be no check of modeled conditions against actual field conditions. If there are unidentified erroneous inputs, the model will generate a meaningless calculation that does not reflect known conditions and does not predict future impacts.*

Applicant's Response: See Applicant response to Comment No. 1.

28) *Simulation Does Not Use Fundamental Hydrogeologic Data - The input to the model does not include head data, permeability data, or spatial variations in such data. The user provides a single specific flux value for vertical flow and a single specific flux value for horizontal flow. Developing these flux values for input must be done outside the model from the appropriate data. Proper reduction of the fundamental hydrologic data is imperative for MIGRATE to render a model that reflects the hydrogeological conditions at this site and to project future impacts. As developed the model used to support this application is not capable of simulating or even remotely resembling actual site conditions.*

Applicant's Response: This comment is false. The model does include head data, permeability data, and spatial variations. The user inputs a Darcy velocity that is calculated by multiplying the hydraulic gradients (created by the head data) by the permeability data. Spatial variations are included in the sensitivity analysis performed as part of the GIA. The calculations of the Darcy velocities and sensitivity analyses are clearly discussed in the text of the GIA and any hydrogeologist with groundwater modeling experience would understand that the head data, permeability data, and spatial variations were included in the GIA.

29) *Mass Balance is not a Constraint - The model does not confirm the flux values that are input for consistency or mass balance. For example, twice as much water can be designated as entering a layer as is leaving the layer and there is no resulting impact, such as head increases, because heads are not part of model input or model computation. Similarly, twice as much water can be defined as leaving a layer as entering the layer, and the layer does not go dry. Further, the model does not consider changes within a layer as water is added or removed along a flow path. These failures result in erroneous model values.*

Applicant's Response: See Applicant response to Comment No. 1.

30) Model Simulates only 2-D Slice - The equations that are solved assume infinite homogeneous and isotropic conditions exist at right angles to the slice that is simulated.

Applicant's Response: See Applicant response to Comment No. 1. Please note that two-dimensional models are more conservative than three-dimensional models as they allow only two degrees of freedom for the modeled contaminants versus three for three-dimensional models.

31) *Model Layers are Infinite and Invariable - There can be no changes to the parameterization of a layer in the model. If a vertical flux of 6 inches per year enters Layer 2 at one point, it enters*

at that rate everywhere in the model. If the water flowing out of the layer horizontally is 12 inches per year, the horizontal flow is 12 inches per year everywhere along it, regardless of water that is specified to be flowing into or out of it vertically. One implication of this is that the specified conditions of liner properties and liner fluxes appropriate for flow through the liners are also assigned outside the landfill where conditions are known to be dramatically different. Again, this is an inaccurate characterization, results in an incorrect representation of conditions renders the erroneous model predictions, and fails properly to assess potential impacts.

Applicant's Response: See Applicant response to Comment No. 1.

32) BaselinelBackground Concentrations Cannot Be Set - The model assumes that there is zero concentration of a contaminant outside the landfill at the start of the simulation and that only the landfill is a source of the contaminant. While this assumption is perhaps appropriate for strictly anthropogenic compounds, it is not a valid constraint for any compound that is also naturally occurring or that exists in background due to a pre-existing source, such as is common in agricultural communities.

Applicant's Response: This comment is deceptive. Once again, KPRG has made a comment that shows their lack of groundwater modeling experience. As discussed earlier, the GIA was developed and executed following State regulations and IEPA Guidance Document LPC-PA2. The Applicant was required to model the CWU and then compare its predicted results to the background concentrations at the Site.

The purpose of the model is to predict the affect that the landfill will have on groundwater quality, which it does well. With regards to PCBs, it can safely be assumed that groundwater up-gradient of the landfill has non-detectable concentrations of PCBs; therefore, the point made is moot.

33) Only Vertical Migration from Landfill is Simulated - The model can only simulate contamination migrating downward from the base of a landfill. Lateral migration from the flanks cannot be simulated, nor can such lateral contamination be simulated as migrating downward with groundwater flow - as is observed and documented at this site.

Applicant's Response: See Applicant response to Comments No. 1 and 13. KPRG's comments are very misleading, in that the model simulates vertical migration from the landfill floor and lateral migration through the aquifer.

Design of the GIA Simulations

34) Simulations Only Evaluate Landfill Half-Space - The simulation is structured to look only at the results of contamination from the center of the landfill to the downgradient edge of the landfill. With respect to early migration and migration through the clay liners, contamination migration is dominated by diffusion which knows no upgradient and downgradient limitations. Further, this spatial perspective does not allow simulation of the Municipal solid waste landfill that will be upgradient of the chemical waste facility. Contamination from the chemical waste facility will add to that from the municipal facility. This failure again results in inaccurate results from the model.

Applicant's Response: This comment is misleading. As discussed in Applicant response to Comment No. 9, KPRG does not understand that diffusion was considered in the groundwater models. The most conservative way to model the Site is to include diffusion and model the down-gradient end of the facility.

As mentioned in Applicant response to Comment No. 32, the Applicant was required to model the CWU and then compare its predicted results to the background concentrations at the Site.

The purpose of the model is to predict the affect that the landfill will have on groundwater quality, which it does well. With regards to PCBs, it can safely be assumed that groundwater up-gradient of the landfill has non-detectable concentrations of PCBs; therefore, the point made is moot.

35) *Simulations Only Evaluate Zone of Attenuation - The simulation is structured only to look at the first 100 feet from the waste boundary. The model should be structured to allow simulation of the system at greater distances. Simulations that look at the solution at greater distances often reveal problems in the inputs to the numeric parameters at distances greater than 100 feet. That check is not possible as the model is structured for this GIA.*

Applicant's Response: As pointed out in Applicant response to Comments No. 1 and 2, the GIA was developed and executed following State regulations and IEPA Guidance Document LPC-PA2. The IEPA regulations require the GIA to evaluate predicted concentrations at 1/3 the distance to the zone of attenuation (ZOA)(33.3 feet), 2/3 the distance to the ZOA (66.6 feet), and at the ZOA (100 feet). Expanding the evaluation further away from the CWU, as suggested by KPRG, seems illogical since potential impacts from the CWU would first be identified closer to the landfill footprint rather than farther away.

36) *Simulations Only Evaluate 100 years Post-Closure - The simulations for this GIA are limited to 100 years post-closure. If the landfill is built successfully to its design, that period of time will largely be a period of refilling to bring the system back to equilibrium. To establish risks from the facility, simulations need to be run to determine the approximate time when the landfill reaches equilibrium conditions. Additional simulations would then be necessary to consider the eventual and permanent condition of outward flow for at least 100 years after equilibrium conditions are reached.*

Applicant's Response: This is false. As identified in Applicant response to Comment No. 10, maximum outward vertical Darcy velocities are incorporated into the groundwater models from day one of the operating life of the landfill and continued 100 years after the operating life of the facility. The groundwater models assumed that the landfill was leaking from day one, so calculating an equilibrium point (as discussed by KPRG) and then applying an outward gradient would be less conservative. Therefore, the models supplied in the Application consider the eventual and permanent condition of outward flow for at least 100 years after equilibrium conditions are reached, KPRG just did not realize it due to their limited modeling experience.

37) *Simulations Ignore Vertical Flow in Soils - The Landfill Applicants' simulations do not include the observed vertical flow in the glacial sediments at the site.*

Applicant's Response: This comment is false. As shown in Attachment 3, outward vertical Darcy velocities are incorporated into the groundwater models from day one of the operating life of the landfill and continued 100 years after the operating life of the facility. The groundwater models assumed that the landfill was leaking from day one, so calculating an equilibrium point (as discussed by KPRG) and then applying an outward gradient would be less conservative. As clearly pointed out by KPRG, an inward gradient will likely exist at the Site, so vertical flow in the soils would be upwards towards the landfill. Clinton Landfill, Inc. conservatively assumed an outward vertical Darcy velocity set equal to an assumed maximum seepage velocity out of the landfill.

38) *Simulations Preclude Vertical Flow below Uppermost Aquifer - The Landfill's simulations do not allow any penetration of contamination below the upper-most sand.*

Applicant's Response: KPRG and Associates, Inc. is correct that the groundwater models do not allow vertical flow below the modeled aquifer. If vertical flow was allowed downward below the modeled aquifer predicted concentrations in the aquifer would be diluted, creating a less conservative groundwater model. Clinton Landfill, Inc. prefers to use a more conservative model which is more protective of the public health, safety, and welfare.

39) *Simulations Ignore Overlying and Adjacent Municipal Landfill - The simulations assume the chemical waste facility is a facility with nothing around it. The concentrations used as source terms do not recognize the potential of municipal leachate impacting the leachate in the chemical waste unit. The simulations do not consider the impacts of contaminant migration from the municipal landfill to groundwater that is upgradient of the chemical waste landfill, contamination to which the latter facility would add.*

Applicant's Response: This comment is deceptive. In accordance with the facility design in the Application, a separation layer will exist between the municipal solid waste landfill and the CWU, therefore the leachate from the municipal solid waste landfill will not impact the leachate in the CWU. See Applicant response to Comments No. 32 and 34, for a response to concerns about the groundwater below the municipal solid waste landfill and the CWU.

40) *Sensitivity Simulations Test Single Parameters - The sensitivity runs that were made are not meaningful from the standpoint of hydrogeology. Accepting for the sake of argument that inputs to the base case did represent parameters appropriate to a well-characterized and calibrated understanding of the site hydrogeology, the purpose of the sensitivity runs is to determine whether the results vary significantly if there are errors in that original interpretation. That cannot be done by taking a single parameter and changing its value. Doubling the hydraulic conductivity for example is unrealistic and unreliable unless a corresponding change is made to other parameter(s), such as recharge, such that the input set still describes a calibrated system. Sensitivity runs of single parameters require a demonstration that the variation maintains a modeled domain with parameterization that is at least possible. Without such demonstration, as was done with this implementation of MIGRATE, runs potentially simulate systems that cannot exist. Such modeling does not provide indications of meaningful uncertainties in fate and transport.*

Applicant's Response: This comment is erroneous. As pointed out in Applicant response to Comment No. 1, it is unclear whether or not KPRG understands that the Federal Toxic Substances Control Act (TSCA) regulations do not require a GIA and that the GIA was required under 35 Ill. Admin. Code Section 811.317 and 812.316. Therefore, the GIA was developed and executed following State regulations and IEPA Guidance Document LPC-PA2. Illinois Environmental Protection Agency Guidance Document LPC-PA2 requires that, "*Sensitivity analysis should be conducted separately for each model input parameter, boundary condition, etc., using baseline model results as the standard for comparison*".

Hydrogeologic Conditions for the Simulations

41) *Flow Directions Simulated Are Not Possible - The orientation of the model slice needs to be parallel to the direction of horizontal flow. As discussed in earlier comments, flow directions are mapped in a manner inconsistent and physically impossible with respect to the mapped distribution of the sands.*

Applicant's Response: See Applicant response to Comment No. 17.

42) *Vertical Fluxes Simulated Are Unsupported by Data - The vertical fluxes that are used in the simulations are not representative of the vertical fluxes observed in site data. First, the vertical fluxes used by the applicant ignore vertical flow through the glacial sediments and are simply assigned at all layers as the hypothetical flow leaking through the landfill liner - a rate far less than the flow through the glacial sediments. Second, the model assigns a no-flow, no-diffusion boundary at the base of the sand being simulated. This precludes evaluation of further downward migration in a system dominated by vertical from the surface to the Mahomet Aquifer.*

Applicant's Response: See Applicant response to Comments No. 37 and 38.

43) *Pre-Construction Flow Is Simulated - As discussed above, the evaluation of the flow directions and hydraulic gradients is based upon pre-construction head readings at the various wells. Even at this point, significant differences have developed as a result of construction activities. Further changes will occur from additional construction as more area is put under the footprint of liners and as surface water is re-routed. Meaningful fate and transport modeling can only be done using the best understanding of the post-construction hydrogeology that will control post-construction migration. No attempt has been made to develop an understanding of that controlling system.*

Applicant's Response: See Applicant response to Comment No. 20.

Additional Review Notes

44) *The copy of the CQA Report and Certification by SKS Engineers, Inc. dated March 2007 provided was incomplete and out of order.*

Applicant's Response: The SKS Engineer's CQA report was not used in developing the design of the chemical waste unit.

45) *In Attachment 5, Section 6 - the calculated field permeability average was incorrect. SKS incorrectly calculated an average Boutwell field permeability result of 3.28×10^{-9} cm/sec versus the actual value of 9.82×10^{-9} cm/sec. This error results in a false conclusion that the horizontal field permeability could be calculated by multiplying the laboratory permeability by a*

multiplier of 2 when the actual multiplier was 0.334. Due to this error, SKS' calculation underestimates the horizontal field permeability.

Applicant's Response: In reviewing the field reports for the Boutwell field permeability results provided in Section 4 of Attachment 5 of the February 2009 USEPA addendum, the three Boutwell field permeability horizontal values were 4.406×10^{-9} cm/sec, 2.98×10^{-9} cm/sec, and 2.437×10^{-9} cm/sec which results in an average value of 3.28×10^{-9} cm/sec.

In developing the GIA model a hydraulic conductivity value of 1×10^{-7} cm/sec was used, which is more than 30 times more permeable than the empirical results demonstrate. This further proves the conservative nature of the GIA model.

46) *The January 2009 Slope Stability Analysis by the Shaw Group using the SLIDE modeling program analyzed only one mode of failure: foundation stability. However, given the proximity of the proposed Clinton Landfill No. 3 to the existing municipal solid waste landfill (plans ultimately call for one to "toe out" above the other),a complex failure mode should also be simulated. Such a complex failure could occur if one failure mode induces another. For example, a rotational or translational slide could induce a flow of or a fall failure of the foundation. Such two-part failure scenarios were not contemplated and the potential affects of the existing manmade landfill structure were not considered.*

Applicant's Response: Within Section 3 and Appendix H.2 of the October 2007 USEPA permit application; Shaw analyzed the following potential slope stability failure scenarios:

1. Waste active face with circular failure;
2. Excavation face with circular failure;
3. Foundation circular failure;
4. Final landform conditions with circular failure through the foundation soil;
5. Final landform conditions with circular failure through the waste; and
6. Final landform conditions with block failure through the liner system.

The critical cross-section sections were analyzed for each of the potential slope stability failure scenarios. Additionally, each potential failure scenario was analyzed for long and short term soil drainage conditions and static and seismic conditions. Over 26 slope stability analyses were performed and scenarios achieved factors of safety that were protective of the public health, welfare, and safety.

47) *Due to the stable chemical nature of PCBs, their potential to threaten groundwater resources extends past the stated monitoring period (34 years of active landfill use and 30 years of post closure). According to the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry, there are.up to 209 individual chlorinated compounds that are known as PCBs. Despite a wealth of research concerning these chemicals, their exact half lives remain unknown. However, studies by the USEPA and others of sediments in New York's Hudson River indicate PCBs have the potential to persist in soils and sediments for more than 60 years. Therefore, the proposed monitoring period is inadequate to protect area potable water supplies.*

Applicant's Response: Based on the PCBs groundwater model assessment submitted to the USEPA, PCBs will not migrate out of the 3-foot recompacted clay liner even after 1,000 years.

This model does not even consider the geosynthetic liner system or the 150 feet of in-situ clay beneath the recompacted clay liner which further demonstrates that the CWU will never negatively impact the Mahomet Aquifer. This PCBs groundwater model assessment did not include the degradation of PCBs which makes the model even more conservative.

The Hudson River case study is an excellent demonstration of the environmental fate of PCBs, i.e. that PCBs are not water soluble and, therefore are virtually immobile. In an uncontrolled environment (such as any waterway), PCBs bioaccumulate in fish and other aquatic organisms because they are immobile and because they are slow to degrade. However, in a controlled environment, i.e. a landfill, the inherent immobility of PCBs means that they will never migrate out of the landfill to be exposed to any living organism. Modeling is not required to demonstrate this to those with an understanding of PCB environmental fate and transport. It appears that KPRG either does not understand the fundamental fact that PCBs are immobile in the environment, or is simply trying to detract from that simple fact by attacking the modeling which further demonstrates that PCBs are not mobile.

48) *A possible conflict of interest was noted in that Peoria Disposal Company (PDC), the proposed landfill's owner, appears to be planning to use its subsidiary, PDC Laboratories, Inc., to analyze quarterly, semi-annual, and annual groundwater samples. In KPRG's opinion, the analysis should be conducted by an independent laboratory with no affiliation or shared interests with PDC.*

Applicant's Response: Clinton Landfill, Inc. will utilize a testing laboratory with all required certifications to perform the required groundwater analyses and all other environmental testing required by the facility permits. All data will be generated in keeping with USEPA SW-846 and any other applicable and governing laboratory protocols. PDC Laboratories, Inc. is not a subsidiary of CLI, but is an affiliate. Clinton Landfill, Inc. prefers to use the affiliated laboratory not because of the affiliate relationship, but rather because it is familiar with the laboratory's certifications, procedures, and controls, and has a higher confidence level than it would with an "outside" laboratory that the integrity of its data product is fully defensible and beyond reproach.

PDC Laboratories is a NELAC-certified laboratory known for the reliability and integrity of its services. As a result of its reliability and integrity, PDC Laboratories is one of the largest commercial laboratories in the Midwest. PDC Laboratories provides analytical services to the State of Illinois, many private industrial corporations and landfills, as well as municipally owned landfills. Furthermore, the IEPA frequently collects and independently analyzes groundwater sample splits from the PDC #1 Landfill in Peoria, Illinois and has never reported an issue with the results reported by PDC Laboratories.

49) *The Appendix D drawing from the January 2009 Additional Information on the LFG Management System was missing from the attachment produced by USEPA.*

Applicant's Response: "January 2009 Additional Information" was submitted to the IEPA to address concerns by the IEPA on permit application Log No. 2008-054. These concerns were addressed and permit application Log No. 2008-054 was approved by the IEPA on January 8, 2010 as Modification No. 9 to its existing permit.

The same drawing was submitted to the USEPA as part of the February 2009 additional information request as Drawing No. D23, contained within Attachment No. 3.

Summary and Conclusion

50) The applications for Clinton Landfill No.3, including the chemical waste cells gained IEPA approval based upon computer simulations that estimated acceptable levels of contamination at the lateral compliance boundary 100 years after landfill closure. Those simulations were performed using a program that is extremely limited in its capabilities. The simulations performed largely ignored limitations of the software. The limitations of the software were seemingly exploited instead to generate acceptable results that do not reflect probable reality.

The partially biased implementation of the modeling software limitations is not the greatest problem with the GIA. The greatest problem is the failure of the applicant to produce a reasonable, meaningful, and representative interpretation of the site hydrogeology based upon the extensive degree of exploration and applicable data. Based upon the expressed understanding of the site, it is apparent that the expressed "understanding" is not unbiased interpretation - but rather is a statement of a preconceived notion or anticipation of the geology and hydrogeology. The results are simulations of possible fate and transport of contaminants from the chemical waste units, but without support from site data.

To meaningfully simulate the potential of the site to impact the surrounding areas, the characterization data must be reviewed in detail and interpreted into a geologic and hydrogeologic system that honors known geologic and hydrogeologic principles and actual site data. That new understanding of the site must then be conveyed into a three-dimensional numerical groundwater model capable of assessing impacts to groundwater in the vicinity of the landfill both laterally and vertically. That assessment needs be done at the 100-ft and 100-yr thresholds. But the assessment also must be performed at times and places that represent the maximum and/or most damaging to human health and the environment (i.e. after equilibrium conditions are established which will occur at some yet undefined time after leachate collection system shut-down). That new assessment should include an integrated assessment of the time(s) and place(s) of impact to the Mahomet Aquifer regardless of arbitrary regulatory timeframes.

Applicant's Response: Clinton Landfill, Inc. maintains that the Application for the development of a Chemical Waste Unit (CWU) at the Clinton Landfill No. 3 provides long-term protection of the environment and meets or exceeds the stringent design and performance standards contained in State and Federal landfill regulations. The design provided within the Application includes the latest landfill design concepts which have been demonstrated to be protective of the environment. Unique to the proposed facility are the number and extent of safeguards employed. Additionally, the proposed design works in conjunction with a suitable location and favorable site geology and hydrogeology to assure that the public health, safety, and welfare will be protected.

Moreover, the Applicant has gone to the extraordinary step of having the entire Application (design and groundwater model) peer reviewed by Dr. Craig Benson, "Technical Review: Proposed Chemical Waste Unit at the Clinton Landfill No. 3, Dewitt County, Illinois" (See Attachment 5). Dr. Benson is internationally renowned for his work in environmental engineering and landfill design. His extensive resume is provided in Attachment 6.

Dr. Benson formed the following conclusions based on his review:

- The proposed CWU complies with and exceeds the technical requirements in TSCA for disposal facilities;

- The geological setting, the redundant multiple liner system for the proposed CWU, and the final cover ensure isolation of the waste and protection of the Mahomet Aquifer and shallow ground water units beneath the proposed CWU;

- The design of the containment system, the construction quality assurance program, and the monitoring plan for leachate, ground water, surface water, and air will mitigate threats to the environment; and

- The perpetual post-closure care and monitoring program will ensure that the threats to the environment are properly managed so long as the waste remains a potential risk, thereby ensuring protection of the public health, welfare, and safety.

Regardless of KPRG's comments on the groundwater modeling, KPRG ignores the basic fact that the mobility of PCBs is so low that computer modeling is not even required to demonstrate, to those knowledgeable regarding the environmental fate and transport of PCBs, that the facility is safe. Furthermore, KPRG disingenuously claims that the site's hydrogeologic conditions are "pre-conceived" to be favorable to facility development. However, it is KPRG that ignores the ISGS's conclusion that groundwater within the Mahomet Aquifer, which is separated from the bottom of the landfill by the engineering liner system and more than 150 feet of glacial clays, receives very little surface recharge in the site vicinity. The claims made by KPRG, which are based on absolutely no data, directly refute the ISGS study, as well as the reviews conducted by the IEPA and Dr. Craig Benson, an internationally renown authority on environmental engineering and landfills.

We feel this response should address all comments submitted by KPRG to the USEPA in a correspondence dated July 22, 2010. If you have any questions or concerns please contact me at 630-762-3315.

Sincerely,
Shaw Environmental, Inc.

Jesse Varsho, P.E., P.G.
Project Manager

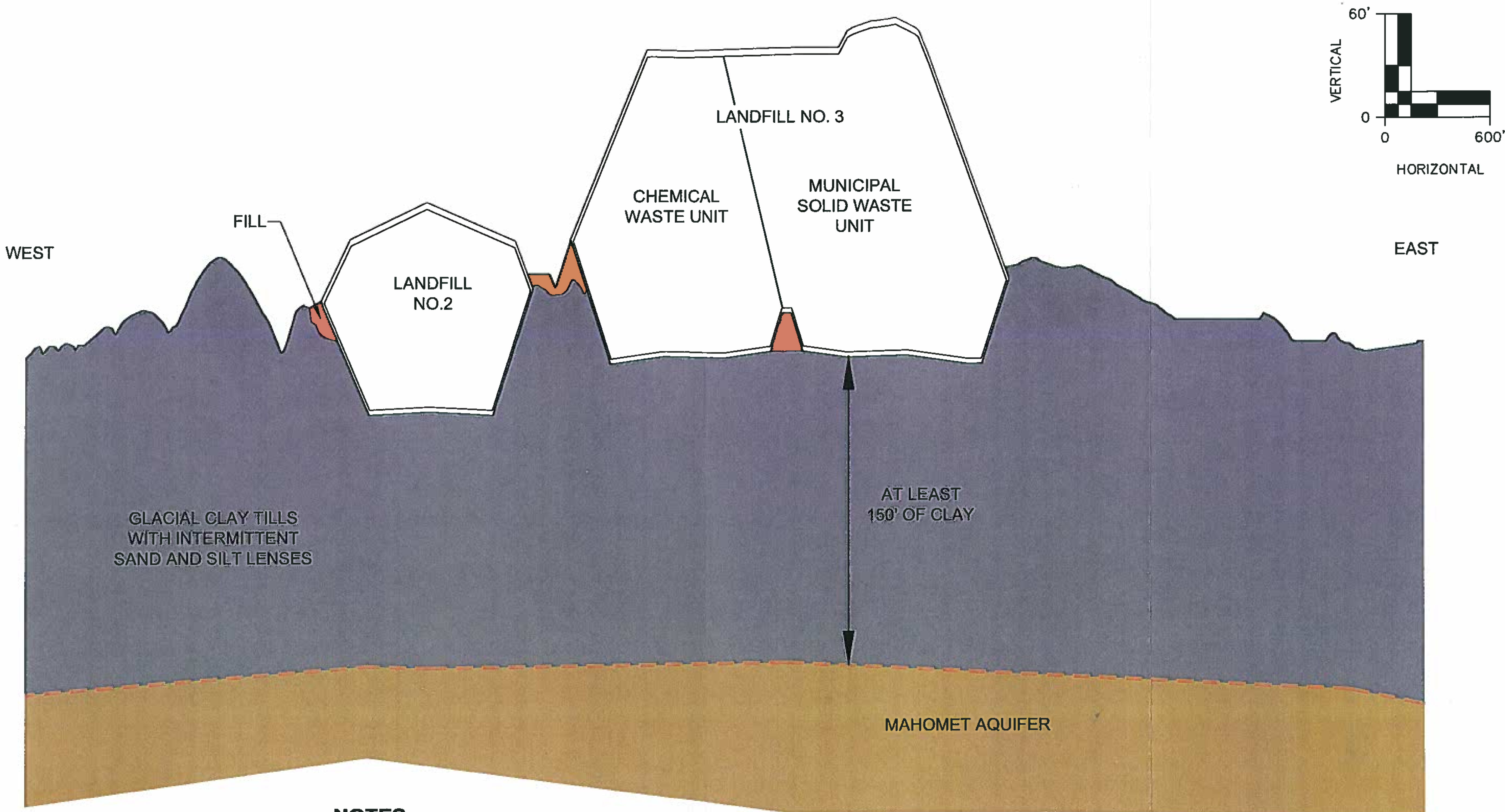
LICENSED PROFESSIONAL ENGINEER
JESSE PAUL VARSHO
062-059069
STATE OF ILLINOIS

Daniel Drommerhausen, P.G.
Sr. Hydrogeologist

LICENSED PROFESSIONAL GEOLOGIST
DANIEL J. DROMMERHAUSEN
196-001038
ILLINOIS

cc: George Armstrong, PDC
Ron Edwards, PDC
Ron Welk, CLI

FIGURES



NOTES

1. THIS REGIONAL GEOLOGIC CROSS SECTION IS BASED ON INFORMATION FROM ON-SITE BORING LOCATIONS AND OFF-SITE PRIVATE WATER WELL LOGS. ACTUAL CONDITIONS MAY VARY.
2. THIS GEOLOGIC CROSS SECTION WAS DEVELOPED TO SHOW THE LOCATION OF THE MAHOMET AQUIFER AND ITS POSITION RELEVANT TO THE INVERT GRADES OF THE CLINTON LANDFILL NO.2 AND NO.3.
3. THE THICKNESS OF THE GLACIAL CLAY TILLS WITH INTERMITTENT SAND AND SILT LENSES IS APPROXIMATELY 170 FEET THICK BELOW THE INVERT OF THE CLINTON LANDFILL NO.3. CLAY MAKES UP AT LEAST 150 FEET OF THE 170 FEET OF GLACIAL CLAY TILLS WITH INTERMITTENT SAND AND SILT LENSES.

REV. NO.	DATE	DESCRIPTION

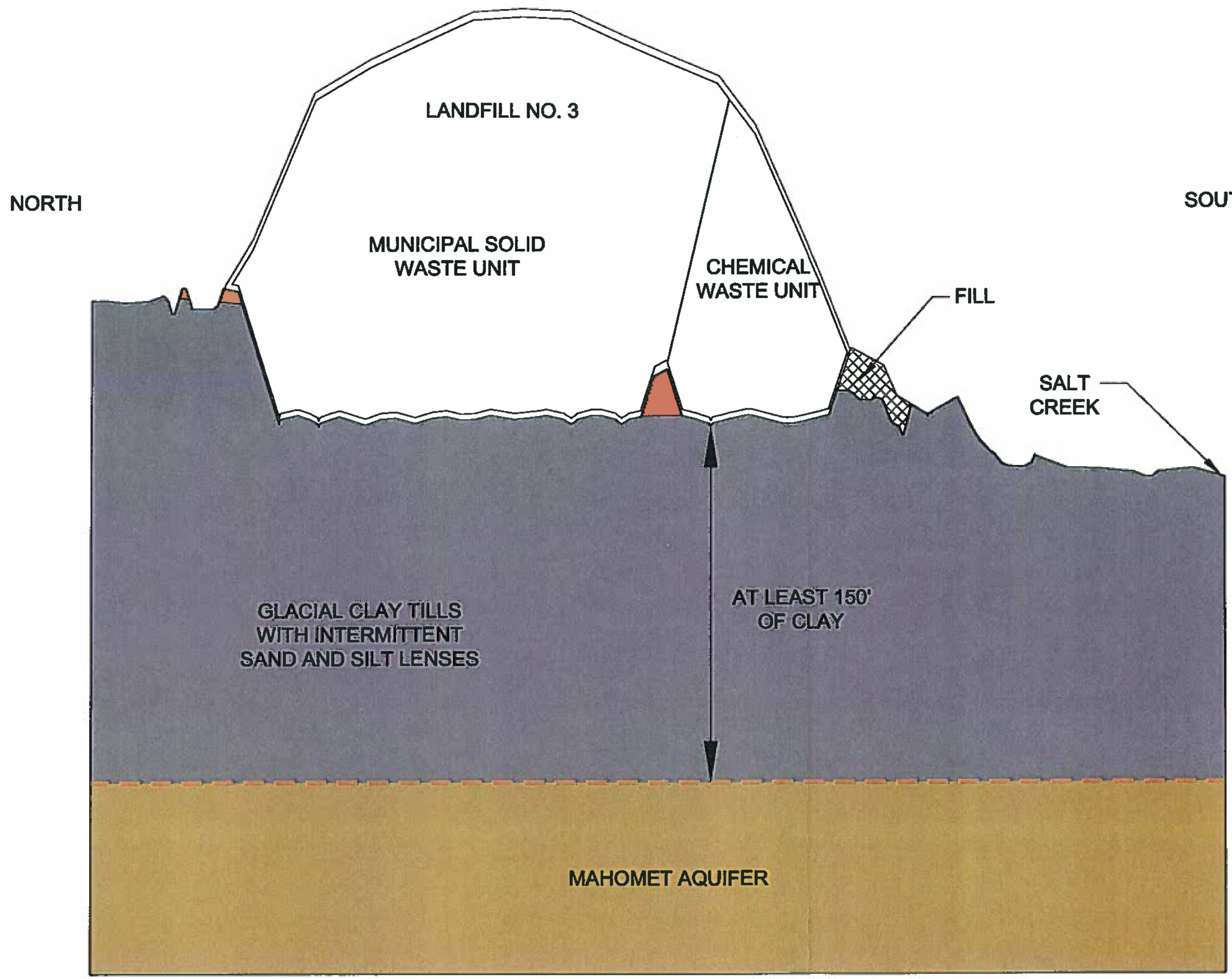
area Clinton Landfill, Inc.

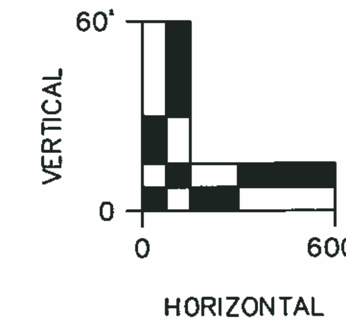
Shaw® Shaw Environmental, Inc.

CLINTON LANDFILL NO.3 CHEMICAL WASTE UNIT
DEWITT COUNTY, ILLINOIS

FIGURE 1
REGIONAL GEOLOGIC CROSS SECTION - WEST TO EAST

DRAWN BY:	APD	APPROVED BY:	DJD	PROJ. NO.:	128017	DATE:	AUGUST 2010





NOTES

1. THIS REGIONAL GEOLOGIC CROSS SECTION IS BASED ON INFORMATION FROM ON-SITE BORING LOCATIONS. ACTUAL CONDITIONS MAY VARY.
2. THIS GEOLOGIC CROSS SECTION WAS DEVELOPED TO SHOW THE LOCATION OF THE MAHOMET AQUIFER AND ITS POSITION RELEVANT TO THE INVERT GRADES OF THE CLINTON LANDFILL NO.3.
3. THE THICKNESS OF THE GLACIAL CLAY TILLS WITH INTERMITTENT SAND AND SILT LENSES IS APPROXIMATELY 170 FEET THICK BELOW THE INVERT OF THE CLINTON LANDFILL NO.3. CLAY MAKES UP AT LEAST 150 FEET OF THE 170 FEET OF GLACIAL CLAY TILLS WITH INTERMITTENT SAND AND SILT LENSES.

REV. NO.	DATE	DESCRIPTION

area Clinton Landfill, Inc.

Shaw® Shaw Environmental, Inc.

CLINTON LANDFILL NO.3 CHEMICAL WASTE UNIT
DEWITT COUNTY, ILLINOIS

FIGURE 2
REGIONAL GEOLOGIC CROSS SECTION - NORTH TO SOUTH

DRAWN BY: BWM	APPROVED BY: DAM	PROJ. NO.: 128017	DATE: AUGUST 2010

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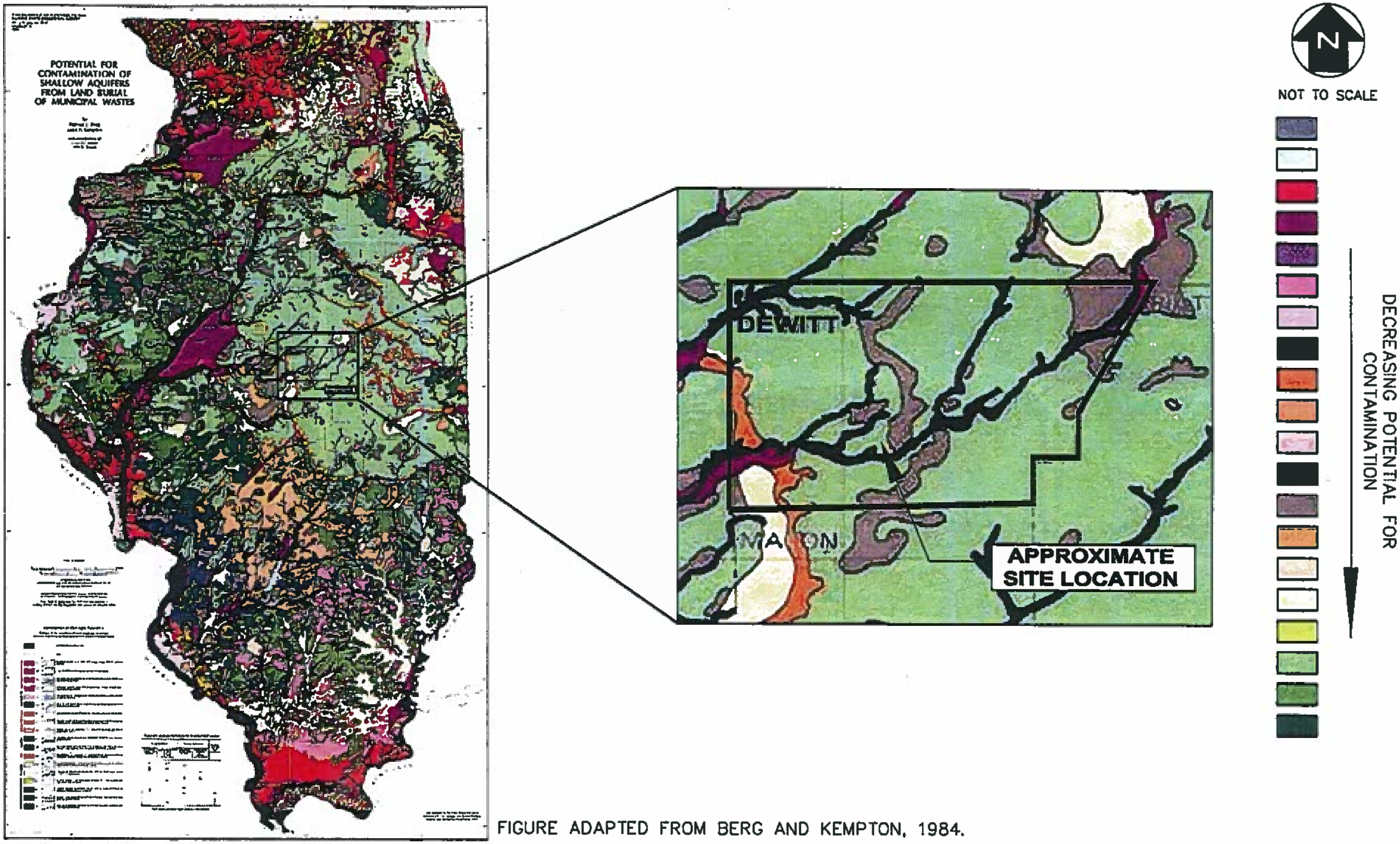

FIGURE ADAPTED FROM BERG AND KEMPTON, 1984.

Shaw® Shaw Environmental, Inc.

CLINTON LANDFILL NO.3 CHEMICAL WASTE UNIT
DEWITT COUNTY, ILLINOIS

FIGURE 3
DEWITT COUNTY AQUIFER SENSITIVITY

DRAWN BY:	APD	APPROVED BY:	OJD	PROJ. NO.:	128017	DATE:	AUGUST 2010

ATTACHMENT 1

Hackley, Panno, and Anderson
July/August 2010

Shaw

Chemical and isotopic indicators of groundwater evolution in the basal sands of a buried bedrock valley in the midwestern United States: Implications for recharge, rock-water interactions, and mixing

Keith C. Hackley[1,†], Samuel V. Panno[1], and Thomas F. Anderson[2]
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ABSTRACT

Buried bedrock valley aquifers can be found throughout Canada and the northern United States where glacial deposits have filled in previously exposed bedrock valleys. The Mahomet bedrock valley is an east-west–trending buried valley in central Illinois containing basal Pleistocene sands and gravels making up the Mahomet aquifer and the contemporaneous Sankoty Mahomet aquifer, which are the major sources of freshwater for east-central Illinois. The hydrochemical characteristics of the Mahomet and Sankoty Mahomet aquifers change significantly across the buried bedrock valley. To determine the geochemical processes controlling the chemistry of the water, possible groundwater mixing, and the regions of major recharge, over 80 samples from the Mahomet aquifer, the Sankoty Mahomet aquifer, and shallower aquifers were analyzed for their chemical and isotopic composition, including $\delta^{18}O$, δD, $\delta^{13}C$, $\delta^{34}S$, ^{14}C, and ^{3}H.

Four geochemical regions were observed across the aquifers. The central and eastern region of the Mahomet aquifer had dilute chemistry and medium ^{14}C activities, suggesting relatively recent recharge from the surface. The northeastern Mahomet aquifer region had variable sulfate and $\delta^{34}S$ values, medium chloride concentrations, and low ^{14}C activity, suggesting mixing with bedrock groundwater along with sulfate reduction. The western Mahomet aquifer region had the highest chloride, dissolved organic carbon, and methane concentrations and showed a continuous decrease in ^{14}C activity, suggesting seepage from bedrock units, strong reducing conditions, and isolation from surficial recharge. Characteristics of the Sankoty Mahomet aquifer indicated rapid freshwater recharge and mixing with western Mahomet aquifer water.

The δD and $\delta^{18}O$ values indicated little to no Pleistocene water in the Mahomet bedrock valley aquifer system, suggesting an age limit of ca. 11,000 yr B.P. for most of the groundwater. The tritium data indicated modern recharge in some shallower aquifers, but little to none in the Mahomet aquifer and Sankoty Mahomet aquifer, except near a river where stacked sands may have created a hydrologic window to the Mahomet aquifer. It appears that most of the Mahomet aquifer is well protected from surficial contamination. The approach used in this study enabled us to better understand and identify the processes that control the groundwater chemistry within the buried Pliestocene aquifer in central Illinois; processes that may be prevalent in other buried bedrock valley aquifers distributed throughout much of North America.

†E-mail: hackley@isgs.uiuc.edu

INTRODUCTION

Groundwater is an important source of freshwater for much of the population in the United States, making up 22% of all freshwater withdrawals (Solley et al., 1998). As population and industry continue to expand across the country, the availability of groundwater resources becomes a more critical issue. In some parts of the country, such as the high plains, groundwater is the major source of freshwater, and usage is outpacing recharge (Alley et al., 1999). Maintenance of water quality in potable aquifers is another concern. For example, in the midwestern United States, the quality of water in some of the shallower aquifers has been degraded due to infiltration of agricultural chemicals (USGS, 1999a). In addition, road deicers in the north-central and northeastern United States are contaminating shallow aquifers (Pilon and Howard, 1987; Kelly and Wilson, 2003).

Approximately 21% of the people in Illinois rely on groundwater as their primary source of drinking water (USGS, 1999b). Like most of the midwestern states, Illinois has abundant groundwater resources located within both bedrock units and shallower unlithified glacial deposits. A few of the glacial aquifers are major freshwater resources for numerous municipalities. This investigation focused on the Mahomet aquifer (MA) and the Sankoty-Mahomet aquifer, which are contemporaneous Pleistocene-age unlithified sands and gravels filling ancient bedrock valleys in east-central Illinois. The Mahomet aquifer is an east-west–trending aquifer deposited in the Mahomet bedrock valley. The Mahomet aquifer extends from western Indiana to central Illinois, where it intersects the north-south–trending Sankoty Mahomet aquifer in the Mackinaw bedrock valley (Fig. 1). The Mahomet aquifer and the Sankoty Mahomet aquifer have been supplying high-quality freshwater to municipalities, industries, homeowners, and farmers for more than four decades. Over the last two decades, the use of, and interest in, the Mahomet and Sankoty Mahomet aquifers has increased due to expanding population and industry in east-central Illinois, as well as depletion of surrounding communities' surface-water reservoirs during periods of drought (Illinois State Water Plan Task Force, 1997). The increase in withdrawal and potential future use of these aquifers have raised questions concerning the quality and quantity of water in the aquifers and their future integrity.

Although the geology and hydrogeology of the buried Mahomet bedrock valley have been the subject of several previous studies over the

GSA Bulletin; July/August 2010; v. 122; no. 7/8; p. 1047–1066; doi: 10.1130/B26574.1; 17 figures; Data Repository item 2009286.

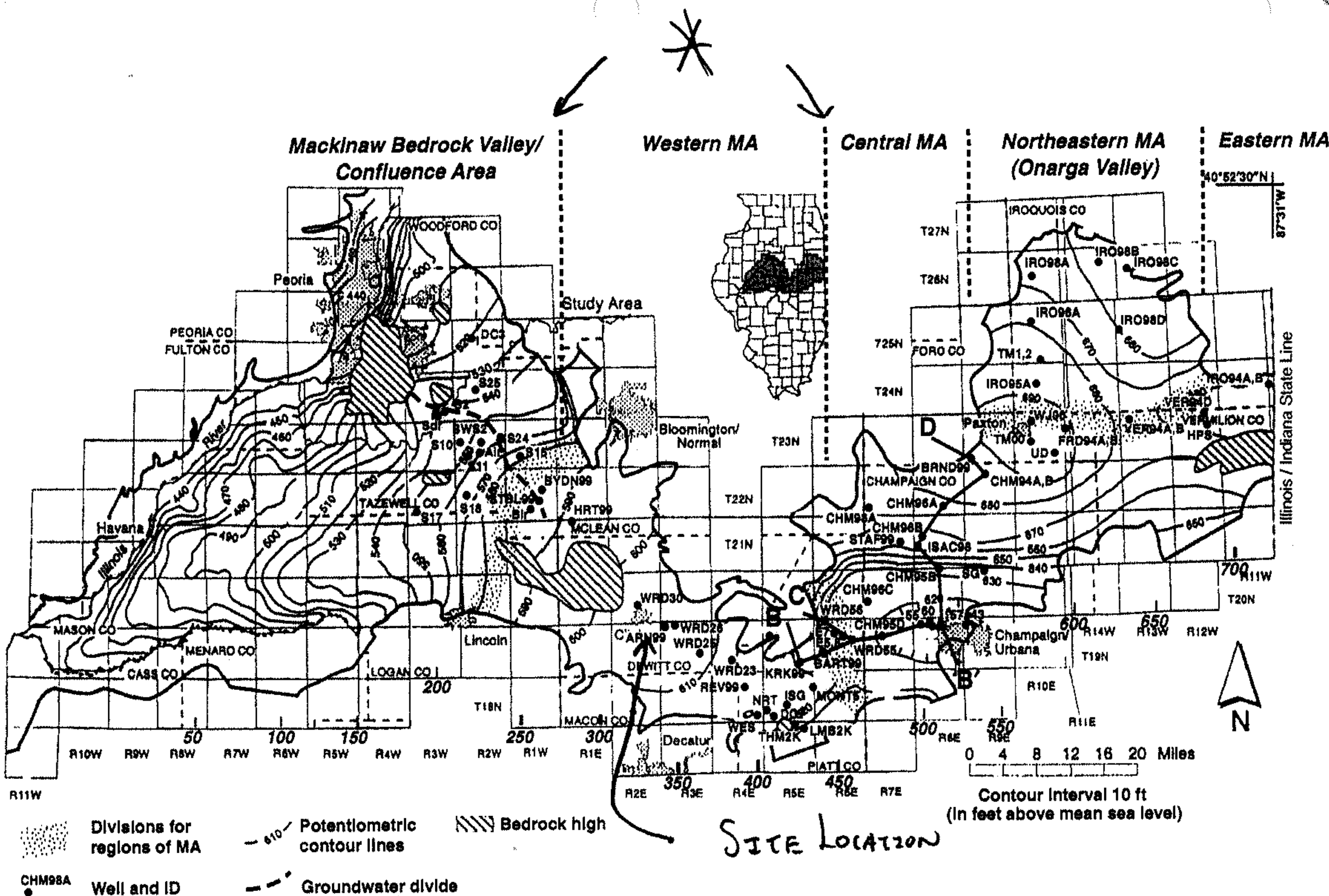

Figure 4. Map showing the location of the wells sampled from the Mahomet bedrock valley aquifer system. The contours are the potentiometric surface for the basal Mahomet aquifer (MA) (Wilson et al., 1998). The Illinois plane coordinate system (divided by 1000) is shown at southernmost township lines. Major regions are separated by shaded line and labeled across the top of the diagram. Cross-section lines B-B′, C-B′, and D-B′ are also included.

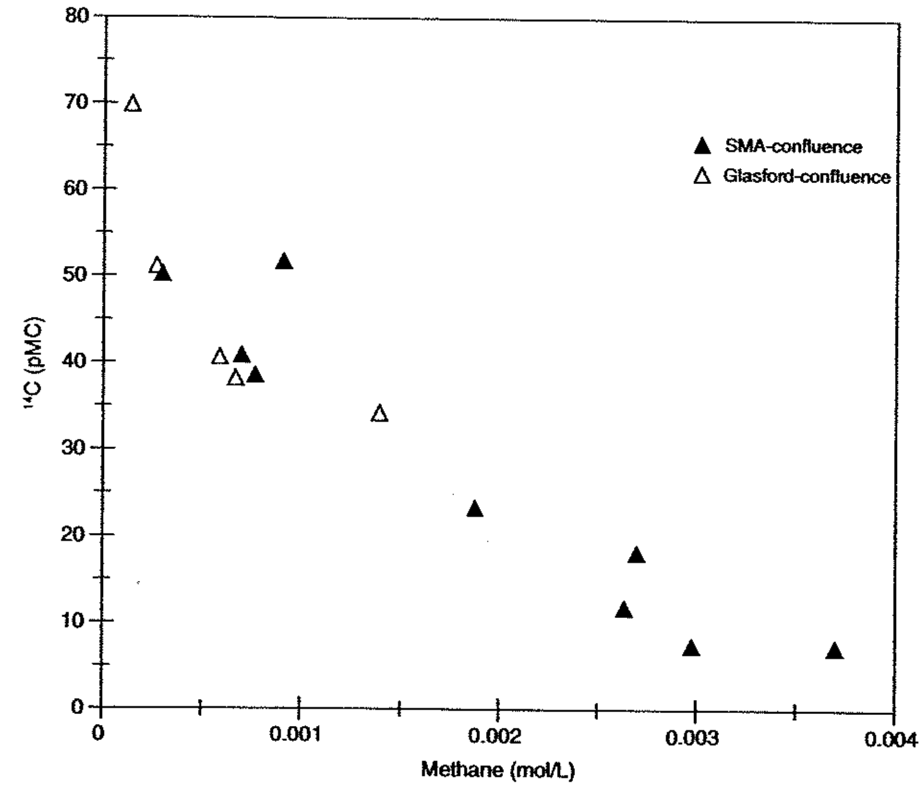

Figure 14. Comparison of ^{14}C and CH_4 concentration in the confluence region; r^2 for the Sankoty Mahomet aquifer data is 0.9.

activities observed in groundwater from samples of the Mahomet aquifer and the Glasford Sand in the northeastern part of the Mahomet bedrock valley indicate a mixture of deeper upwelling groundwater and shallow infiltrating groundwater plus sulfate reduction occurring in parts of the northeastern region of the Mahomet bedrock valley. The mixture of groundwater from bedrock units in the northeastern region appears to extend into northern Vermillion County. The increased Cl^- concentrations and continuous drop in ^{14}C activities observed for the western part of the Mahomet aquifer (Fig. 15) suggest there has been greater isolation from surficial recharge and seepage from bedrock units mixing with the Mahomet aquifer groundwater flowing from the central region westward. The cross sections that cut the Mahomet bedrock valley diagonally (Figs. 13 and 16–17) show the relationships among the shallower aquifers, the deep basal sand aquifer, and the sides of the bedrock valley from where the lithology of the bedrock changes abruptly near the Piatt-Champaign County line to where the bedrock is primarily carbonate in Champaign County. Chloride concentrations and ^{14}C activities are included on the cross sections. The results show an increase in Cl^- and decrease in ^{14}C activity near the sides of the valley, especially close to the Pennsylvanian-age bedrock on the western side of the aquifer (see Fig. 3 for bedrock lithology). This emphasizes the relationship of the Pennsylvanian-age bedrock to the seepage of older more saline groundwater into the western Mahomet aquifer compared to the carbonate bedrock in the central portion of the Mahomet aquifer.

As the groundwater from the Mahomet aquifer flows into the Sankoty Mahomet aquifer, the chemical composition and ^{14}C activity change dramatically. In this confluence area, the geochemical makeup of the groundwater of the basal Pleistocene sands and gravels is strongly influenced by a combination of relatively rapid recharge of younger, more dilute water infiltrating from the surface and the microbial processes associated with methanogenesis.

SUMMARY AND CONCLUSIONS

The chemical and isotopic characteristics of the groundwater in the aquifers of the Mahomet bedrock valley and adjacent confluence area have revealed many important aspects of the groundwater evolution in aquifers that have been created from glacial deposits filling in the topographic undulations of the previous bedrock land surface. The δD and $\delta^{18}O$ values for most of the groundwater in the Mahomet aquifer and the shallower Glasford sands are quite similar to present-day precipitation. These data indicate that there is little to no Pleistocene water remaining in the aquifer system, putting an upper age limit for most of the groundwater at the start of the Holocene, ca. 11,000 yr B.P. The tritium results indicate that there is modern recharge into the Wedron sands and some of the Glasford sands, but very little modern water occurs in the basal sand of the Mahomet bedrock valley. Of the sites sampled, only one area in the Mahomet aquifer near where the Sangamon River crosses the bedrock valley had detectible tritium. These tritium data are consistent with recent seismic and monitoring well drawdown studies by the ISGS and ISWS that have suggested a hydraulic window where groundwater discharges to the Sangamon River when the river is low and groundwater recharges during periods of high stage or excessive groundwater pumping (Roadcap and Wilson, 2001).

The central-eastern region of the Mahomet aquifer contained the highest ^{14}C activity and most dilute groundwater compared to the rest of the Mahomet aquifer, indicating that the groundwater in this region has gone through the least water-rock interaction. These isotopic and geochemical characteristics imply that this region is the area of most rapid recharge for most of the Mahomet aquifer, as proposed by Panno et al. (1994). The very low Cl^- concentrations in the central Mahomet aquifer region suggest that high volumes of freshwater (glacial meltwaters) probably flushed the stacked sand deposits and leached the more soluble minerals so that the present-day groundwater has relatively low dissolved solids concentration.

The chemical and isotopic results for the Mahomet aquifer in the western and northeastern (Onarga Valley) regions indicate that these areas of the aquifer are relatively isolated from surficial recharge and have been significantly influenced by the infiltration of older (low $^{14}C_{DIC}$ activity) groundwater from bedrock units with greater dissolved ion concentrations. The enrichment of SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and B, and Sr^{2+} in the Onarga Valley is probably the result of water-rock interactions with bedrock lithology, including Silurian, Devonian, and Mississippian carbonates and Pennsylvanian cyclothem type deposits (shales, coals, and argillaceous limestones and sandstones). The $\delta^{34}S$ and $\delta^{13}C$ values as well as the SO_4^{2-} and DIC concentrations in and around the Onarga Valley region suggest that groundwater upwelling through bedrock units is dissolving secondary gypsum, precipitating calcite, and mixing with fresher groundwater in the Mahomet and Glasford

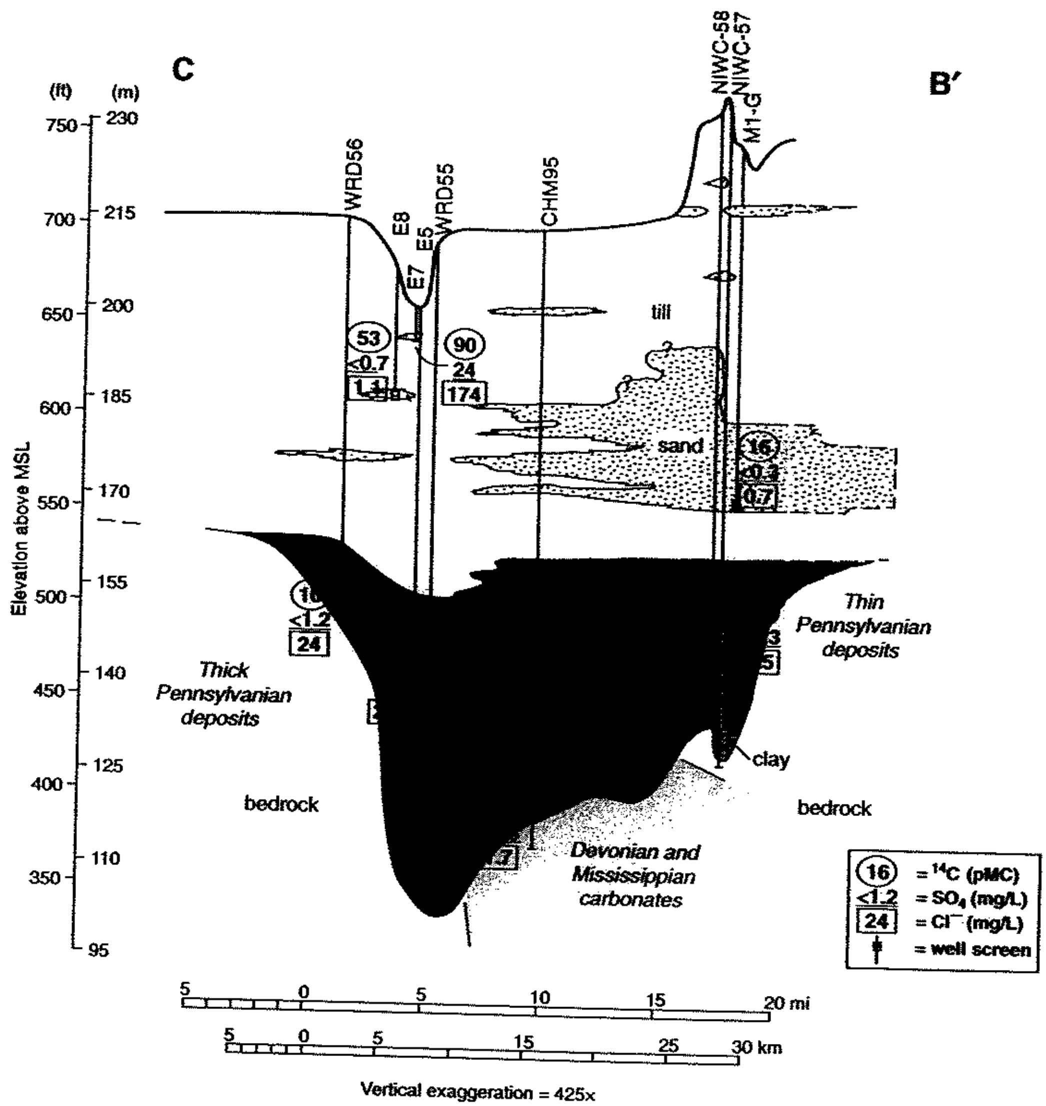

Figure 16. Cross section (C-B′) of the Mahomet bedrock valley including ^{14}C, $[SO_4^{2-}]$, and $[Cl^-]$ data for several wells (modified from Hackley, 2002). Note the lower ^{14}C activities and higher Cl^- concentrations near the western side of the valley, where the bedrock is composed of Pennsylvanian deposits. MSL—mean sea level.

sands. The isotopic data also indicate that SO_4^{2-} reduction and oxidation of organic carbon occur as the groundwater moves up into the Mahomet aquifer and shallower sands. Evidence of mixing between infiltrating groundwater from bedrock in the Onarga Valley and groundwater from the Mahomet and Glasford sands extends into northern Vermillion County. The low ^{14}C activities observed in this area are due to the influx of older groundwater from bedrock units, dissolution of carbonates, and oxidation of organic matter due to SO_4^{2-} reduction.

The western region of the Mahomet aquifer is characterized by higher concentrations of CH_4, DOC, Cl^-, Na^+, and HCO_3^-, greater $\delta^{13}C$ values, and a progressive decrease in $^{14}C_{DIC}$ activities to the west. The isotopic data support the hypothesis that the higher concentrations of chemical constituents (especially Cl^- and Na^+) are primarily explained by the influx of saline groundwater from the Pennsylvanian-age bedrock (Panno et al., 1994). Methane production is undoubtedly a consequence of strong reducing conditions in this part of the aquifer. The relatively high DOC concentrations in the western Mahomet aquifer could also be associated with the influx of deeper groundwater from the Pennsylvanian-age bedrock units or perhaps leaching of organic matter in clastics from these bedrock units and/or diffusion from organic rich Plieistocene deposits. The progressive decrease in $^{14}C_{DIC}$ activity is probably a consequence of several processes: infiltration of older groundwater from bedrock units, methanogenesis, and the dissolution of carbonates in the aquifer, as well as radioactive decay as the water slowly migrates westward. The progressive decrease in ^{14}C and the lack of significant shallow sand deposits above the Mahomet aquifer in the western region imply that this area is fairly isolated from surficial recharge.

The confluence area where the Mahomet aquifer and Sankoty Mahomet aquifer meet shows large variations in ^{14}C activity and chemical constituents, including Cl^- concentrations. This area is significantly influenced by a combination of groundwater mixing between relatively dilute infiltrating surficial water that has high ^{14}C activities and low Cl^- concentrations with older groundwater emerging from the basal sands of the Mahomet aquifer containing a greater amount of dissolved constituents and the microbial processes associated with methanogenesis.

The isotopic and chemical characteristics of groundwater in the basal sands of the Mahomet and Mackinaw bedrock valleys indicate that

Chemical and isotopic indicators of groundwater evolution in the basal sands of a buried bedrock valley in the midwestern United States: Implications for recharge, rock-water interactions, and mixing

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ABSTRACT

Buried bedrock valley aquifers can be found throughout Canada and the northern United States where glacial deposits have filled in previously exposed bedrock valleys. The Mahomet bedrock valley is an east-west–trending buried valley in central Illinois containing basal Pleistocene sands and gravels making up the Mahomet aquifer and the contemporaneous Sankoty Mahomet aquifer, which are the major sources of freshwater for east-central Illinois. The hydrochemical characteristics of the Mahomet and Sankoty Mahomet aquifers change significantly across the buried bedrock valley. To determine the geochemical processes controlling the chemistry of the water, possible groundwater mixing, and the regions of major recharge, over 80 samples from the Mahomet aquifer, the Sankoty Mahomet aquifer, and shallower aquifers were analyzed for their chemical and isotopic composition, including $\delta^{18}O$, δD, $\delta^{13}C$, $\delta^{34}S$, ^{14}C, and ^{3}H.

Four geochemical regions were observed across the aquifers. The central and eastern region of the Mahomet aquifer had dilute chemistry and medium ^{14}C activities, suggesting relatively recent recharge from the surface. The northeastern Mahomet aquifer region had variable sulfate and $\delta^{34}S$ values, medium chloride concentrations, and low ^{14}C activity, suggesting mixing with bedrock groundwater along with sulfate reduction. The western Mahomet aquifer region had the highest chloride, dissolved organic carbon, and methane concentrations and showed a continuous decrease in ^{14}C activity, suggesting seepage from bedrock units, strong reducing conditions, and isolation from surficial recharge. Characteristics of the Sankoty Mahomet aquifer indicated rapid freshwater recharge and mixing with western Mahomet aquifer water.

The δD and $\delta^{18}O$ values indicated little to no Pleistocene water in the Mahomet bedrock valley aquifer system, suggesting an age limit of ca. 11,000 yr B.P. for most of the groundwater. The tritium data indicated modern recharge in some shallower aquifers, but little to none in the Mahomet aquifer and Sankoty Mahomet aquifer, except near a river where stacked sands may have created a hydrologic window to the Mahomet aquifer. It appears that most of the Mahomet aquifer is well protected from surficial contamination. The approach used in this study enabled us to better understand and identify the processes that control the groundwater chemistry within the buried Pliestocene aquifer in central Illinois; processes that may be prevalent in other buried bedrock valley aquifers distributed throughout much of North America.

INTRODUCTION

Groundwater is an important source of freshwater for much of the population in the United States, making up 22% of all freshwater withdrawals (Solley et al., 1998). As population and industry continue to expand across the country, the availability of groundwater resources becomes a more critical issue. In some parts of the country, such as the high plains, groundwater is the major source of freshwater, and usage is outpacing recharge (Alley et al., 1999). Maintenance of water quality in potable aquifers is another concern. For example, in the midwestern United States, the quality of water in some of the shallower aquifers has been degraded due to infiltration of agricultural chemicals (USGS, 1999a). In addition, road deicers in the north-central and northeastern United States are contaminating shallow aquifers (Pilon and Howard, 1987; Kelly and Wilson, 2003).

Approximately 21% of the people in Illinois rely on groundwater as their primary source of drinking water (USGS, 1999b). Like most of the midwestern states, Illinois has abundant groundwater resources located within both bedrock units and shallower unlithified glacial deposits. A few of the glacial aquifers are major freshwater resources for numerous municipalities. This investigation focused on the Mahomet aquifer (MA) and the Sankoty-Mahomet aquifer, which are contemporaneous Pleistocene-age unlithified sands and gravels filling ancient bedrock valleys in east-central Illinois. The Mahomet aquifer is an east-west–trending aquifer deposited in the Mahomet bedrock valley. The Mahomet aquifer extends from western Indiana to central Illinois, where it intersects the north-south–trending Sankoty Mahomet aquifer in the Mackinaw bedrock valley (Fig. 1). The Mahomet aquifer and the Sankoty Mahomet aquifer have been supplying high-quality freshwater to municipalities, industries, homeowners, and farmers for more than four decades. Over the last two decades, the use of, and interest in, the Mahomet and Sankoty Mahomet aquifers has increased due to expanding population and industry in east-central Illinois, as well as depletion of surrounding communities' surface-water reservoirs during periods of drought (Illinois State Water Plan Task Force, 1997). The increase in withdrawal and potential future use of these aquifers have raised questions concerning the quality and quantity of water in the aquifers and their future integrity.

Although the geology and hydrogeology of the buried Mahomet bedrock valley have been the subject of several previous studies over the

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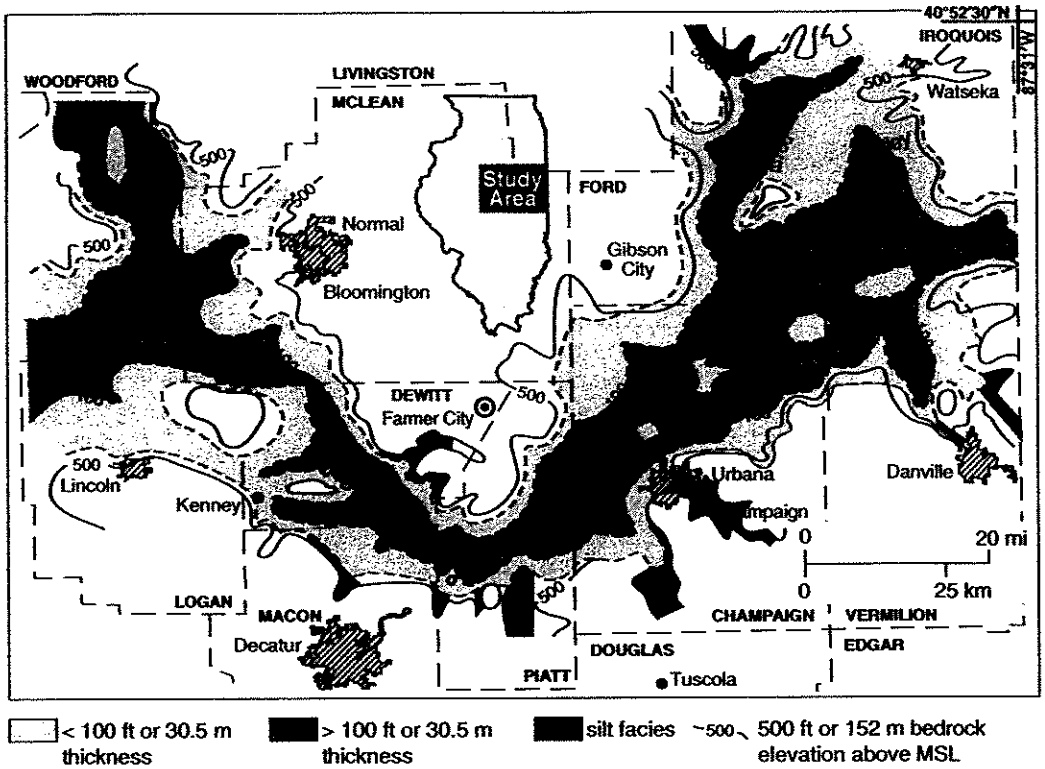


Figure 1. Isopach map of the Mahomet sand in the Mahomet bedrock valley (MBV) as defined by the 500 ft elevation contour (modified from Kempton et al., 1991). MSL—mean sea level.

past 60 yr (Horberg, 1945; Stephenson, 1967; Visocky and Schicht, 1969; Kempton et al., 1982, 1991; Wilson et al., 1998), the geochemical reactions that control the chemistry of the groundwater, the major areas of recharge, and the age of the groundwater have only begun to be studied (Panno et al., 1994; Hackley, 2002). Arsenic is also a concern for some parts of the Mahomet aquifer and shallower units (Warner, 2001; Warner et al., 2003; Kirk et al., 2004; Kelly, 2005).

To help improve our understanding of the geochemical characteristics of the groundwater in central Illinois, we conducted a geochemical study of the Mahomet aquifer and Sankoty Mahomet aquifer systems using both chemical and isotopic analyses of the water and many of its dissolved constituents. The major objectives of this investigation were to: (1) determine the geochemical reactions controlling the chemical and isotopic composition of groundwater within the aquifers, and (2) identify the major areas of recharge.

Chemical and isotopic variations observed in the groundwater within the Mahomet and Sankoty Mahomet aquifers and their bounding aquifers have been used to help define the geochemical evolution, including microbial processes and possible mixing of different groundwater sources. Indicators of biogeochemical reactions within the buried aquifers change along the groundwater flow path from areas where there is little obvious microbial influence to areas where there is significant microbial influence, including sulfate reduction and methanogenesis. The redox conditions that are associated with changes in sulfate and methane concentrations are reflected in other parameters as well, such as the bicarbonate concentration and the stable carbon isotope values of dissolved inorganic carbon. For example, sulfate reduction in groundwater is usually coupled with oxidation of organic matter, which typically leads to more negative carbon-13 isotopic compositions and positive sulfur-34 isotopic compositions. On the other hand, groundwater with substantial microbial methane generation typically contains very little to no sulfate and exhibits more positive carbon-13 isotopic compositions. Changes in carbon-13, carbon-14, and chloride concentrations across the Mahomet and Sankoty Mahomet aquifers reflect different degrees of water-rock interaction, biogeochemical reactions, as well as influxes of younger and fresher water from above or older, more saline groundwater from underlying bedrock. A combination of the chemical and isotopic data for both the inorganic and organic components of the groundwater allows us to create a more complete understanding of the reactions that control the bulk chemistry and helps to delineate locations where the groundwater is receiving significant recharge.

Geological Setting and Background

The Mahomet aquifer is a major aquifer made up of sands and gravels originating from glacial outwash deposited by Pleistocene continental glaciers in an extensive bedrock valley in east-central Illinois. The Mahomet aquifer was once considered part of the larger "Mahomet-Teays" buried drainage system, which was believed to extend eastward into Virginia. However, as discussed by Melhorn and Kempton (1991), studies have indicated that the Teays drainage system was not a single cohesive drainage system. The Mahomet aquifer is just one of many buried bedrock valley aquifers that exist across much of the Midwest, not to mention the northern United States and parts of Canada (NRCAN, 2008; Warner and Arnold, 2005; Shaver and Pusc, 2005; Bleuer et al., 1991).

A number of studies have examined the physical nature of the Mahomet aquifer, delineating the basic shape, size, and stratigraphy of the deposits within the bedrock valley, as well as the geology and hydrogeology of the aquifer (Horberg, 1945, 1953; Stephenson, 1967; Visocky and Schicht, 1969; Kempton et al., 1982, 1991). When using the 153 m (500 ft) bedrock elevation contour to define its boundaries, the Mahomet bedrock valley in Illinois is over 200 km (124 mi) long and ranges from ~13 km (8 mi) wide at the Illinois-Indiana border to ~32 km (20 mi) at its widest points. The Mahomet aquifer begins in western Indiana and extends to central Illinois, where it intersects, in a large confluence area, with the north-south–trending Sankoty Mahomet aquifer in the Mackinaw bedrock valley. The Mackinaw bedrock valley is filled with sands and gravels of the Sankoty Sand Member of the Banner Formation, which make up the Sankoty Mahomet aquifer and are contemporaneous with the sands and gravels of the Mahomet aquifer (Kempton et al., 1991).

The sand and gravel that constitute the Mahomet aquifer and occupy the basal parts of the buried Mahomet bedrock valley are known as the Mahomet Sand Member of the Banner Formation and are generally greater than 30 m thick (Fig. 1). The Banner Formation is estimated to have formed more than 400,000 yr ago (Grimley, 1996) and is regarded as pre-Illinoisan in age (Willman et al., 1975; Hansel and Johnson, 1996). The Mahomet Sand Member is overlain by tills of the Banner, Glasford, and Wedron Formations (Fig. 2). The three major formations are typically separated by weathered zones, in some cases, with substantial soil development, periodically enriched with organic matter, and, in some places, peat deposits. Most of the Glasford Formation is of Illinoian age (more than 150,000 yr old) (Grimley, 1996) and contains locally important sand and gravel layers and lenses intercalated with the till. These sands and gravels are referred to as the Glasford Sand, and they form a significant aquifer in some parts of the Mahomet bedrock valley. The Glasford Formation is overlain by Wisconsinan Stage deposits, including the Robein Silt, Henry Formation, and the Wedron Formation (Fig. 2). Both the Wedron and Henry Formations contain relatively small sand and gravel outwash deposits that are thinner and much more limited in scope than either the Mahomet aquifer or Glasford Sand. The Robein Silt contains a large amount of organic matter, including wood fragments, peat deposits, and an organic-rich paleosol known as the Farmdale Geosol (Curry and Follmer, 1992).

The bedrock exposed in the floor and walls of the Mahomet bedrock valley includes rocks of the Silurian, Devonian, Mississippian, and Pennsylvanian systems (Fig. 3) (Kempton et al., 1991). Very few wells in the Mahomet bedrock valley area are screened in the bedrock units because of their low yields and increasing salinity with increasing depth (Visocky and Schicht, 1969). The western portions of the Mahomet and the Mackinaw bedrock valleys are cut predominantly through Pennsylvanian rocks consisting mostly of shale interbedded with thin limestones, sandstones, and coal seams. The Pennsylvanian rocks generally have low permeability

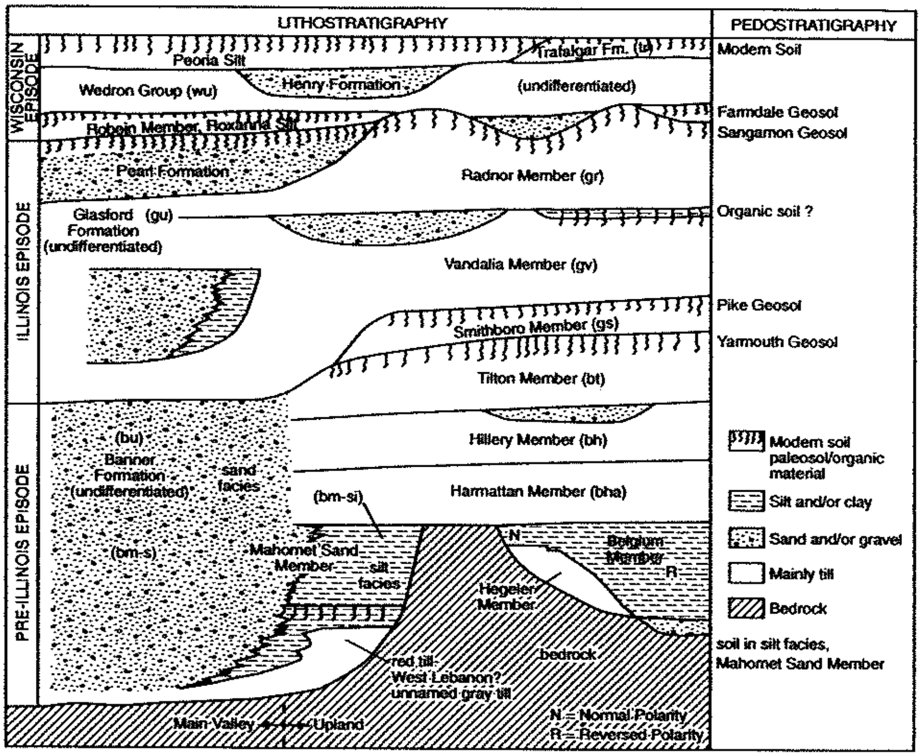


Figure 2. Schematic diagram showing relative stratigraphic relationships between Pleistocene and bedrock formations (modified from Kempton et al., 1991).

and are not an important aquifer in this area (Visocky and Schicht, 1969). However, beyond the bedrock valley, in the bedrock upland areas where the glacial deposits generally are thin and lack significant sands and gravels, the Pennsylvanian rocks are used to supply water for farms and small municipalities (Csallany, 1966). Wells developed in the Pennsylvanian units seldom penetrate more than 200 or 300 ft (61 or 91 m) and usually are screened in the thin limestones and sandstones (Csallany, 1966). The central and eastern portions of the valley expose rocks of the Mississippian, Devonian, and Silurian systems and some of the Pennsylvanian system. The Mississippian, Middle Devonian, and Silurian rocks are predominantly limestone and dolomite, but very few wells in east-central Illinois are developed in these carbonate units (Csallany and Walton, 1963). The Mississippian limestones generally have low permeability and only yield small supplies of water where the rock is fractured and creviced (Csallany and Walton, 1963). The Upper Devonian strata are primarily shale. The Middle Devonian limestone is rarely used as a source of water due to the paucity of secondary permeability and associated solution openings. The water-yielding properties of the Silurian carbonates are highly variable. The greatest yields are obtained in areas where the Silurian carbonate rock is near the bedrock surface and the top of the limestone or dolomite is weathered and contains crevices and dissolution features (Csallany and Walton, 1963). In east-central Illinois, wells producing groundwater from the Silurian carbonate bedrock are primarily in northern Ford county and Iroquois Counties (Woller, 1975; Hamdan, 1970).

Hydrologic characteristics of the Mahomet aquifer and the Glasford aquifer were originally described in Visocky and Schicht (1969), Gibb (1970), Sanderson (1971), and Kempton et al. (1982), and summarized in Kempton et al. (1991). The hydrologic characteristics of the Sankoty Mahomet aquifer sands were described in Wilson et al. (1998). According to Kempton et al. (1991), the hydraulic conductivities for the Mahomet aquifer and the Glasford Sand average $\sim 1.3 \times 10^{-3}$ m/s and 4×10^{-4} m/s, respectively. The hydraulic conductivities measured for the Sankoty Mahomet aquifer and Glasford Sand in the Mackinaw bedrock valley average 9.7×10^{-4} m/s and 2.6×10^{-4} m/s, respectively. The confining glacial-till layers have average vertical conductivities ranging from $\sim 8.8 \times 10^{-10}$ m/s to 2×10^{-7} m/s (Wilson et al., 1998; Kempton et al., 1991). The hydraulic gradient for most of the Mahomet aquifer is ~0.19 m/km, except near the cone of depression that has recently developed

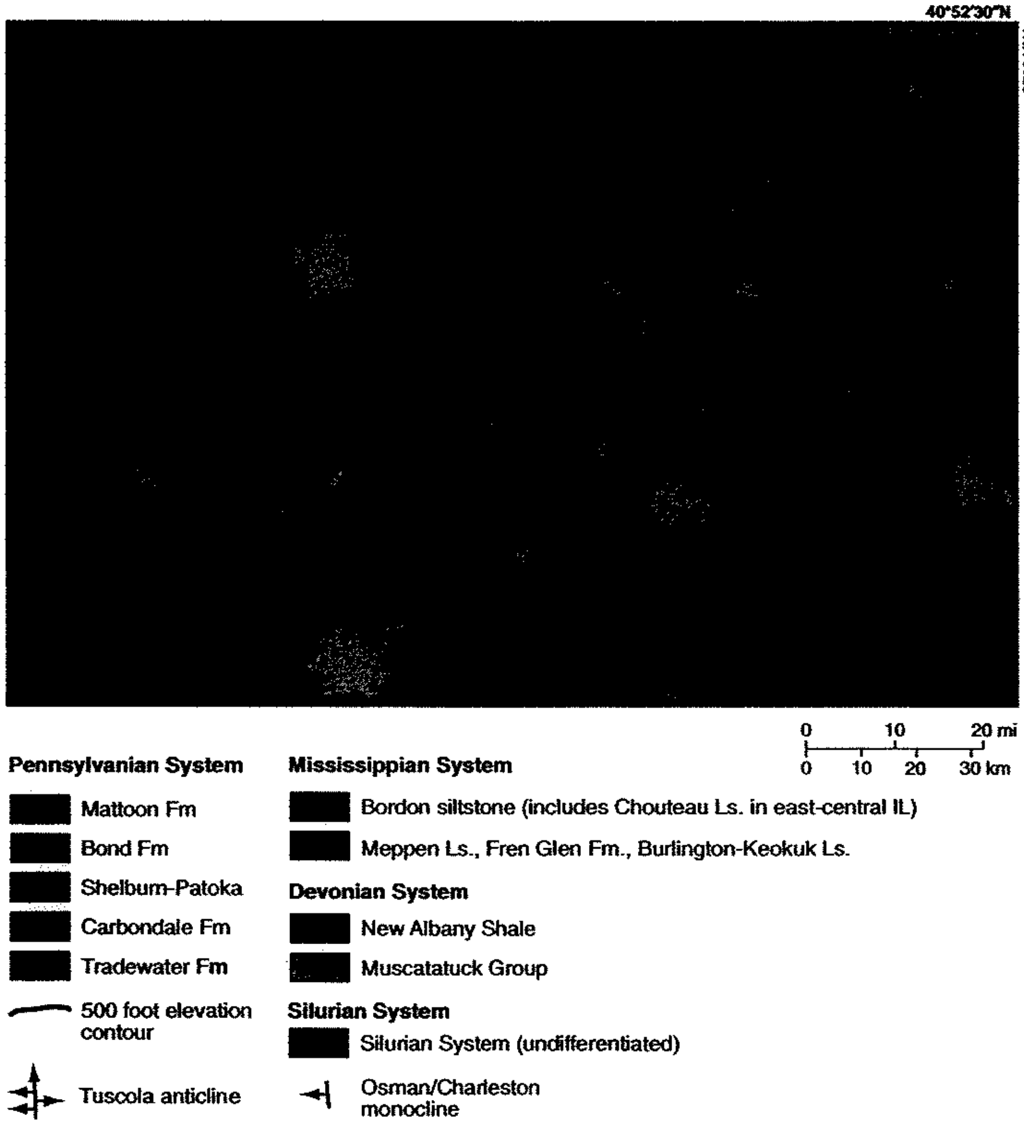


Figure 3. Bedrock geology for the area of east-central Illinois containing the Mahomet aquifer. The Mahomet bedrock valley is outlined relative to the 500 ft elevation contour (modified from Kempton et al., 1991; Kolata et al., 2005). Ls—limestone.

near the cities of Champaign-Urbana (Fig. 4). There is a substantial gradient change in the confluence area where the gradient increases from ~0.22 m/km in the western Mahomet aquifer to 0.78 m/km in the middle of Tazewell County (Wilson et al., 1998). The potentiometric heads in the confluence area indicate there is a groundwater divide that gradually deflects the flow of groundwater from the Mahomet aquifer to the north and to the south as it enters the confluence region (Fig. 4). The potentiometric head of the Glasford Sand aquifer is ~1.5–9 m above that of the Mahomet aquifer, but the Glasford Sand is typically separated from the Mahomet aquifer by ~15–30 m of confining glacial till. Historical records indicate the highest hydraulic heads for the Mahomet aquifer were located in northern Champaign, southern Ford, and northwestern Vermilion Counties (Kempton et al., 1991). In the northeastern portion of the Mahomet aquifer, known as the Onarga Valley, hydraulic head data indicate that groundwater gradients are reversed (Hamdan, 1970). Groundwater may originate from surrounding uplands, percolate down into the bedrock valley, and recharge the Mahomet aquifer and up into the Glasford Aquifer in the central portion of the Onarga Valley (Hamdan, 1970).

Hydrochemically, three water types have been identified in the Mahomet aquifer (Panno et al., 1994). Groundwater in the central portion of the aquifer is a dilute-type water characterized by Ca^{2+}, Mg^{2+}, and HCO_3^-. Onarga Valley groundwater has more total dissolved solids (TDS) and is characterized by Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-}. Groundwater in the western portion of the Mahomet aquifer is characterized by Ca^{2+}, Mg^{2+}, and HCO_3^-, with relatively large concentrations of Na^+ and Cl^-. The greater Cl^- and Na^+ concentrations were interpreted to be the result of groundwater upwelling from bedrock near the edge of the Charleston Monocline (part of the La Salle anticlinorium), which runs approximately perpendicular to the trend of the buried bedrock valley near the border of Piatt and Champaign Counties (Fig. 3).

SAMPLING AND ANALYTICAL METHODS

This paper includes the analytical results from 86 groundwater samples collected from throughout the Mahomet bedrock valley and much of the Mackinaw bedrock valley (Fig. 4).

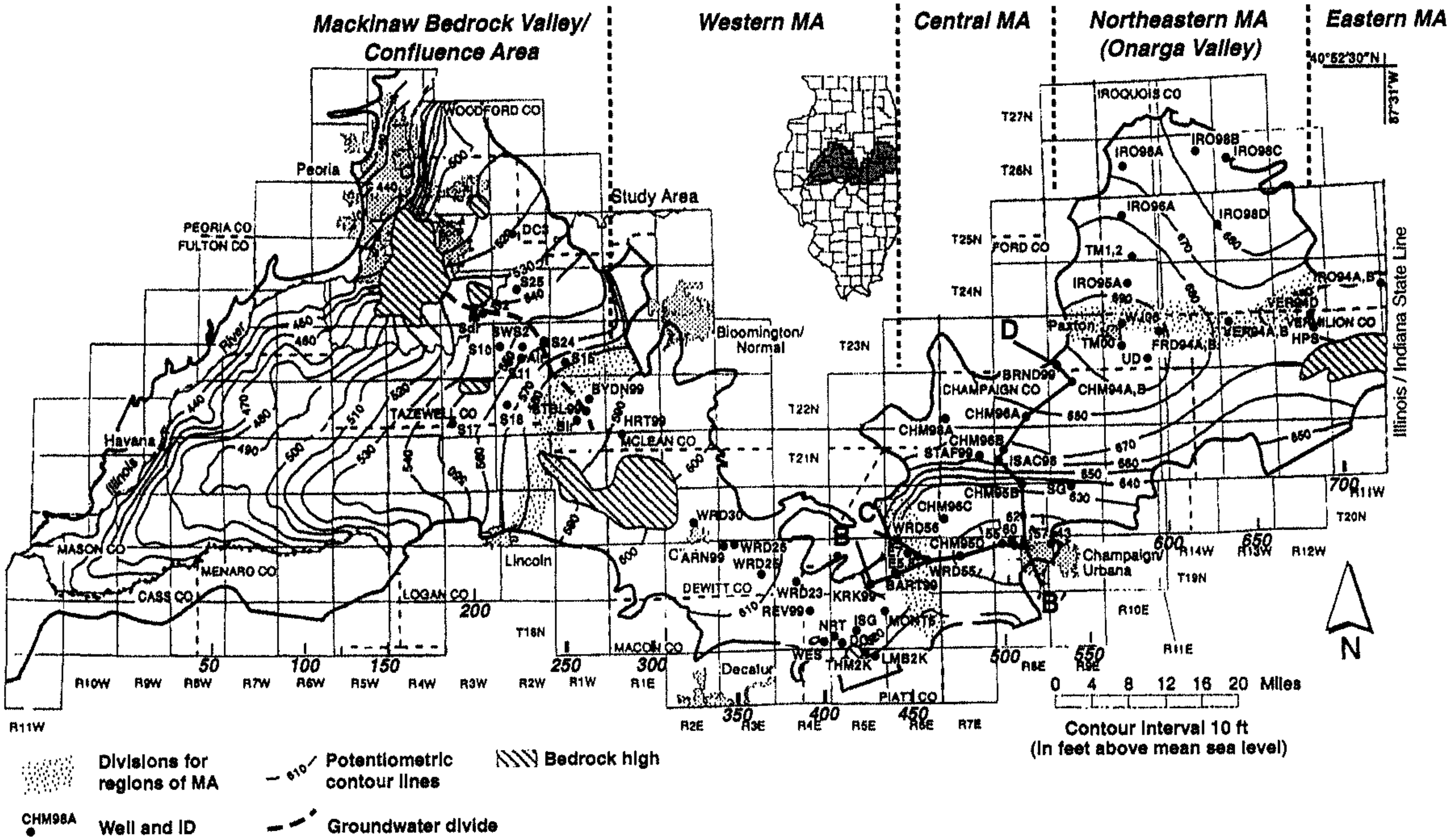


Figure 4. Map showing the location of the wells sampled from the Mahomet bedrock valley aquifer system. The contours are the potentiometric surface for the basal Mahomet aquifer (MA) (Wilson et al., 1998). The Illinois plane coordinate system (divided by 1000) is shown at southernmost township lines. Major regions are separated by shaded line and labeled across the top of the diagram. Cross-section lines B-B′, C-B′, and D-B′ are also included.

Sampling sites extend from the Indiana-Illinois border westward to the central part of Illinois (Tazewell County). Most of the groundwater samples were obtained from the basal Mahomet and Sankoty Sand Members of the Banner Formation, some from the overlying, more localized, sands within the Glasford Formation, and a few from relatively shallow sands in the Wedron Formation above the Glasford Formation. Water samples were collected from residential wells, monitoring wells drilled by the Illinois State Water Survey and the Illinois State Geological Survey, a few municipal water supply wells near Champaign-Urbana (Champaign County) and Monticello (Piatt County), Illinois, and one spring in the western part of the Mahomet bedrock valley.

Sample Collection

Water samples from residential wells were collected from outside spigots that were not connected to water softeners (commonly used in rural areas). Samples from municipal wells were collected from spigots located on the discharge pipe at the wellheads. At each site a "Y" connection was fastened to the spigot, to which a long hose and a short Viton tube were attached. The water was allowed to run for ~20–30 min through the hose and tubing while field parameters were monitored. Once field parameters stabilized, a high-capacity 0.45 µm filter was attached to the short tubing and flushed with ~500 mL of water prior to collecting samples for most chemical and isotope analyses.

Field parameters, including pH, Eh, specific conductance, and temperature, were measured for each sampling site. The pH and specific conductance meters were automatically compensated for temperature. All the electrodes were calibrated in the field with appropriate standards prior to sampling. The techniques used to collect the groundwater samples for chemical analyses are described by Wood (1981). Samples for cations and anion analyses were filtered in the field through the high-capacity inline filters and collected in 30 and 60 mL high density polyethylene (HDPE) bottles, respectively. The cation samples were acidified in the field with concentrated nitric acid to a pH <2. Samples for dissolved organic carbon (DOC) analyses were collected in precleaned 250 mL amber glass bottles and preserved with 0.25% sulfuric acid. These water samples were placed in a cooler packed with ice for transportation to the laboratory, where they were stored at 4 °C until analyzed. DOC is reported as nonvolatile organic carbon (NVOC).

Groundwater samples taken for methane gas determination were collected in 1 gallon (4 L) collapsible containers having caps that were fitted with plastic spigots. The containers were evacuated in the field using a portable direct-drive pump. Thirty mls of 0.13% Zephrin chloride solution, a preservative, was added to the containers prior to evacuation. The collapsible containers were then immediately connected to the Viton tubing via the spigot in the cap. Unfiltered water was allowed to flush the connecting tubes and spigot for several seconds to rid the system of air bubbles, and then the valve was opened to collect the water sample. The sample container was filled with slightly less than one gallon of water and brought back to the laboratory for processing that same afternoon. These large samples were not kept chilled.

Water samples collected for isotopic analyses were filtered in the field. Samples for δD and $\delta^{18}O$ were collected in 30 mL glass amber bottles using a cap fitted with a cone-shaped plastic insert to ensure a tight seal. The $\delta^{13}C$ samples were collected in 125 mL HDPE bottles, and the $\delta^{34}S$ and ^{3}H samples were collected in 1 L HDPE bottles. The samples were transported to the laboratory in an ice-filled cooler and stored at 4 °C until analyzed. Samples taken for carbon-14 (^{14}C) analysis of dissolved inorganic carbon (DIC) were collected in collapsible five-gallon (20 L) containers. A stir bar was placed in the container, which was evacuated in the field prior to being filled with water. Filtered water samples were directly passed into the evacuated container using a thick-walled Tygon tubing connected to the container's spigot valve. The Tygon tubing and spigot valve were purged with the formation water through a small opening in the valve prior to filling the container. The direct connection to the sample container minimized degassing and contact with atmospheric carbon dioxide. These samples were too large for refrigeration in the laboratory and were processed as quickly as possible for ^{14}C analysis (within 48 h).

Those samples containing significant methane (CH_4) gas were analyzed for $\delta^{13}C$ and δD. Samples taken for stable isotope analyses on CH_4 were collected in quart-size (1 L) glass jars using the water-displacement technique as described by Meents (1960).

Analyses

The groundwater samples were analyzed chemically for major and minor cations, anions, DOC, and CH_4 concentration. Concentrations of cations were determined by the Illinois State Water Survey (ISWS) using a Model 1100 Thermo-Jarrell Ash inductively coupled argon–plasma spectrometer (ICAP). Anion concentrations were determined at the ISGS using a Dionex 2110i ion chromatograph (IC), following U.S. EPA Method 300 (O'Dell et al., 1984). The DOC concentration was determined at the ISWS using a Dohrmann total organic carbon analyzer and following methods similar to those described in ASTM D-4839–88 (1994).

The concentration of dissolved CH_4 in the water was determined by analyzing the composition of the gas bubble from the 4 L collapsible container and using a best-fit polynomial for CH_4 solubility data between 0 and 30 °C (Dean, 1992) to calculate the concentration of CH_4. The sample containers were brought back to the laboratory and weighed immediately. The quantity of water was determined from the difference between the full and empty weights of the collapsible sample containers. By the time the sample was returned to the laboratory, the dissolved gases had equilibrated to atmospheric pressure and come out of solution, making a bubble inside the container. The gas was extracted from the containers that same afternoon using an appropriate-size graduated syringe and needle. Prior to extracting the gas, saturated sodium sulfate solution was used to fill the needle and dead space at the end of the syringe in order to minimize air contamination of the samples and prevent dissolution of the gas sample into the solution while in the syringe. The gas was extracted by pushing the needle directly through the plastic collapsible container and drawing the gas bubble into the syringe. The quantity of gas extracted was measured using the graduated marks on the syringe and was injected into a previously evacuated glass vial (Vacutainer®) fitted with a septum. The gas samples were then analyzed on a gas chromatograph (GC).

Stable isotopic analyses included $\delta^{18}O$ and δD of the water, $\delta^{13}C$ of the DIC, $\delta^{34}S$ of the dissolved SO_4^{2-} sulfur, and $\delta^{13}C$ and δD of the CH_4. The $\delta^{18}O$ value of the water samples was determined using a modified CO_2-H_2O equilibration method as originally described in Epstein and Mayeda (1953), with modifications described in Hackley et al. (1999). The δD of water was determined using the Zn-reduction method described in Coleman et al. (1982) and Vennemann and O'Neil (1993), with modifications described in Hackley et al. (1999). The $\delta^{13}C$ of DIC was determined using a gas-evolution technique. Approximately 10 mL of water were injected into an evacuated vial containing 100% phosphoric acid and a stir bar. The CO_2 evolved from the water sample was cryogenically purified on a vacuum system and sealed into a Pyrex break tube for isotopic analysis. The $\delta^{34}S$ of the SO_4^{2-} was determined by precipitating the SO_4^{2-} as $BaSO_4$ and converting the sulfur to SO_2 by combustion with a V_2O_5-SiO_2 mixture, similar to that described by Yanagisawa and Sakai

(1983) and Ueda and Krouse (1986). The $\delta^{13}C$ and δD values of the CH_4 samples were determined by combusting the CH_4 and collecting the products CO_2 and H_2O as described by Hackley et al. (1999).

The δD, $\delta^{13}C$, $\delta^{18}O$, and $\delta^{34}S$ values were determined on a dual inlet ratio–mass spectrometer. Each sample was directly compared to an internal standard calibrated versus an international reference standard. The final results are reported versus the international reference standards. The δD and $\delta^{18}O$ results are reported versus the international Vienna Standard Mean Ocean Water (V-SMOW) standard. The $\delta^{13}C$ results are reported versus the Peedee belemnite (PDB) reference standard. The $\delta^{34}S$ results are reported versus the Canyon Diablo Troilite (CDT) standard. Analytical reproducibility for δD, $\delta^{18}O$, $\delta^{13}C$, and $\delta^{34}S$ is equal to or less than ±1.0‰, ±0.1‰, ±0.15‰, and ±0.3‰, respectively.

Radioisotope analyses included ^{3}H on the water and ^{14}C on the DIC. The ^{3}H analyses were done by the electrolytic enrichment process (Ostlund and Dorsey, 1977) and the liquid scintillation counting method. The electrolytic enrichment process consists of distillation, electrolysis, and purification of the ^{3}H enriched samples. The precision for the tritium analyses reported in this study is ≤ ±0.25 TU.

The ^{14}C activity of the DIC was analyzed using conventional techniques, and results were corrected for $\delta^{13}C$ compositions. The DIC was extracted from the water samples by acidification; the released CO_2 was quantitatively collected on a vacuum line. The CO_2 from acidification was cryogenically purified and converted to benzene as outlined in Coleman (1976). The ^{14}C activity was measured using the liquid scintillation spectrometry technique developed by Noakes et al. (1965, 1967). The ^{14}C results are reported as percent modern carbon (pMC) relative to the NBS reference material (oxalic acid #1). Modern carbon (100 pMC), by convention, is defined as 95% of the activity of the oxalic acid reference standard (Clark and Fritz, 1997).

RESULTS AND DISCUSSION

The chemical and isotopic results (GSA Data Repository, Tables DR1, DR2, and DR3[1]) show important patterns across the basal sands of the Mahomet aquifer and Sankoty Mahomet aquifer. Four hydrochemical facies were observed in the basal sands of the Banner Formation, each of which had different ^{14}C and/or $\delta^{13}C$ characteristics. Groundwater in the central and eastern regions of the Mahomet aquifer (Champaign County, southern Ford County, and parts of Vermillion County) is primarily Ca-Mg-HCO_3 water with very low Cl^- concentration and ^{14}C values around 30 pMC. Groundwater in the western region (Piatt County, DeWitt County, and McLean County) is a Ca-Mg-HCO_3 water with a notable influence from Na-Cl–type waters. Groundwater in this western region also shows decreasing ^{14}C values toward the west and the greatest $\delta^{13}C$ values observed for DIC compared to the rest of the Mahomet aquifer. Groundwater in the northeastern region of the Mahomet aquifer (the Onarga Valley), in Iroquois County and parts of northern Vermillion County, is primarily Ca-Mg-HCO_3 with some Ca-Mg-SO_4 waters and exhibits smaller ^{14}C concentrations and more negative $\delta^{13}C$ values than the central and eastern regions of the aquifer. The groundwater in the Sankoty Mahomet aquifer is primarily Ca-Mg-HCO_3 water with variable Na^+ and Cl^- concentrations and a large range of ^{14}C and $\delta^{13}C$ values. The dominance of major cations and anions for the different facies is shown in a trilinear diagram (Fig. 5). These results suggest trends from Ca-Mg-HCO_3 waters to Ca-Mg-SO_4– and Na-Cl–type waters in the aquifers of the Mahomet bedrock valley system, based on the generalized evolution of groundwater due to water-rock interactions (Chebotarev, 1955; Schoeller, 1959). However, as indicated in the following discussions for each region of the buried bedrock aquifers, many of the chemical variations observed are actually due to mixing of younger, more dilute groundwater with older, more mineralized groundwater seeping from bedrock units in the various regions of the bedrock valley or mixing of relatively fresh recharge water with groundwater emerging from a part of the Pleistocene aquifer that is more confined. The isotopic composition ($\delta^{18}O$ and δD) of most of the water sampled from the Mahomet and Sankoty Mahomet aquifers is similar to present-day precipitation, suggesting the age of the water is no older than the start of the Holocene. There are a couple of samples that have slightly more negative isotopic compositions, and these are in regions of the aquifer that have evidence of inputs from bedrock units.

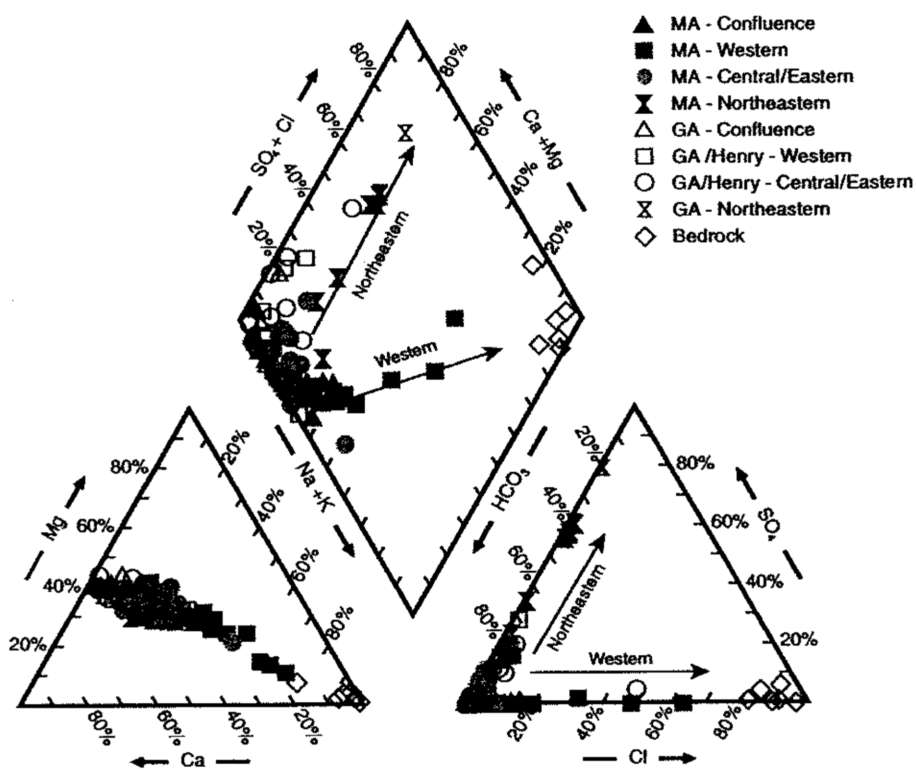


Figure 5. Trilinear and piper diagrams of groundwater samples from the Mahomet bedrock valley hydrologic system. Different symbols represent samples from the Mahomet and shallower aquifers in the different regions across the Mahomet Valley. Bedrock data are from Panno et al. (1994). Arrows depict geochemical evolutionary trends observed in the western and northeastern regions.

[1]GSA Data Repository item 2009286, data tables and additional text and figures referred to in the main document, is available at http://www.geosociety.org/pubs/ft2009.htm or by request to editing@geosociety.org.

Central-Eastern Mahomet Aquifer Region

Groundwater in the central and eastern regions of the Mahomet aquifer has the smallest total dissolved solids content, as exemplified by the small chloride concentrations (Fig. 6) and the relatively low specific conductance values (Fig. DR1 [see footnote 1]). The low specific conductance and chloride concentrations suggest significantly less water-rock interaction compared to the rest of the Mahomet aquifer. The relatively dilute nature of this groundwater led Panno et al. (1994) to suggest that there is more rapid recharge from the surface in the central region than the western and northeastern regions of the Mahomet aquifer. The greater ^{14}C activity in central-eastern area of the Mahomet aquifer, near 35 pMC (Fig. 7), supports this hypothesis. There is an unusually thick sequence of stacked sand deposits (Panno et al., 1994; Hackley, 2002) in the central region of the Mahomet bedrock valley that corresponds to the potentiometric high (Fig. 4), providing additional geologic and hydrologic evidence that the area is an important recharge zone for the Mahomet aquifer.

Typically, assuming the lithology and geochemistry of the local geology and aquifers are similar, one would expect the $^{14}C_{DIC}$ activity in the groundwater near a recharge zone to be relatively large compared to groundwater at a similar stratigraphic level further away from the recharge zone. Most wells screened in the Glasford Formation in Champaign and Ford Counties, had relatively large $^{14}C_{DIC}$ activities (58–65 pMC), as would be expected for a relatively shallow aquifer near a recharge zone. However, the $^{14}C_{DIC}$ results from a few wells in the same area suggest the situation is complicated. For example, one of the Glasford wells, BRND-99, on the border of southern Ford County and northern Champaign County, had a relatively low $^{14}C_{DIC}$ activity (28.1 pMC) compared to most other wells drilled to a similar stratigraphic level in the bedrock valley (Table DR3B [see footnote 1]). Relatively low ^{14}C values were also observed in other wells in the Glasford aquifer (CHM-94B and TM-00), as well as in the Mahomet aquifer (CHM-94A and WJ-00), which are located in or near the same area of stacked sands and topographical high in northern Champaign and southern Ford Counties. Biogeochemical reactions such as sulfate reduction and methanogenesis may help to explain the lower ^{14}C values in these wells. The $\delta^{13}C$ values for some of the wells are more negative (<–14‰) than most of the other wells in the central and eastern regions, suggesting the input f isotopically lighter carbon, probably due to oxidation of organic matter related to the sulfate reduction. Most of these wells with low $\delta^{13}C$ values also had positive $\delta^{34}S$ values, with concentrations ranging from below detection limits to 51 mg/L (Tables DR2 and DR3 [see footnote 1]). The well with no detectable sulfate, BRND-99, had detectable CH_4, suggesting that after sulfate concentrations were depleted, fermentation reactions associated with methanogenesis took over, which could have contributed additional ^{14}C-depleted bicarbonate to lower $^{14}C_{DIC}$ values. The fermentation reactions that occur along with methanogenesis break down complex organic compounds into simpler molecules such as fatty acids, carbon dioxide, protons, and hydrogen (Klass, 1984).

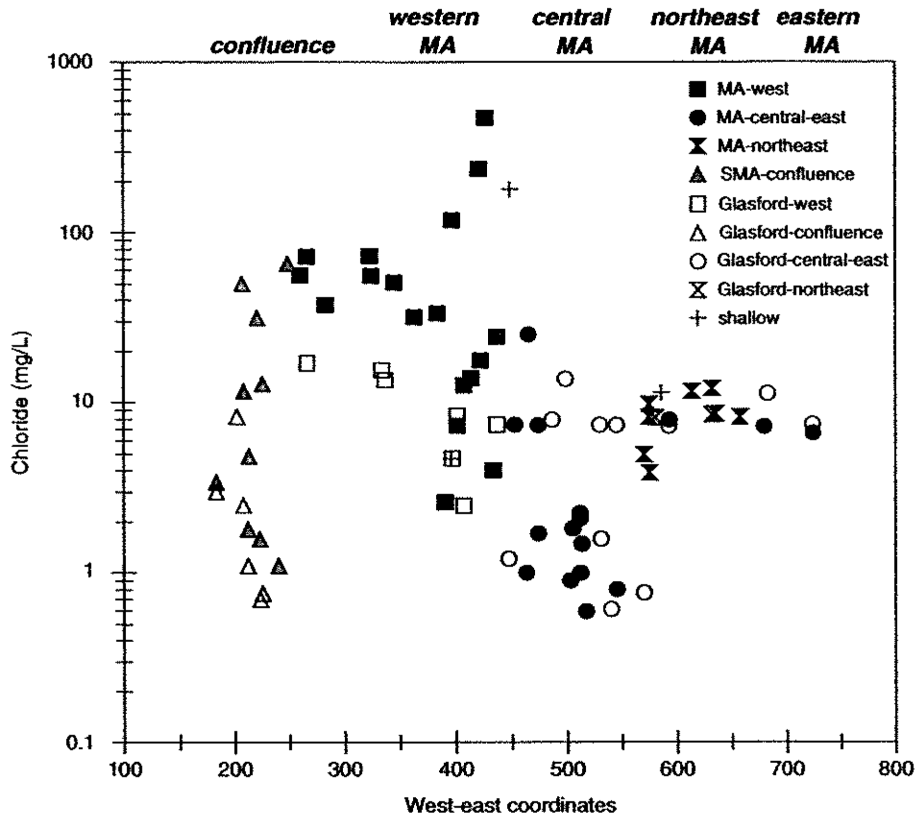


Figure 6. Distribution of Cl⁻ concentrations for groundwater samples plotted geographically across the Mahomet bedrock valley system. Different symbols are used for different regions of the Mahomet Valley. Closed symbols are samples from the Mahomet aquifer, while open symbols are from the shallower Glasford and Wedron aquifers (Coordinates used for *x*-axis are Illinois plane coordinates divided by 1000; see location map Fig. 3.).

Northeastern Mahomet Aquifer (Onarga Valley) Region

Groundwater in the Onarga Valley, the segment of the Mahomet bedrock valley that trends north-northeast, contains low $^{14}C_{DIC}$ activities (Fig. 7) and high SO_4^{2-} concentrations (Table DR2 [see footnote 1]). The bedrock consists of Silurian and Devonian marine limestones and dolostones and Pennsylvanian shales, sandstones, and coals. Panno et al. (1994) suggested that the source of the high SO_4^{2-} concentrations is the dissolution of sulfate minerals associated with the weathered bedrock units. Because of the minimal amounts of dissolved oxygen available in groundwater, the SO_4^{2-} concentrations observed in the Onarga Valley are not possible by pyrite oxidation alone but are plausible by dissolution of sulfate minerals as determined by geochemical modeling (Panno et al., 1994). The additional low (negative) $\delta^{34}S$ results for samples with large SO_4^{2-} concentrations reported in this study support the suggestion that the sulfate minerals being dissolved were originally derived from the oxidation of pyrite in the Pennsylvanian coal and shales as well as Devonian shales. The $\delta^{34}S$ associated with sulfur from reduced sulfides such as pyrite are typically negative (Hackley and Anderson, 1986; Kaplan, 1983; Goldhaber and Kaplan,

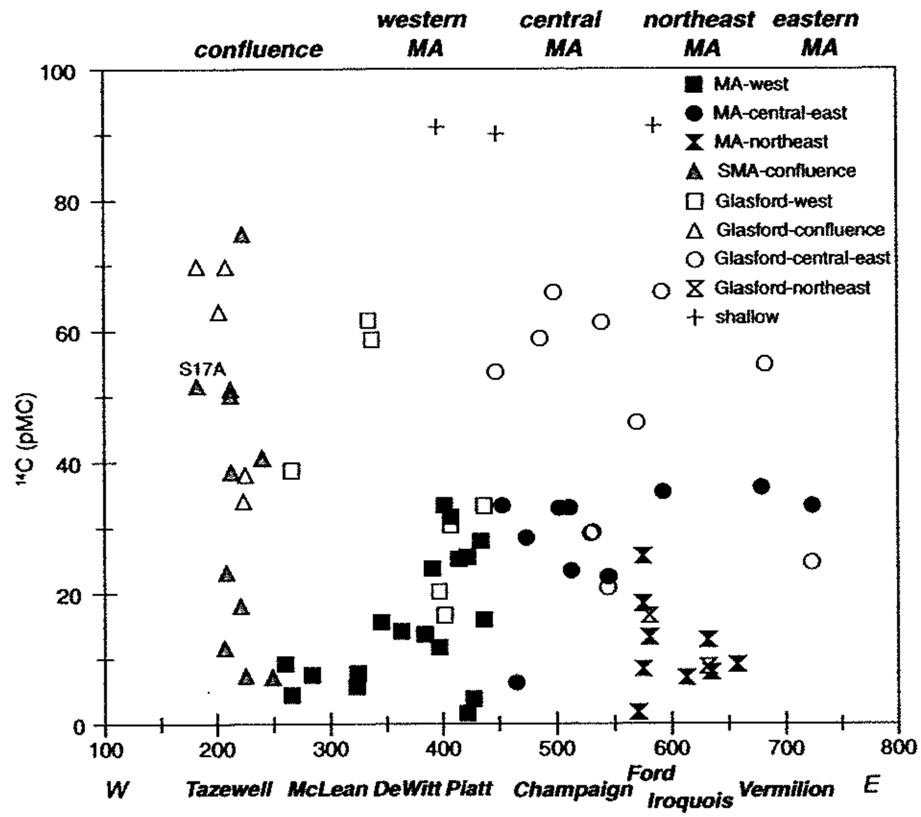


Figure 7. ^{14}C activity of dissolved inorganic carbon (DIC) for samples taken from the Mahomet bedrock valley system plotted geographically from west to east across the bedrock valley. Different symbols are used for different regions of the Mahomet Valley. Closed symbols are all from the Mahomet aquifer, while open symbols are from the shallower Glasford and Wedron aquifers.

1980, 1974). Prior to deposition of the Pleistocene sediments, bedrock units exposed in the valley would have undergone weathering for a prolonged period. For example, secondary gypsum and iron-sulfate formation from pyrite oxidation has been observed in recent soils and lignite overburden piles (Wagner et al., 1982; Nettleton et al., 1982; Dixon et al., 1982). Thus, gypsum and iron sulfates may be present in the weathered bedrock surface of the Mahomet bedrock valley in this region.

If gypsum is present at the base of the Mahomet bedrock valley, along with dolomite and calcite, then there is the possibility that de-dolomitization may be occurring in the Onarga Valley region. De-dolomitization has been reported in other aquifers containing gypsum in the presence of limestones and dolomite (Back and Hanshaw, 1970; Wigley et al., 1978; Back et al., 1983; Plummer et al., 1990). Although no physical evidence of gypsum was reported in the geological logs from the drilling records in the northeastern Mahomet aquifer, the trends observed between concentrations of Ca, Mg, and HCO_3 versus SO_4 suggest that de-dolomitization has probably occurred (see GSA Data Repository [see footnote 1]).

The relatively low $^{14}C_{DIC}$ activities in both the Mahomet aquifer and shallower Glasford aquifer in the Onarga Valley region (Fig. 7) are consistent with upward movement of groundwater passing through bedrock units up into the Pleistocene deposits in the central part of Onarga Valley (Hamdan, 1970). Dissolution of the Paleozoic bedrock carbonates would add ^{14}C-free carbonate ions to the DIC pool, diluting the ^{14}C activity. In addition, $\delta^{13}C_{DIC}$ values in this region are unusually negative (–14‰ to –21‰) (Fig. 8; Table DR3 [see footnote 1]), suggesting that oxidation of organic matter has also contributed to the DIC. Organic carbon, dissolved or sedimentary, would be isotopically depleted compared to the DIC of groundwater. For example, the δ^{13}C values of sedimentary organic matter collected from glacial deposits throughout Illinois range between –24‰ to –30‰ (Liu and Coleman, 1981; Liu et al., 1986). Thus, input of dissolved CO_2 from the oxidation of organic compounds would shift the carbon isotopic composition of the DIC to more negative values. The high SO_4^{2-} concentration observed in the groundwater of this northeastern region is a likely source of electron acceptors for anaerobic oxidation of organic matter within the aquifer. Dissolved CO_2 from the oxidation of DOC or sedimentary organic matter originating from the Illinoian or pre-Illinoian Pleistocene sediments or the Paleozoic bedrock strata would also dilute the ^{14}C content. Thus, the low $^{14}C_{DIC}$ concentrations in the northeastern region of the Mahomet aquifer can be attributed to a combination of older groundwater passing through previously exposed bedrock valley units, resulting in the dissolution of sedimentary carbonates, plus the oxidation of buried sedimentary organic matter through sulfate reduction.

The relationship between δ^{34}S and $[SO_4^{2-}]$ in the northeastern region and surrounding areas of the Mahomet bedrock valley can be used to estimate the relative importance of SO_4^{2-} reduction and groundwater mixing as the controlling factors for the variable SO_4^{2-} concentration observed in the Mahomet aquifer (Fig. 9). Because much of the Onarga Valley is topographically lower than surrounding areas, groundwater could be percolating down in the perimeter regions of the Onarga Valley and flowing through and mixing with groundwater from bedrock units. Thus, the isotopic composition and concentration of SO_4^{2-} observed in the shallow sands of the Wedron and Glasford Formations, as well as the Mahomet aquifer beyond the immediate vicinity of the Onarga Valley, would be important to consider for evaluating mixing and sulfate reduction influences. The mixing curve in Figure 9 was calculated using the groundwater samples from the vicinity of the northeastern Mahomet bedrock valley with the highest and lowest SO_4^{2-} concentration and their respective δ^{34}S values as end members. The Rayleigh fractionation curves in Figure 9 were calculated using a fractionation factor of $\alpha = 1.015$, which is reasonable for fresh groundwater systems (Busby et al., 1991; Eberts and George, 2000). The different calculated Rayleigh curves show the trends that would be expected if the sulfate reduction process were initiated at different SO_4^{2-} concentrations. The trend of δ^{34}S values and SO_4^{2-} concentration for most of the samples falls closer to the mixing relationship rather than the Rayleigh fractionation curves, especially the overall fractionation curve initiated from the highest SO_4^{2-} concentration.

Although SO_4^{2-} reduction is probably not the dominant process responsible for the decrease in SO_4^{2-} concentration in the Mahomet aquifer in the northeastern region and surrounding areas, the δ^{34}S and $[SO_4^{2-}]$ data do show that

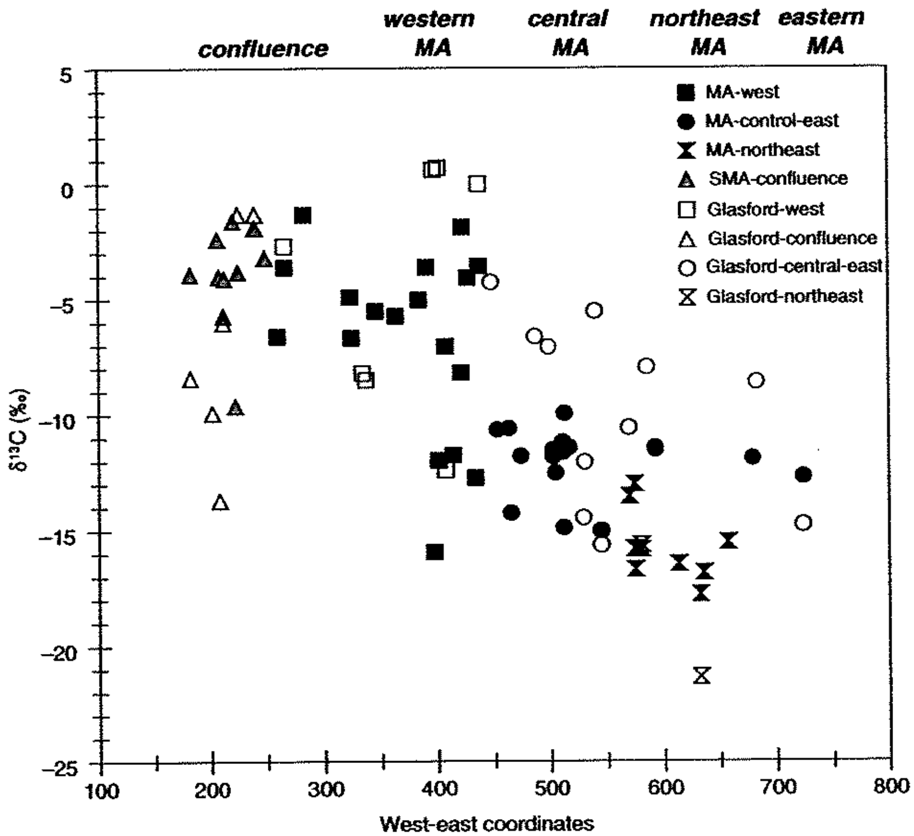


Figure 8. Distribution of $\delta^{13}C_{DIC}$ values for groundwater samples plotted geographically across the Mahomet bedrock valley system. Different symbols are used for different regions of the Mahomet Valley.

SO_4^{2-} reduction is definitely occurring, and in some cases may be dominant. The very positive $\delta^{34}S$ values in groundwater from shallower sands (+15‰ to +30‰) overlying the Mahomet aquifer in the Mahomet bedrock valley (central-eastern and the western regions) are most likely due to SO_4^{2-} reduction. The primary source of dissolved SO_4^{2-} in the shallow tills would be the oxidation of pyrite, which typically has negative $\delta^{34}S$ values (−10‰ to −16‰, according to Van Stempvoort et al., 1994). The low SO_4^{2-} concentrations and very positive $\delta^{34}S$ values measured in samples from these shallower aquifers are probably characteristic of the SO_4^{2-} in groundwater that eventually infiltrates the deeper Mahomet aquifer in areas of downward gradients. In addition to these shallower groundwater samples, one of the deeper samples (I98C) in the Mahomet aquifer in the northeastern region also had a very positive $\delta^{34}S$ value (+57‰), strong evidence of SO_4^{2-} reduction being a dominant process for this site. The $\delta^{34}S$ values of other samples from the northeastern region suggested that SO_4^{2-} reduction has overprinted the general mixing trend exhibited for most of the Mahomet aquifer samples in the region. For example, assuming the chosen end members are correct, groundwater at sites I98B, I95A, and especially I98D have significantly more positive $\delta^{34}S$ values than would be expected from mixing alone. The more positive $\delta^{34}S$ values at these sites are likely due to microbial SO_4^{2-} reduction occurring in conjunction with mixing. Groundwater at sites I96A, V94A, and T2 also appears to have been slightly influenced by SO_4^{2-} reduction processes (Fig. 9). Sulfate reduction in the Mahomet aquifer samples is supported by their more negative $\delta^{13}C_{DIC}$ values relative to most of the other samples in the central and eastern portion of the Mahomet aquifer (Table DR3a [see footnote 1]; Fig. 8). The more negative $\delta^{13}C$ values suggest an input of isotopically light carbon by the oxidation of organic matter, which would occur during the SO_4^{2-} reduction process.

Thus, the chemical and isotopic data suggest that the wide range in SO_4^{2-} concentrations in the eastern half of the Mahomet aquifer is caused by a combination of groundwater mixing and SO_4^{2-} reduction. Mixing occurs between upwelling high-SO_4^{2-} groundwater from the Onarga Valley in northeastern region and lower-SO_4^{2-} groundwater in the basal Mahomet sand from the central region. The large SO_4^{2-} concentration in the Glasford Sand and Mahomet aquifer in northern Vermilion (V94B&A) suggests that the upwelling groundwater from the Onarga Valley has also mixed with groundwater in parts of Vermilion County. In the rest of the Mahomet aquifer, it would appear that groundwater from the shallower aquifers has percolated down to the Mahomet aquifer, with SO_4^{2-} subjected to various degrees of sulfate reduction. The microbial SO_4^{2-} reduction contributes to the decrease in SO_4^{2-} concentration as well as an increase in the $\delta^{34}S$ of the remaining SO_4^{2-}. This reduction process also results in more negative $\delta^{13}C_{DIC}$ values and adds to the dilution of ^{14}C activity of the DIC, which is already low in the northeastern region of the Mahomet aquifer as a result of the upwelling older groundwater from the bedrock in this area.

Besides the elevated SO_4^{2-} concentrations, groundwater samples in the vicinity of the northwestern region are anomalously high in other constituents including B and Sr, which appear to be related to the local lithology (Hackley, 2002; Table DR2; Figs. DR3 and DR4 [see footnote 1]). Boron is typically associated with minerals such as tourmaline, biotite, and amphiboles (Hem, 1992) or perhaps with shales and coals (Krauskopf, 1967). The Upper Devonian New Albany, the Mississippian Bordin Siltstone, and the Pennsylvanian Tradewater Formations exposed in the bedrock in the northeastern and central parts of the Mahomet bedrock valley (Kolata et al., 2005) contain shales, coals, siltstones, and argillaceous sandstones, some with noticeable mica flakes (Willman et al., 1975), and they are probably the primary source of the elevated boron in this part of the Mahomet aquifer. The source of Sr is probably the Mississippian, Silurian, and Devonian carbonates (Fig. 3) or clastics from these formations, which make up most of the exposed bedrock for this region of the valley.

Western Mahomet Bedrock Valley Region

Within the transition zone between the central and western regions of the Mahomet aquifer, there appears to be a fraction of rather young groundwater percolating down through sand units beneath the Sangamon River, as indicated by the tritium results. Two groundwater samples from the basal sands in this region contained a small amount of detectable tritium (Table DR3A [see footnote 1]). The tritium data support recent seismic and water-well pumping studies that indicate there is a hydraulic connection between the Sangamon River and the Mahomet aquifer in

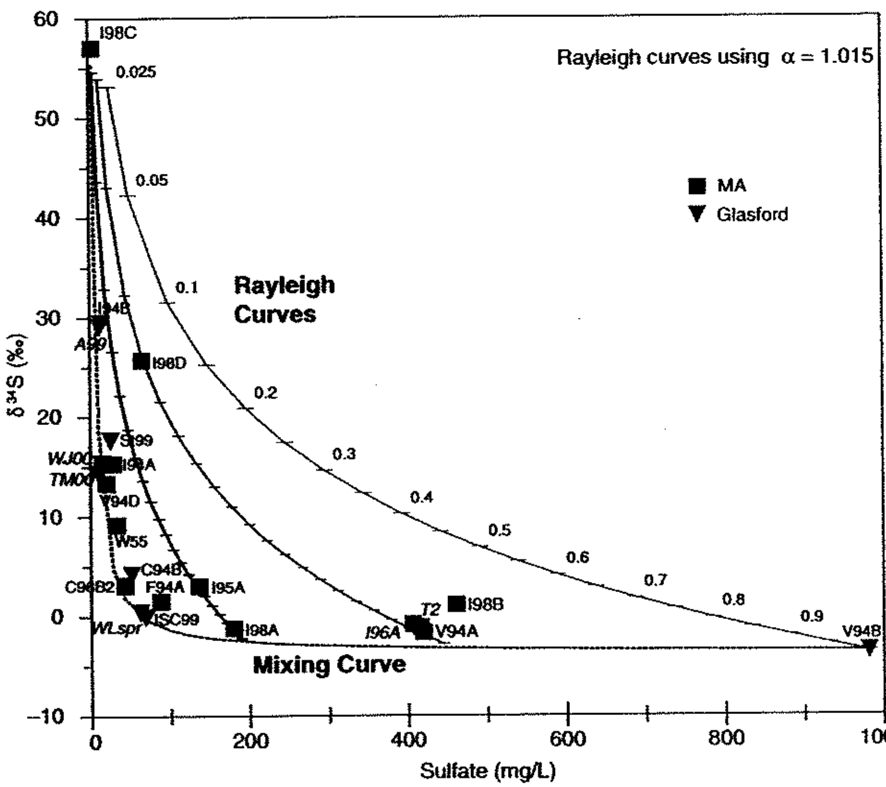


Figure 9. δ^{34}**S versus** [SO_4^{2-}] **for groundwater samples collected from the Mahomet aquifer and shallower sands. Diagram includes a calculated mixing curve and Rayleigh fractionation curves to help determine whether physical mixing or redox processes are affecting the variability of** [SO_4^{2-}]**. The multiple Rayleigh curves show how sulfate reduction reactions could overprint the overall mixing process. (Tick marks on Rayleigh curves indicate fraction of original** [SO_4^{2-}] **remaining.)**

this area (Carstens, 2004; Roadcap and Wilson, 2001). The ^{14}C activity of these two samples did not show an increase; in fact, the ^{14}C of one was similar to other samples in the central region (30 pMC), while the other sample was quite low (11 pMC), suggesting that there has been significant amounts of groundwater with less than 30 pMC mixing with the younger water percolating down from near the surface. There was also CH_4 detected in the Mahomet aquifer and Glasford aquifer in the same area, indicating degradation of buried organic debris (including fermentation reactions), which would tend to dilute the ^{14}C activity of the DIC as well as influence the $\delta^{13}C$ and concentration of DIC.

Just west of the boundary between the central and western parts of the Mahomet aquifer, (in Piatt County), SO_4^{2-} concentrations drop to very small values, often below detection limits, and CH_4 concentrations increase abruptly (Fig. 10). In the sequence of microbial reduction processes, SO_4^{2-} is consumed prior to microbial production of CH_4 (Oremland and Taylor, 1978). This is because SO_4^{2-}-reducing bacteria are more efficient in utilizing the available energy sources, such as hydrogen and acetate, and out-compete methanogens (Martens and Berner, 1974; Abram and Nedwell, 1978; Kristjansson et al., 1982). Thus, in groundwater where methanogenesis occurs, SO_4^{2-} concentrations are usually quite small or not detectable. The $\delta^{13}C$ and δD values of CH_4 from the Mahomet aquifer indicate that the CH_4 is of microbial origin, formed by the CO_2 reduction pathway (Fig. 11). This is in agreement with the results of Coleman et al. (1988), who studied the origin of CH_4 in several glacial drift and shallow Paleozoic deposits throughout Illinois.

The western Mahomet aquifer also shows an east-west trend of progressively higher specific conductance (Fig. DR1 [see footnote 1]) and Cl^- concentrations (Fig. 6) compared to the rest of the aquifer. Sodium concentrations also increase in this part of the Mahomet aquifer. The increases in Na^+ and Cl^- concentrations suggest contribution of more saline groundwater from bedrock units. The main influx of saline groundwater probably occurs near the west flank of the La Salle anticlinorium (Panno et al., 1994). The largest concentrations of Cl^- and the lowest ^{14}C concentrations observed in this study were from samples located in Piatt County, just west of the Osman-Charleston monocline (Fig. 3), which is associated with the La Salle anticlinorium in central Illinois.

Both the change in bedrock lithology (Fig. 2) associated with the Osman-Charleston monocline and the seepage of groundwater from bedrock units in the western region of the Mahomet aquifer may contribute to the strongly reducing conditions, as indicated by the disappearance of SO_4^{2-} and elevated levels of CH_4 concentration as one moves further west along the Mahomet aquifer from the central region. The units exposed along the bottom of the bedrock valley in the western region are the Pennsylvanian Modesto and Bond Formations (Kempton et al., 1991; Willman et al., 1975). These Pennsylvanian shales, coals, and argillaceous limestones, or perhaps clastics from these units, in the western part of the Mahomet bedrock valley probably contain relatively large amounts of sedimentary organic matter, which would result in more reducing conditions compared to the Mahomet aquifer overlying primarily carbonate bedrock units in the central and eastern regions. Organic carbon is a strong reductant and an important substrate for many microbial oxidation-reduction reactions (Stumm and Morgan, 1981). Influx of groundwater from the organic-bearing bedrock units may contain high levels of DOC, or DOC may be leaching out of clastics from the bedrock units, which would enhance reducing conditions in this part of the Mahomet aquifer. The data show a dramatic increase in DOC in the western part of the Mahomet aquifer that starts rather abruptly near the Piatt-Champaign County line (Fig. 12). However, the constituents that indicate strongly reducing conditions (CH_4 and NVOC) do not correlate well with the increased Cl^- concentrations, which are believed to be associated with upwelling groundwater from the bedrock units in this region. For example, the correlation coefficient (r^2) between Cl^- and CH_4 is 0.25, and r^2 between Cl^- and NVOC is 0.04 for the western Mahomet aquifer. Furthermore, some of the samples from the shallower Glasford aquifer, especially in the western region, also have quite elevated NVOC values (as high as 8.3 mg/L with a mean of 4.1; Table DR2B [see footnote 1]). Thus, a substantial amount of the DOC in the western Mahomet aquifer may be associated with the paleosols and peat deposits often found within the glacial tills themselves, typically located between the Pleistocene formations (Fig. 2) (Kempton et al., 1991). The organic matter associated with the Pleistocene deposits is much younger and

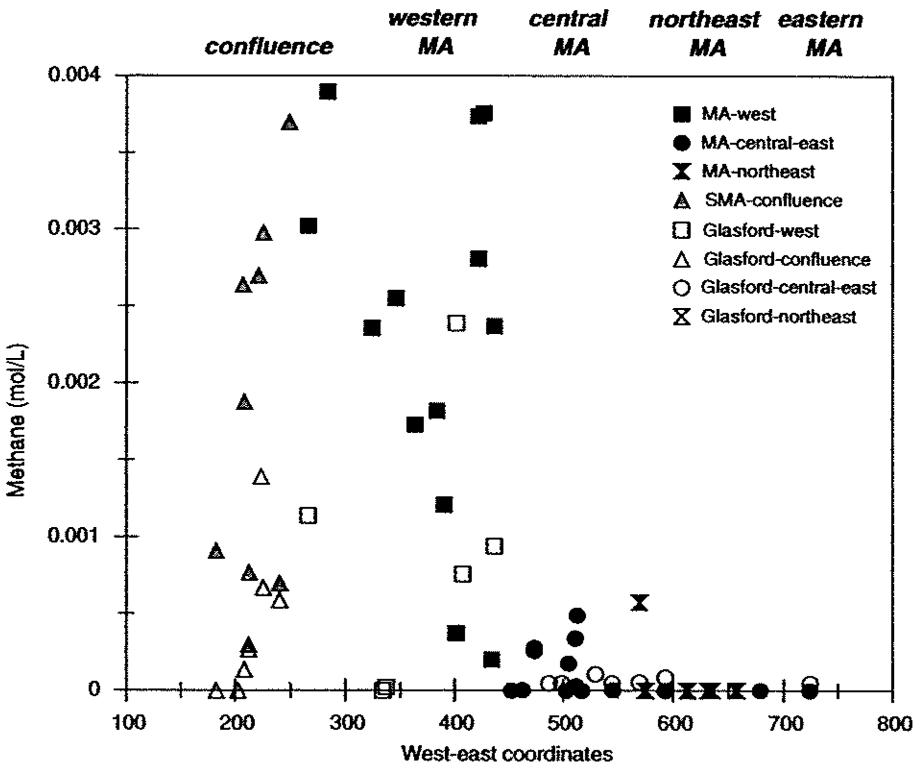
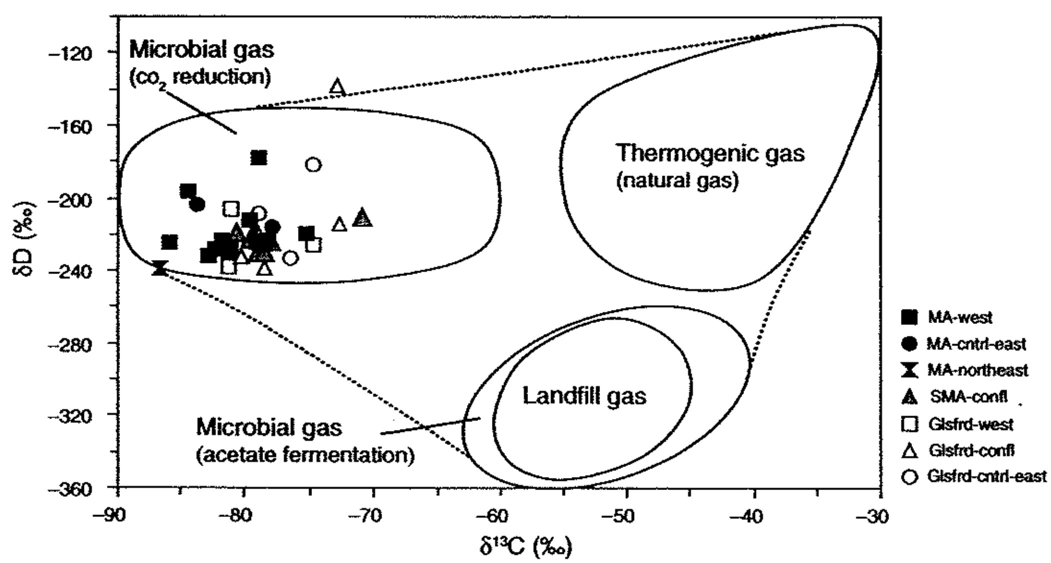


Figure 10. Methane concentration for groundwater samples versus geographic location from west to east in the aquifers of the Mahomet bedrock valley system.

should be more labile compared to the Paleozoic bedrocks; however, the substantial increase in NVOC geographically correlates with the change in bedrock lithology from carbonates to Pennsylvanian shale and coal. As indicated by McMahon and Chapelle (1991), DOC can diffuse into aquifers from surrounding aquitards; thus, the elevated levels of NVOC in the western portion of the Mahomet aquifer are probably due to a combination of influx from the surrounding tills and the organic-rich Pennsylvanian bedrock units. Another consequence of the strongly reducing conditions and minimal SO_4^{2-} concentrations in the western part of the Mahomet aquifer is the elevated concentrations of arsenic (As) observed in this area, which are believed to be due to its mobilization from the reduction of iron oxyhydroxides within the aquifer sands and gravel (Kelly, 2005; Kirk et al., 2004; Warner, 2001; Panno et al., 1994).

The ^{14}C activity and the $\delta^{13}C$ of the DIC in the western region of the Mahomet aquifer are quite different compared to the central region. There is a progressive decrease in ^{14}C westward in the thalweg of the Mahomet bedrock valley toward the confluence area (Fig. 7), and the $\delta^{13}C$ values are more positive (Fig. 8). There are several possible reasons for the lower ^{14}C activity of the DIC in the western portion of the Mahomet aquifer, including: influx of older groundwater from bedrock, CH_4 production, and isolation from surficial recharge. The simplest explanation is that groundwater in this portion of the Mahomet aquifer is more isolated from surficial recharge and simply ages as it slowly moves westward. However, the strong reducing conditions associated with larger DOC concentrations and CH_4 production also help to explain the lower ^{14}C activity. The elevated concentrations of CH_4 suggest there has been excess CO_2 added to the water by fermentation reactions associated with methanogenesis. In the Mahomet aquifer, the microbial reactions associated with methanogenesis would generally add ^{14}C-depleted carbon to the groundwater, increasing the DIC concentration, diluting the ^{14}C content, and altering the $\delta^{13}C$ of the DIC. As observed in other aquifers where methanogenesis occurs (Barker and Fritz, 1981; Grossman et al., 1989; Hackley et al., 1992; Arevena et al., 1995),

Figure 11. δD and $\delta^{13}C$ of CH_4 from groundwater of the Mahomet bedrock valley system. Enclosed areas represent isotopic compositions typically observed for different sources of methane (Whiticar et al., 1986; Coleman et al., 1993; Hackley et al., 1996).



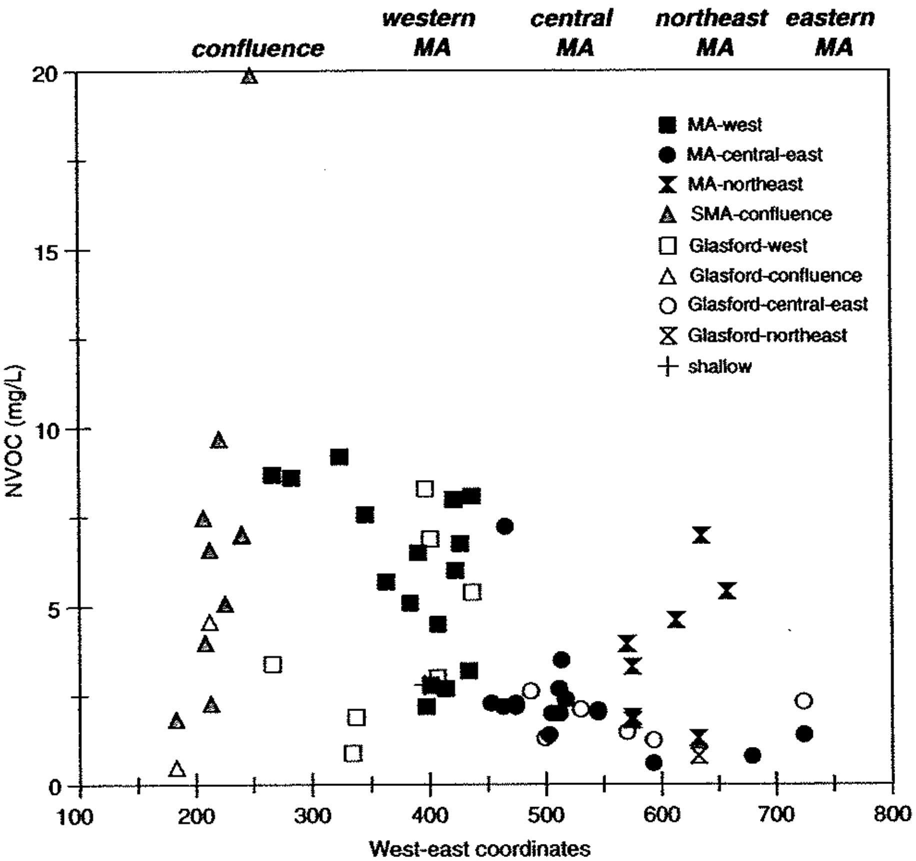


Figure 12. Distribution of dissolved organic carbon (as nonvolatile organic carbon [NVOC]) in Mahomet bedrock valley system.

significantly more positive $\delta^{13}C$ values occur in the western region of the Mahomet aquifer compared to the eastern half of the aquifer (Fig. 8). The increased $\delta^{13}C$ values primarily result from the fractionation effect associated with methanogenesis in which the isotopically light carbon (^{12}C) is preferentially used in the microbial process to produce CH_4, leaving the remaining CO_2 enriched in ^{13}C. Additionally, inputs of CO_2 due to fermentation reactions could also result in dissolution of carbonates, which are relatively enriched in ^{13}C ($\delta^{13}C \sim 0‰$; Anderson and Arthur, 1983). Thus, the carbon isotopic fractionation associated with methanogenesis and the dissolution of carbonates would overwhelm any isotopically light carbon input from the fermentation reactions of organic matter (^{13}C-depleted carbon). It is also possible that the CH_4, or at least some of the CH_4, may be associated with the upwelling saline water from the bedrock units, which would add ^{14}C-depleted and possibly ^{13}C-enriched DIC to the western portion of the Mahomet aquifer, diluting the ^{14}C concentration and increasing the $\delta^{13}C$ values. Unfortunately, we do not have any groundwater samples from bedrock beneath the Mahomet bedrock valley, but a sample collected where the Pennsylvanian bedrock is closer to the surface (112 m), ~40 km to the southeast, contained significant amounts of methane and had a $\delta^{13}C_{DIC}$ value of +25‰.

Although methanogenesis and the influx of older bedrock water are important, these do not appear to be the only causes for the progressive decrease in ^{14}C observed in the western Mahomet aquifer system. Sample KRK-99 has a high concentration of CH_4 but a $^{14}C_{DIC}$ value that is only a few pMC less than those samples up-gradient just to the east (WRD-55 and CHM-95D). As previously discussed, there is also evidence that the area near KRK-99 may be close to stacked sands, as indicated by the cross section in Figure 13, and/or a groundwater window where recharge from the surface is more open compared to wells sampled toward the east and western parts of the Mahomet aquifer. Thus, isolation from surficial recharge and natural radioactive decay must also contribute to the progressive decrease in $^{14}C_{DIC}$ activity in the western part of the Mahomet aquifer.

Confluence and Sankoty-Mahomet Region

Within the Sankoty Mahomet aquifer, the chemistry becomes more dilute, specific conductivity decreases (Fig. DR1 [see footnote 1]), Cl^- concentration decreases (Fig. 6), CH_4 concentration decreases (Fig. 10), and the ^{14}C values increase sharply (Fig. 7) compared to the up-gradient western part of the Mahomet aquifer. These trends suggest that there is significant flux of younger freshwater into the Sankoty Mahomet aquifer in the confluence area. This fits well with the decreased amount of glacial till covering the sands in this region (Herzog et al., 1995). The samples containing the highest Cl^- and CH_4 concentrations and lowest ^{14}C activities in the confluence area tend to follow a groundwater divide that has an east-west trend within this area (Fig. 4). The groundwater chemistry becomes more dilute and has greater ^{14}C activity as the water flows to the south and north away from the groundwater divide and around a bedrock high toward the Illinois River. The rather rapid change in geochemistry is strong evidence that there is substantial recharge from the surficial units to the Sankoty Mahomet aquifer in the confluence area compared to the rest of the Mahomet aquifer. For example, the correlation coefficient between Cl^- and two other constituents in the Sankoty Mahomet aquifer that had relatively high concentrations in the western Mahomet aquifer, CH_4 and Na^+, was 0.70 and 0.68 respectively. However, the correlation coefficient between Cl^- and $^{14}C_{DIC}$ was only 0.52, suggesting other mechanisms besides dilution have affected the variability of constituents, especially $^{14}C_{DIC}$, in the confluence area.

In addition to mixing, the microbial processes involved with methanogenesis appear to have significantly influenced the groundwater geochemistry of the Sankoty Mahomet aquifer. The $\delta^{13}C$ value of the DIC in the confluence area was rather enriched in the heavier isotope and ranged from –5.7‰ to –1.6‰, with the exception of one sample that was –9.6‰. The more positive $\delta^{13}C$ compositions reflect the influence of microbial CH_4 production. The isotopic composition of the CH_4 is similar to the other samples in the Mahomet aquifer and representative of microbial drift gas (Fig. 11). The concentration of CH_4 in the Sankoty Mahomet aquifer ranged from ~0.9 to 3.7 mmol/L, which is greater than that observed in the shallower Glasford Sand (0.1–0.7 mmol/L). As discussed earlier, fermentation reactions associated with methanogenesis add ^{14}C-depleted CO_2 to the groundwater. The correlation coefficient between the CH_4 concentration and ^{14}C activity of the DIC is 0.90 (Fig. 14). Thus, it appears that there is an additional input of microbial methane

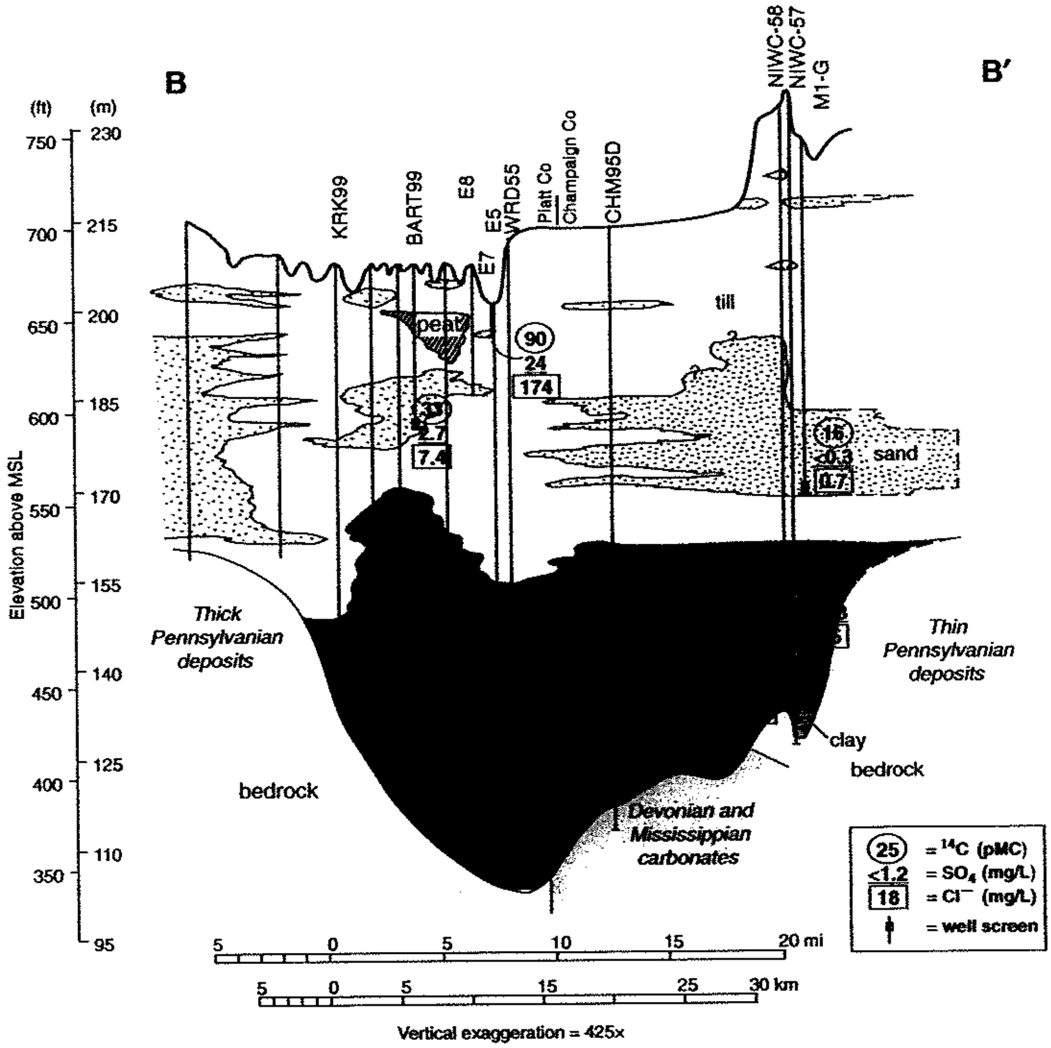


Figure 13. Cross section (B-B′) of the Mahomet bedrock valley including ^{14}C, [SO_4^{2-}], and [Cl^-] data for several wells (modified from Hackley, 2002). Note the lower ^{14}C activities and higher Cl^- concentrations near the sides of the valley, especially on the west side where the bedrock is all Pennsylvanian deposits. MSL—mean sea level.

to the Sankoty Mahomet aquifer in the confluence area. As in the western Mahomet aquifer, strong reducing conditions associated with methanogenesis also affect the arsenic concentrations, which are relatively high in the confluence region (Kelly, 2005; Warner, 2001; Holm, 1995). Thus, although a good deal of the variability in the geochemical composition of the groundwater in the Sankoty Mahomet aquifer is probably due to mixing between groundwater from the western Mahomet aquifer and fresher, young recharging groundwater from the shallower zones, there is also significant influence on the geochemistry due to the methanogenesis processes taking place in this region.

Conceptual Model

Based on the trends in chemistry and isotopic composition throughout the basal aquifers of the Banner Formation and the shallower Glasford Sands, we developed a fundamental conceptual model of groundwater evolution for the Mahomet aquifer and the Sankoty Mahomet aquifer. A plot of the Cl^- concentration and $^{14}C_{DIC}$ activity across the Sankoty Mahomet aquifer and Mahomet aquifer shows the large variations in the data from the confluence area to the easternmost Mahomet aquifer in Illinois (Fig. 15). The arrows and text on the diagrams in Figures 15A and 15B summarize the major influxes of groundwater to the Mahomet aquifer, depicting the overall conceptual model. The chloride concentration is very low in the central part of the Mahomet aquifer, while the ^{14}C activity of the DIC has some of the largest values (excluding the Sankoty Mahomet aquifer in the confluence region). These observations support Panno et al.'s (1994) suggestion that the central area of the Mahomet aquifer is the primary recharge area. This is consistent with historical head data published by Kempton et al. (1991), which showed a potentiometric high in the northern Champaign and southern Ford Counties area. Recent head measurements for the aquifer also indicate potentiometric highs in the area of southern Ford County and near the Illinois-Indiana border, with flow primarily to the south and west (Wilson et al., 1998; Roadcap and Wilson, 2001). The geochemical data are also consistent with the geology, which indicates that the central region has several stacked sand deposits, many of which appear to be connected. The stacked sand deposits may help explain the very low Cl^- concentrations (0.6–2.3 mg/L) observed for much of the central Mahomet aquifer region. Such low Cl^- concentrations suggest that this area was flushed with high volumes of freshwater, perhaps from glacial meltwaters, which leached much of the more soluble minerals from the stacked sand deposits.

The large range of SO_4^{2-} and $\delta^{34}S$ values plus the more negative $\delta^{13}C$ values and low ^{14}C

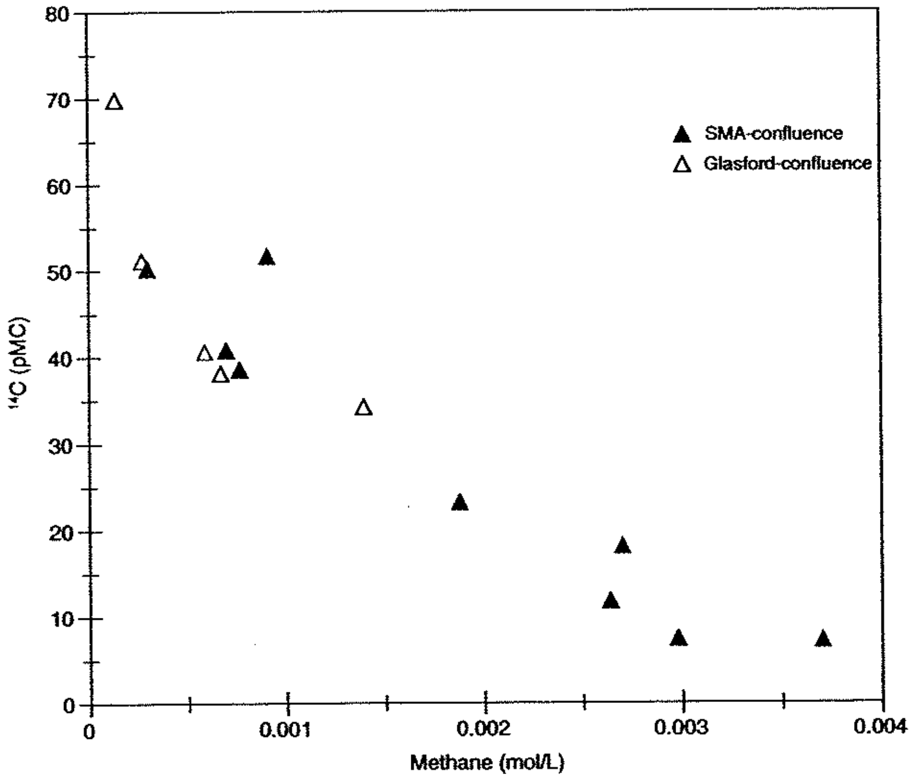


Figure 14. Comparison of ^{14}C and CH_4 concentration in the confluence region; r^2 for the Sankoty Mahomet aquifer data is 0.9.

activities observed in groundwater from samples of the Mahomet aquifer and the Glasford Sand in the northeastern part of the Mahomet bedrock valley indicate a mixture of deeper upwelling groundwater and shallow infiltrating groundwater plus sulfate reduction occurring in parts of the northeastern region of the Mahomet bedrock valley. The mixture of groundwater from bedrock units in the northeastern region appears to extend into northern Vermillion County. The increased Cl^- concentrations and continuous drop in ^{14}C activities observed for the western part of the Mahomet aquifer (Fig. 15) suggest there has been greater isolation from surficial recharge and seepage from bedrock units mixing with the Mahomet aquifer groundwater flowing from the central region westward. The cross sections that cut the Mahomet bedrock valley diagonally (Figs. 13 and 16–17) show the relationships among the shallower aquifers, the deep basal sand aquifer, and the sides of the bedrock valley from where the lithology of the bedrock changes abruptly near the Piatt-Champaign County line to where the bedrock is primarily carbonate in Champaign County. Chloride concentrations and ^{14}C activities are included on the cross sections. The results show an increase in Cl^- and decrease in ^{14}C activity near the sides of the valley, especially close to the Pennsylvanian-age bedrock on the western side of the aquifer (see Fig. 3 for bedrock lithology). This emphasizes the relationship of the Pennsylvanian-age bedrock to the seepage of older more saline groundwater into the western Mahomet aquifer compared to the carbonate bedrock in the central portion of the Mahomet aquifer.

As the groundwater from the Mahomet aquifer flows into the Sankoty Mahomet aquifer, the chemical composition and ^{14}C activity change dramatically. In this confluence area, the geochemical makeup of the groundwater of the basal Pleistocene sands and gravels is strongly influenced by a combination of relatively rapid recharge of younger, more dilute water infiltrating from the surface and the microbial processes associated with methanogenesis.

SUMMARY AND CONCLUSIONS

The chemical and isotopic characteristics of the groundwater in the aquifers of the Mahomet bedrock valley and adjacent confluence area have revealed many important aspects of the groundwater evolution in aquifers that have been created from glacial deposits filling in the topographic undulations of the previous bedrock land surface. The δD and $\delta^{18}O$ values for most of the groundwater in the Mahomet aquifer and the shallower Glasford sands are quite similar to present-day precipitation. These data indicate that there is little to no Pleistocene water remaining in the aquifer system, putting an upper age limit for most of the groundwater at the start of the Holocene, ca. 11,000 yr B.P. The tritium results indicate that there is modern recharge into the Wedron sands and some of the Glasford sands, but very little modern water occurs in the basal sand of the Mahomet bedrock valley. Of the sites sampled, only one area in the Mahomet aquifer near where the Sangamon River crosses the bedrock valley had detectible tritium. These tritium data are consistent with recent seismic and monitoring well drawdown studies by the ISGS and ISWS that have suggested a hydraulic window where groundwater discharges to the Sangamon River when the river is low and groundwater recharges during periods of high stage or excessive groundwater pumping (Roadcap and Wilson, 2001).

The central-eastern region of the Mahomet aquifer contained the highest ^{14}C activity and most dilute groundwater compared to the rest of the Mahomet aquifer, indicating that the groundwater in this region has gone through the least water-rock interaction. These isotopic and geochemical characteristics imply that this region is the area of most rapid recharge for most of the Mahomet aquifer, as proposed by Panno et al. (1994). The very low Cl^- concentrations in the central Mahomet aquifer region suggest that high volumes of freshwater (glacial meltwaters) probably flushed the stacked sand deposits and leached the more soluble minerals so that the present-day groundwater has relatively low dissolved solids concentration.

The chemical and isotopic results for the Mahomet aquifer in the western and northeastern (Onarga Valley) regions indicate that these areas of the aquifer are relatively isolated from surficial recharge and have been significantly influenced by the infiltration of older (low $^{14}C_{DIC}$ activity) groundwater from bedrock units with greater dissolved ion concentrations. The enrichment of SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and B, and Sr^{2+} in the Onarga Valley is probably the result of water-rock interactions with bedrock lithology, including Silurian, Devonian, and Mississippian carbonates and Pennsylvanian cyclothem type deposits (shales, coals, and argillaceous limestones and sandstones). The $\delta^{34}S$ and $\delta^{13}C$ values as well as the SO_4^{2-} and DIC concentrations in and around the Onarga Valley region suggest that groundwater upwelling through bedrock units is dissolving secondary gypsum, precipitating calcite, and mixing with fresher groundwater in the Mahomet and Glasford

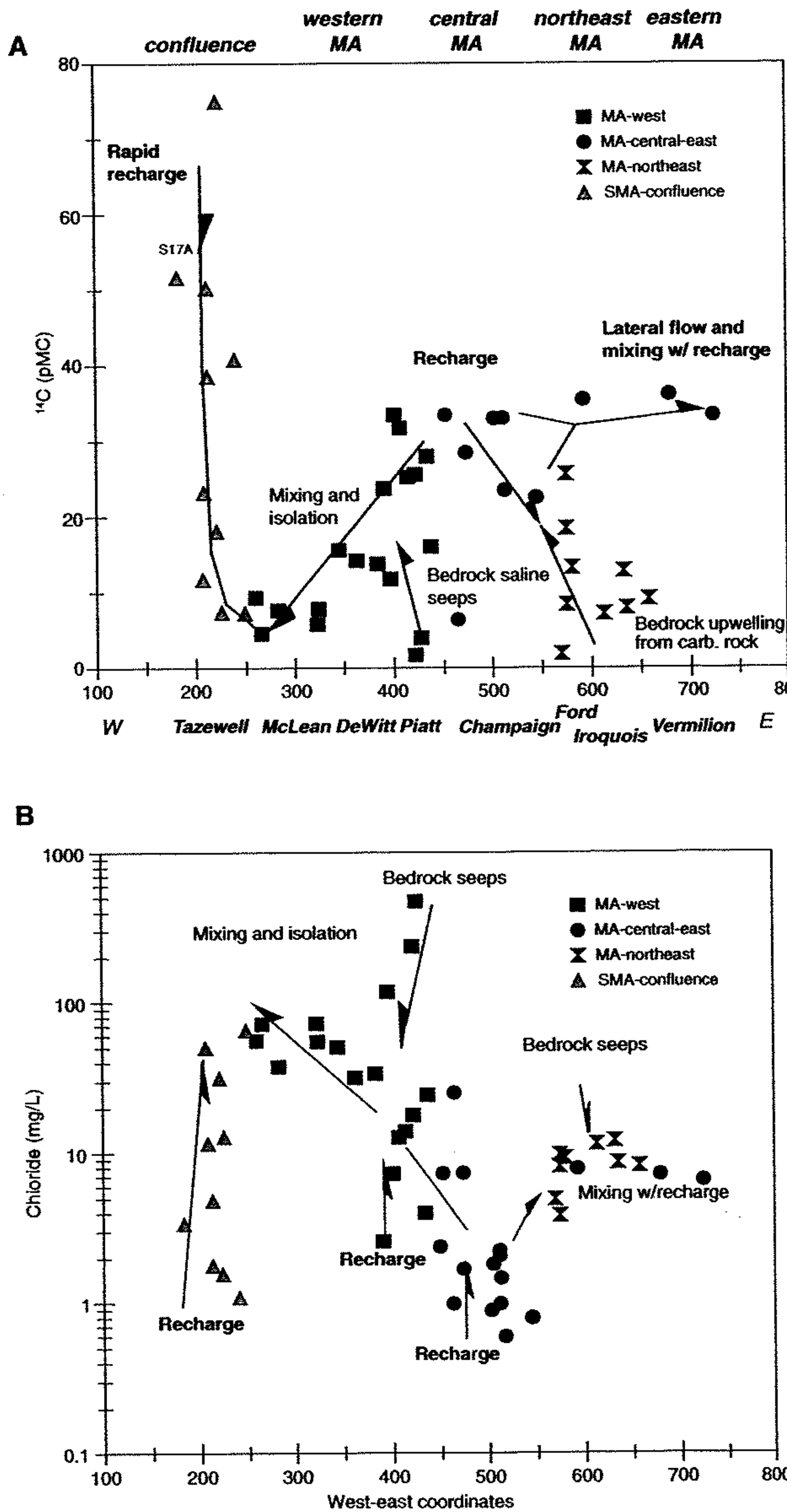


Figure 15. ^{14}C **activity of dissolved inorganic carbon (DIC) (A) and chloride concentration (B) for Mahomet bedrock valley groundwater system and interpretation of data.**

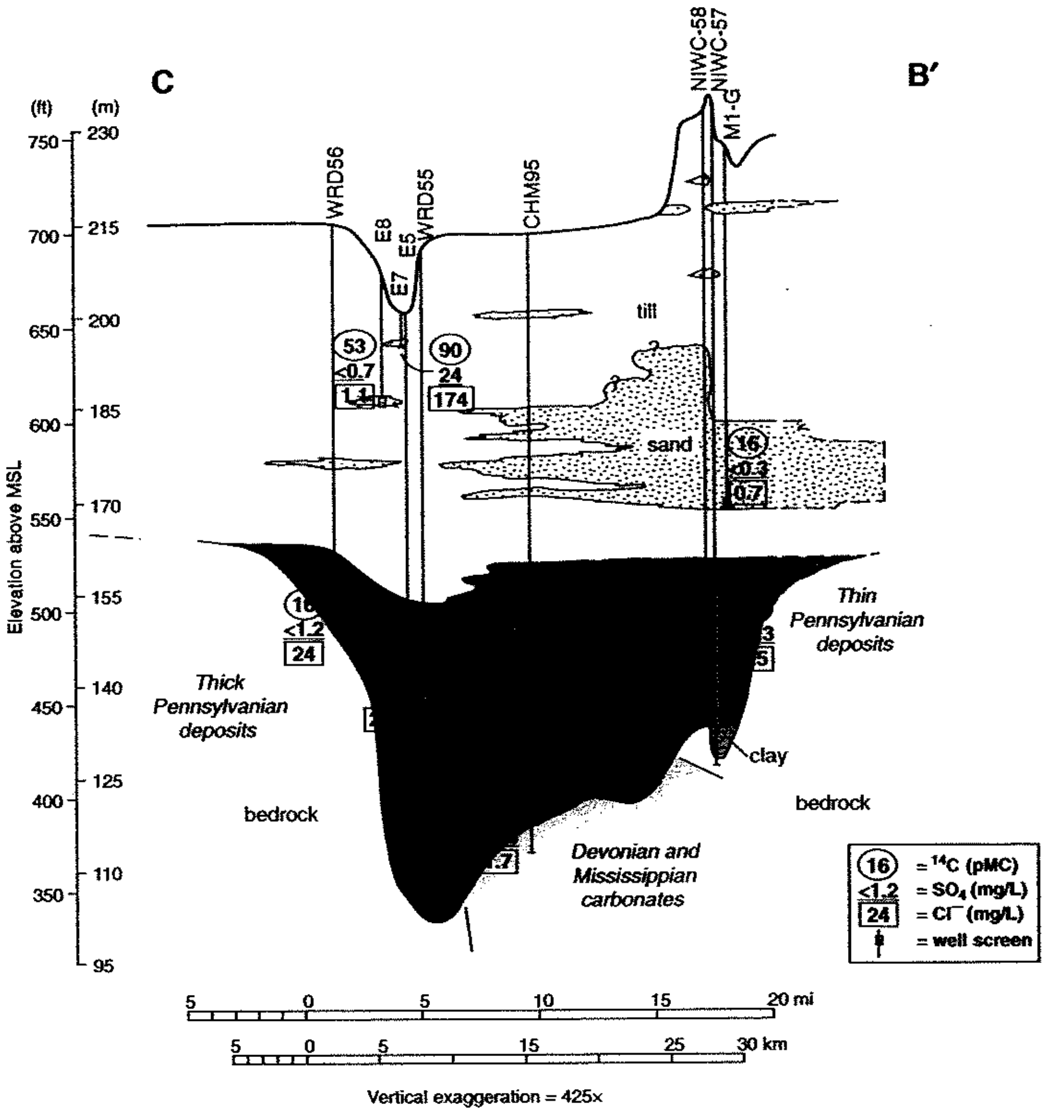


Figure 16. Cross section (C-B′) of the Mahomet bedrock valley including ^{14}C, $[SO_4^{2-}]$, and $[Cl^-]$ data for several wells (modified from Hackley, 2002). Note the lower ^{14}C activities and higher Cl^- concentrations near the western side of the valley, where the bedrock is composed of Pennsylvanian deposits. MSL—mean sea level.

sands. The isotopic data also indicate that SO_4^{2-} reduction and oxidation of organic carbon occur as the groundwater moves up into the Mahomet aquifer and shallower sands. Evidence of mixing between infiltrating groundwater from bedrock in the Onarga Valley and groundwater from the Mahomet and Glasford sands extends into northern Vermillion County. The low ^{14}C activities observed in this area are due to the influx of older groundwater from bedrock units, dissolution of carbonates, and oxidation of organic matter due to SO_4^{2-} reduction.

The western region of the Mahomet aquifer is characterized by higher concentrations of CH_4, DOC, Cl^-, Na^+, and HCO_3^-, greater $\delta^{13}C$ values, and a progressive decrease in $^{14}C_{DIC}$ activities to the west. The isotopic data support the hypothesis that the higher concentrations of chemical constituents (especially Cl^- and Na^+) are primarily explained by the influx of saline groundwater from the Pennsylvanian-age bedrock (Panno et al., 1994). Methane production is undoubtedly a consequence of strong reducing conditions in this part of the aquifer. The relatively high DOC concentrations in the western Mahomet aquifer could also be associated with the influx of deeper groundwater from the Pennsylvanian-age bedrock units or perhaps leaching of organic matter in clastics from these bedrock units and/or diffusion from organic rich Plieistocene deposits. The progressive decrease in $^{14}C_{DIC}$ activity is probably a consequence of several processes: infiltration of older groundwater from bedrock units, methanogenesis, and the dissolution of carbonates in the aquifer, as well as radioactive decay as the water slowly migrates westward. The progressive decrease in ^{14}C and the lack of significant shallow sand deposits above the Mahomet aquifer in the western region imply that this area is fairly isolated from surficial recharge.

The confluence area where the Mahomet aquifer and Sankoty Mahomet aquifer meet shows large variations in ^{14}C activity and chemical constituents, including Cl^- concentrations. This area is significantly influenced by a combination of groundwater mixing between relatively dilute infiltrating surficial water that has high ^{14}C activities and low Cl^- concentrations with older groundwater emerging from the basal sands of the Mahomet aquifer containing a greater amount of dissolved constituents and the microbial processes associated with methanogenesis.

The isotopic and chemical characteristics of groundwater in the basal sands of the Mahomet and Mackinaw bedrock valleys indicate that

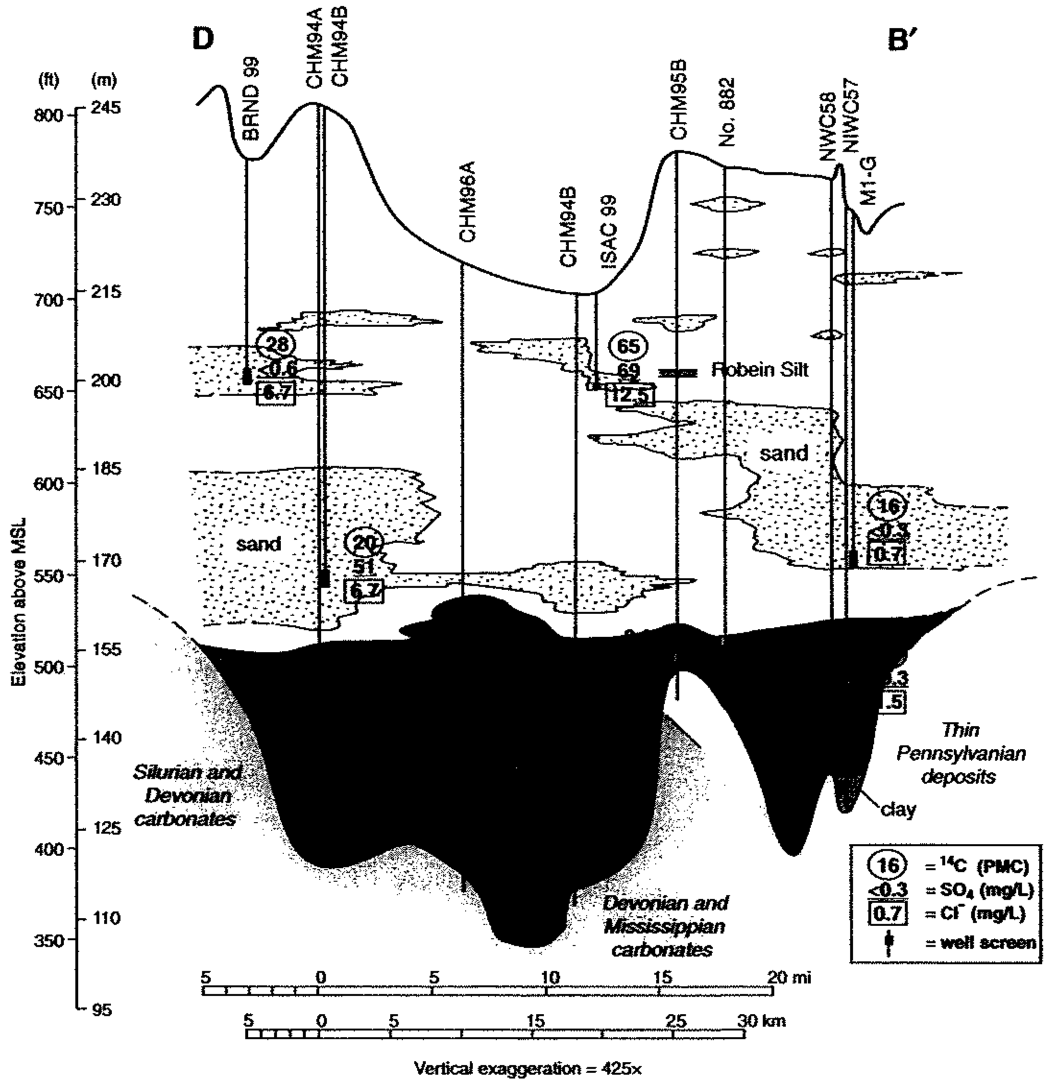


Figure 17. Cross section (D-B′) of the Mahomet bedrock valley including ^{14}C, $[SO_4^{2-}]$, and $[Cl^-]$ data for several wells (modified from Hackley, 2002). Bedrock lithology is primarily carbonates across this part of the valley. Note low Cl^- concentration across Mahomet aquifer. MSL—mean sea level.

this is a complicated geochemical groundwater system. The hydrochemical characteristics appear to be controlled by a combination of bedrock lithology and structure as well as the variability of stacked sands in the Pleistocene deposits above the basal sands in the bedrock valley. Additional information from more detailed studies of the aquifers using geochemical as well as geophysical tools will help to pinpoint hydrologic windows in the aquifer system and quantify the influence of upwelling water from bedrock units. Such data will assist hydrologic modeling for predicting drawdown and future groundwater usage.

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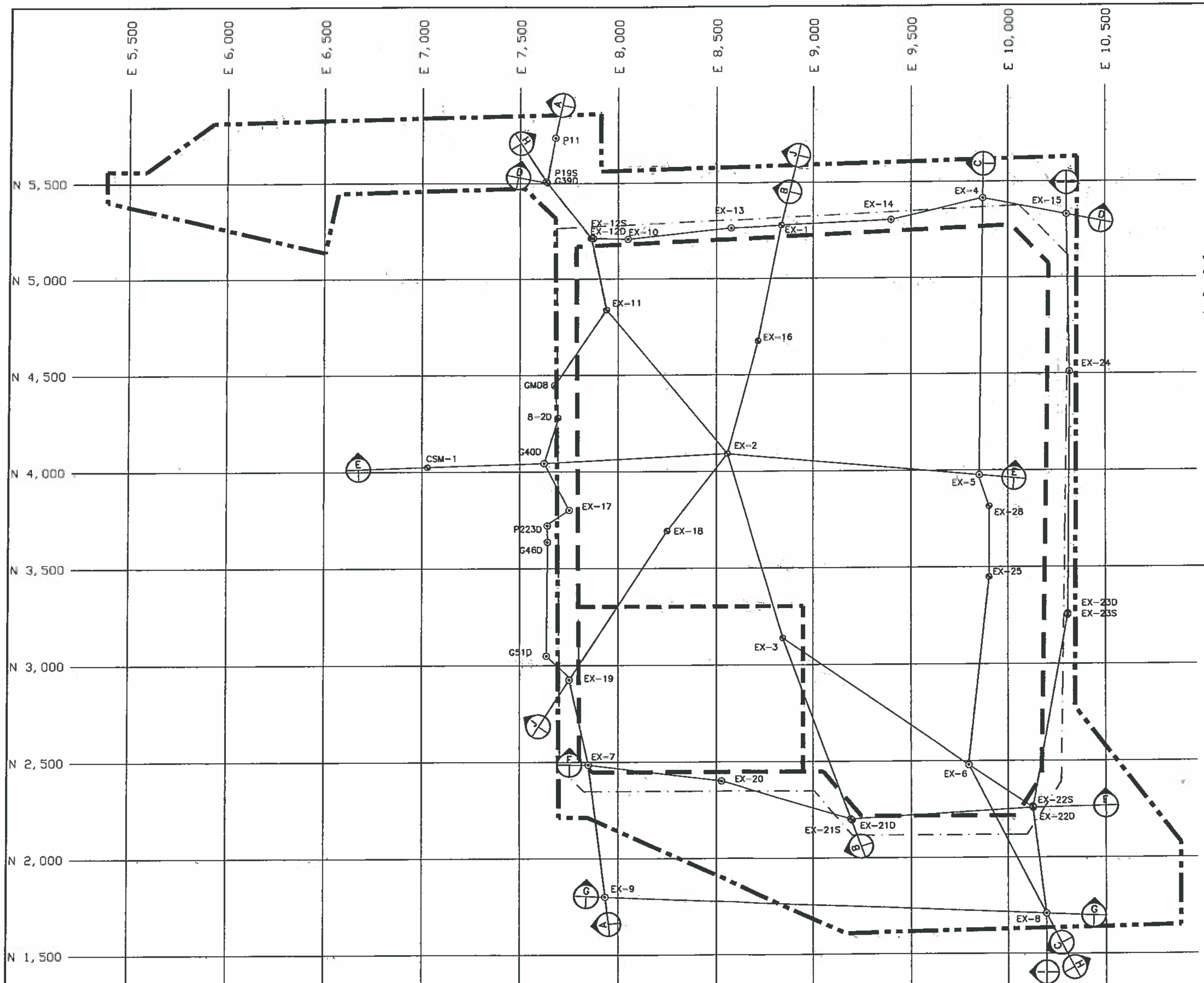
ATTACHMENT 2

Geological Drawings G2 and G3



GRAPHIC SCALE
300' 0 300'

LEGEND

- APPROXIMATE CLINTON LANDFILL NO.3 FACILITY BOUNDARY
- APPROXIMATE EXISTING PERMITTED CLINTON LANDFILL NO.3 WASTE BOUNDARY
- APPROXIMATE CHEMICAL WASTE UNIT BOUNDARY
- ZONE-OF-ATTENUATION
- GEOLOGIC CROSS SECTION MARKER
- EX-14 WELL / PIEZOMETER LOCATION
- EX-18 BORING LOCATION

NOTES

1. DRAWING MODIFIED FROM PDC TECHNICAL SERVICES, INC. DRAWING NO. P-XS1, DATED 2-26-05.

REV. NO.	DATE	DESCRIPTION
2	8-17-07	CROSS SECTION MARKERS HAVE BEEN REVISED TO REMOVE REFERENCES TO OLD DRAWING FILE NAMES.
1	9-17-07	DRAWING HAS BEEN UPDATED TO REFLECT WASTE BOUNDARY OF PROPOSED CHEMICAL WASTE UNITS.

area Clinton Landfill, Inc.

Shaw® Shaw Environmental, Inc.

CLINTON LANDFILL NO. 3 CHEMICAL WASTE UNIT
DEWITT COUNTY, ILLINOIS

PLAN OF SECTIONS FOR SITE GEOLOGIC CROSS SECTIONS

PROJ. NO.:	128017
DESIGNED BY:	MNF
DRAWN BY:	APD
CHECKED BY:	JPV
APPROVED BY:	DJD

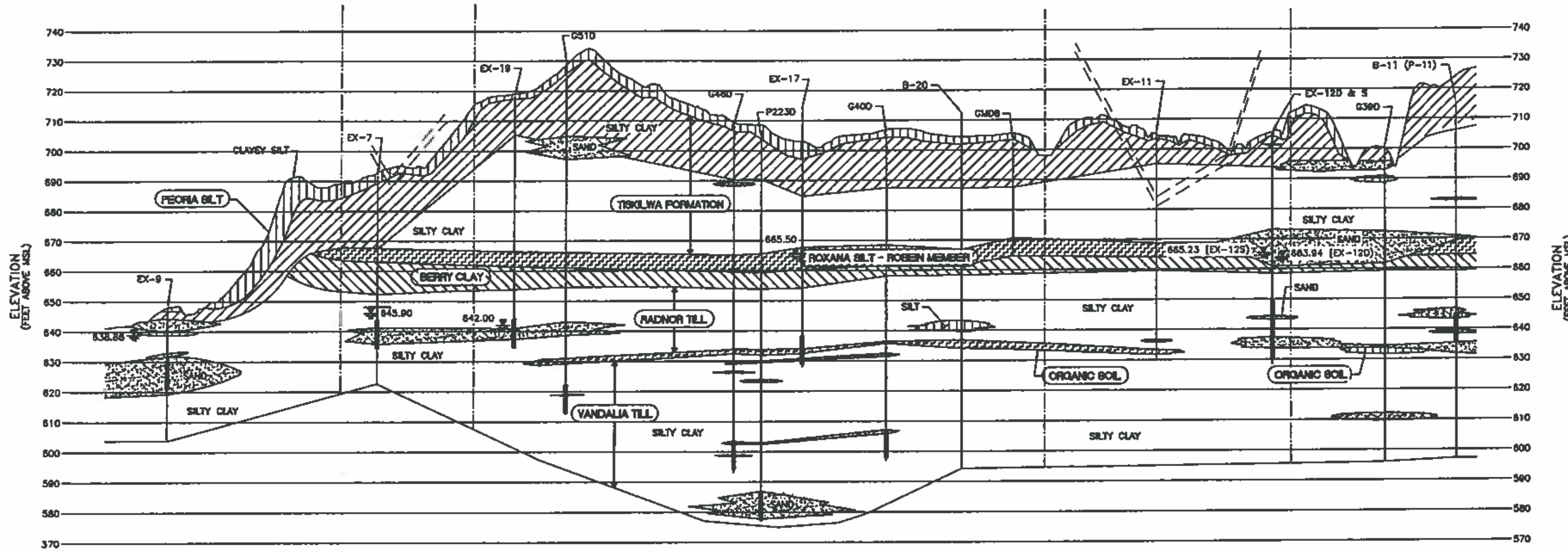
DATE: OCTOBER 2007

DRAWING NO.

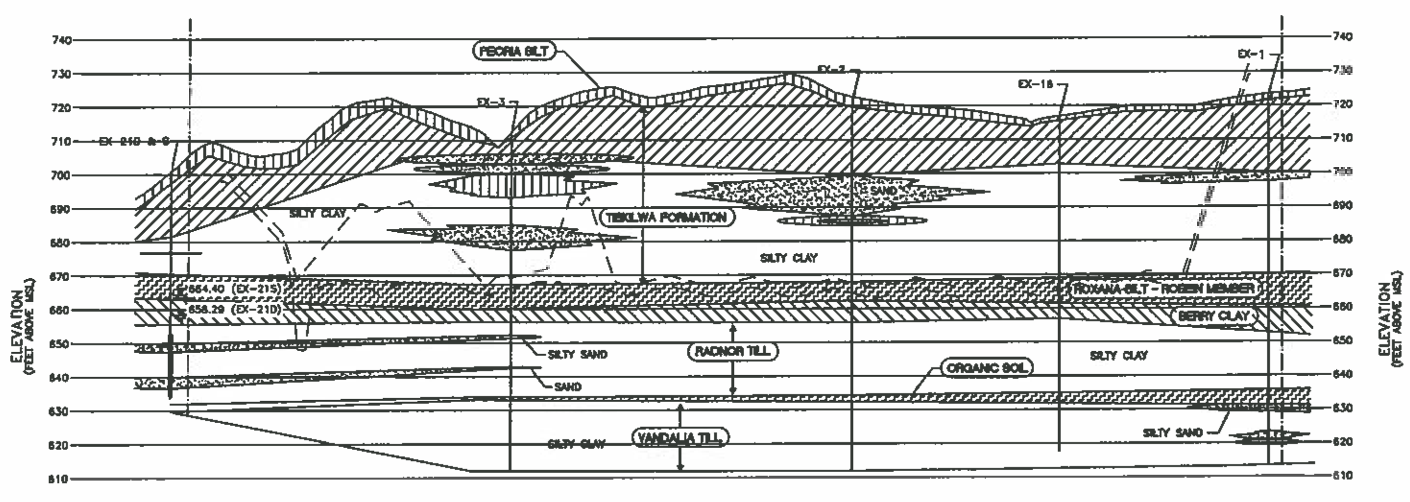
G2

2 OF 21 SHEETS

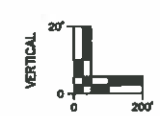
T:\AutoCAD\Projects\128017\dwg\Geologic\Geologic_final\G2.dwg, 8/26/2010 5:31:19 PM



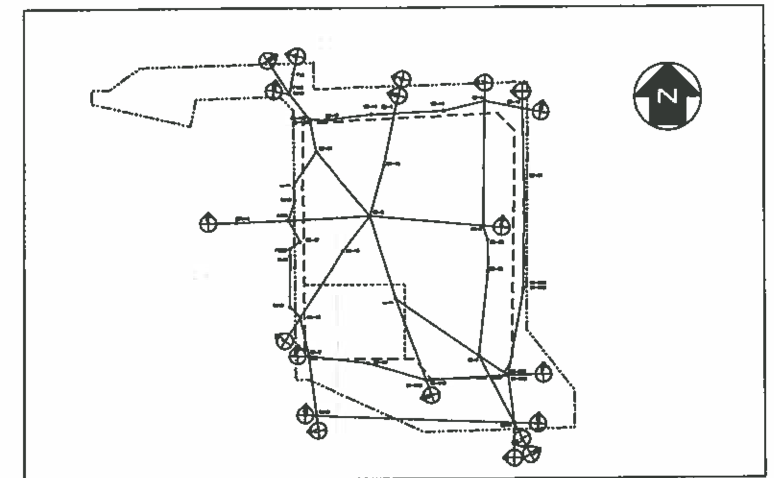
SECTION A
SCALE: 1"=200' HORIZ.
1"=20' VERT.



SECTION B
SCALE: 1"=200' HORIZ.
1"=20' VERT.



GRAPHIC SCALE



KEY MAP
NOT TO SCALE

LEGEND

- APPROXIMATE CLINTON LANDFILL NO. 3 FACILITY BOUNDARY
- APPROXIMATE EXISTING PERMITTED CLINTON LANDFILL NO. 3 WASTE BOUNDARY
- APPROXIMATE CHEMICAL WASTE UNIT BOUNDARY
- EX-2 — BORIND/WELL DESIGNATION
- EXISTIND WELL/PIEZOMETER
- SCREENED INTERVAL
- BOTTOM OF BORING
- POTENTIOMETRIC ELEVATION (NOVEMBER, 2004)
- BROWN SILTY CLAY
- GRAY CLAY WITH VARYING MINOR AMOUNTS OF SILT AND/OR SAND
- BROWN AND/OR GRAY SAND WITH GRAVEL
- GRAY SILY/CLAYEY SILT
- GRAY SANDY SILY/SILTY SAND
- GRAY CLAYEY SAND
- PEAY/ORGANIC SILT
- BLUE CLAY
- PROPOSED TOP AND BOTTOM OF LANDFILL LINER SYSTEM
- ZONE-OF-ATTENUATION

NOTES

1. DRAWING MODIFIED FROM PDC TECHNICAL SERVICES, INC. DRAWING NO. P-XS2, DATED 2-25-05.
2. EXISTING GRADE SHOWN BASED ON AERIAL PHOTO TAKEN MARCH 30, 1999.
3. GEOLOGIC SECTIONS PRESENTED HEREIN ARE BASED ON BORING INFORMATION AND VISUAL OBSERVATIONS, ACTUAL CONDITIONS MAY VARY.
4. 4TH QUARTER 2004 DATA MEASURED ON 11-16-04.

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REV. NO.	DATE	DESCRIPTION
3	8-17-07	MASS EXCAVATION GRADES HAVE BEEN REVISED TO REFLECT PROPOSED CHEMICAL WASTE UNITS.
2	8-17-07	CROSS SECTION MARKERS HAVE BEEN REVISED TO REMOVE REFERENCES TO OLD DRAWING FILE NAMES.
1	8-17-07	DRAWING HAS BEEN UPDATED TO REFLECT WASTE BOUNDARY OF PROPOSED CHEMICAL WASTE UNITS.

area Clinton Landfill, Inc.

Shaw Shaw Environmental, Inc.

CLINTON LANDFILL NO. 3 CHEMICAL WASTE UNIT
DEWITT COUNTY, ILLINOIS

GEOLOGIC CROSS SECTIONS A & B

PROJ. NO.:	128017
DESIGNED BY:	MNF
DRAWN BY:	APD
CHECKED BY:	JPV
APPROVED BY:	DJD
DATE:	OCTOBER 2007
DRAWING NO.	G3

3 OF 21 SHEETS

ATTACHMENT 3

Groundwater Impact Assessment Input Parameter Tables

Shaw

TABLE 812.316-4
INPUT VALUES FOR MODEL - UPPER RADNOR TILL SAND
Clinton Landfill No. 3

	POLLUTE V6.2 Input	Values	Units	
File Information	Baseline Model Input File:	LKWB.IN		
	Baseline Output File:	LKWB.OU		
	Initial Source Concentration	1	mg/l	
	Number of Layers	2		
	Lower Boundary Condition	Infinite		
	Top Boundary	Constant Source		
LAYER 1 Compacted Clay Input Parameters	Hydrodynamic Dispersion Coefficient	1.58E-02	m^2/a	DIFFUSION = 0.0158 m^2/YR.
	Effective Porosity	0.3		
	Density	1.9	g/cm^3	
	Thickness	6.096	m	
	Number of Sublayers	4		
	Vertical Darcy Velocity (Flux)	3.515E-03	m/a	← OUTWARD
LAYER 2 Aquifer Input Parameters	Hydrodynamic Dispersion Coefficient	1.598	m^2/a	
	Effective Porosity	0.35		
	Density	1.9	g/cm^3	
	Thickness	60.96	m	
	Number of Sublayers	13		
	Vertical Darcy Velocity (Flux)	3.515E-03	m/a	← OUTWARD
Times & Distances	Times for Simulation	5, 10, 15, ..., 145	a	
	Vertical Distance (total)	67.056	m	
[In]tegration [P]arameters	Laplace Transform	7, 20, 0, 2		

Notes:

1) m = meters
2) mg/l = milligrams per liter
3) m^2/a = meters squared per year
4) m/a = meters per year
5) cm^3/g = centimeters cubed per gram
6) cm/g^3 = centimeters per cubic gram
7) a = year

TABLE 812.316-5
INPUT VALUES FOR MODEL - LOWER RADNOR TILL SAND
Clinton Landfill No. 3

	MIGRATE V.9 Input	Values	Units	
File Information	Baseline Input File:	LRB.IN		
	Baseline Output File:	LRB.OU		
Landfill Parameters	Width of Landfill Base	929.15	m	
	Base Width	787.54	m	
	Landfill is treated as a	Surface Boundary Condition		
	Initial Source Concentration	1	mg/l	
	Number of Layers	5		
	Lower Boundary Condition	Impermeable		
	Change in Source Concentration	Constant Source		
LAYER 1 (Synthetic Liner) Input Parameters	Vertical Dispersion Coefficient	0.00003	m^2/a	DIFFUSION = 0.00003 m^2/YR
	Effective Porosity	1.0		
	Adsorption Coefficient	0	cm^3/g	
	Density	1.9	g/cm^3	
	Thickness	0.001524 (or 60 mil)	m	
	Number of Sublayers	1		
	Horizontal Dispersion Coefficient	0.00003	m^2/a	
	Horizontal Darcy Velocity	0	m/a	
	Vertical Darcy Velocity	3.515E-03	m/a	OUTWARD
LAYER 2 Clay Liner Input Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a	DIFFUSION = 0.0158 m^2/YR
	Effective Porosity	0.288		
	Adsorption Coefficient	0	cm^3/g	
	Density	1.9	g/cm^3	
	Thickness	0.9144	m	
	Number of Sublayers	3		
	Horizontal Dispersion Coefficient	0.0158	m^2/a	
	Horizontal Darcy Velocity	0	m/a	
	Vertical Darcy Velocity	3.515E-03	m/a	OUTWARD
LAYER 3 Clay Fill Input Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a	DIFFUSION = 0.0158 m^2/YR
	Effective Porosity	0.288		
	Adsorption Coefficient	0	cm^3/g	
	Density	1.9	g/cm^3	
	Thickness	0.2939	m	
	Number of Sublayers	3		
	Horizontal Dispersion Coefficient	0.0158	m^2/a	
	Horizontal Darcy Velocity	0	m/a	
	Vertical Darcy Velocity	3.515E-03	m/a	
LAYER 4 Silty Clay Input Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a	DIFFUSION = 0.0158 m^2/YR
	Effective Porosity	0.286		
	Adsorption Coefficient	0	cm^3/g	
	Density	1.9	g/cm^3	
	Thickness	6.537	m	
	Number of Sublayers	3		
	Horizontal Dispersion Coefficient	0.0158	m^2/a	
	Horizontal Darcy Velocity	0	m/a	
	Vertical Darcy Velocity	3.515E-03	m/a	

TABLE 812.316-5
INPUT VALUES FOR MODEL - LOWER RADNOR TILL SAND
Clinton Landfill No. 3

	MIGRATE V9 Input	Values	Units
LAYER 5 Aquifer Input Parameters	Vertical Dispersion Coefficient	12.84	m^2/a
	Effective Porosity	0.3	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	0.8543	m
	Number of Sublayers	3	
	Horizontal Dispersion Coefficient	64.08	m^2/a
	Horizontal Darcy Velocity	2.099	m/a
	Vertical Darcy Velocity	0	m/a
Times	Times for Simulation 1	5, 10, 15, ..., 145	a
Distances	Lateral Distances	474.34, 481.96, 489.58, 497.2, 504.82	m
Integration Parameters	Talbot	7, 11, 0, 1	
	Gauss	Normal	

Notes:

1) m = meters
2) mg/l = milligrams per liter
3) m^2/a = meters squared per year
4) m/a = meters per year
5) cm^3/g = centimeters cubed per gram
6) cm/g^3 = centimeters per cubic gram
7) a = year

TABLE 812.316-6
INPUT VALUES FOR MODEL - ORGANIC SOIL
Clinton Landfill No. 3

	MIGRATE V.9 Input	Values	Units
File Information	Baseline Input File:	OSB.IN	
	Baseline Output File:	OSB.OU	
Landfill Parameters	Surface Width	1119.15	m
	Base Width	1041.71	m
	Landfill is treated as a	Surface Boundary Condition	
	Initial Source Concentration	1	mg/l
	Number of Layers	5	
	Lower Boundary Condition	Impermeable	
	Change in Source Concentration	Constant Source	
LAYER 1 (Synthetic Liner) Input Parameters	Vertical Dispersion Coefficient	0.00003	m^2/a
	Effective Porosity	1.0	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	0.001524 (or 60 mil)	m
	Number of Sublayers	1	
	Horizontal Dispersion Coefficient	0.00003	m^2/a
	Horizontal Darcy Velocity	0	m/a
	Vertical Darcy Velocity	3.515E-03	m/a
LAYER 2 Clay Liner ut Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.288	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	0.9144	m
	Number of Sublayers	3	
	Horizontal Dispersion Coefficient	0.0158	m^2/a
	Horizontal Darcy Velocity	0	m/a
	Vertical Darcy Velocity	3.515E-03	m/a
LAYER 3 Clay Fill Input Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.288	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	0.2939	m
	Number of Sublayers	3	
	Horizontal Dispersion Coefficient	0.0158	m^2/a
	Horizontal Darcy Velocity	0	m/a
	Vertical Darcy Velocity	3.515E-03	m/a
LAYER 4 Silty Clay Input Parameters	Vertical Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.286	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	6.573	m
	Number of Sublayers	3	
	Horizontal Dispersion Coefficient	0.0158	m^2/a
	Horizontal Darcy Velocity	0	m/a
	Vertical Darcy Velocity	3.515E-03	m/a

DIFFUSION = 0.00003 m^2/YR.

OUTWARD

DIFFUSION = 0.0158 m^2/YR.

OUTWARD

DIFFUSION = 0.0159 m^2/YR.

OUTWARD

DIFFUSION = 0.0159 m^2/YR

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TABLE 812.316-6
INPUT VALUES FOR MODEL - ORGANIC SOIL
Clinton Landfill No. 3

	MIGRATE V.9 Input	Values	Units
LAYER 5 Aquifer Input Parameters	Vertical Dispersion Coefficient	0.526	m^2/a
	Effective Porosity	0.4	
	Adsorption Coefficient	0	cm^3/g
	Density	1.9	g/cm^3
	Thickness	1.042	m
	Number of Sublayers	3	
	Horizontal Dispersion Coefficient	2.505	m^2/a
	Horizontal Darcy Velocity	0.1018	m/a
	Vertical Darcy Velocity	0	m/a
TimesDistances	Times for Simulation 1	5, 10, 15, ..., 145	a
Distances	Lateral Distances	559.57, 567.19, 574.81, 582.43, 590.05	m
Integration	Talbot	7, 11, 0, 1	
Parameters	Gauss	Normal	

Notes:

1) m = meters
2) mg/l = milligrams per liter
3) m^2/a = meters squared per year
4) m/a = meters per year
5) cm^3/g = centimeters cubed per gram
6) cm/g^3 = centimeters per cubic gram
7) a = year

TABLE 812.316-7

INPUT VALUES FOR MODEL - MAHOMET SAND

Clinton Landfill No. 3

	Pollute V 6.2 Input	Values	Units
File Information	Baseline Input File:	MB.IN	
	Baseline Output File:	MB.OU	
	Initial Source Concentration	1	mg/l
	Number of Layers	9	
	Lower Boundary Condition	Infinite	
	Top Boundary	Constant Source	
	Vertical Darcy Velocity (Flux)	3.515E-03	m/a
LAYER 1 (Synthetic Liner) Input Parameters	Hydrodynamic Dispersion Coefficient	0.00003	m^2/a
	Effective Porosity	1.0	
	Density	1.9	g/cm^3
	Thickness	0.001524 (or 60 mil)	m
	Number of Sublayers	1	
LAYER 2 Clay Liner Input Parameters	Hydrodynamic Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.288	
	Density	1.9	g/cm^3
	Thickness	0.9144	m
	Number of Sublayers	1	
LAYER 3 Clay Fill Input Parameters	Hydrodynamic Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.288	
	Density	1.9	g/cm^3
	Thickness	0.2939	m
	Number of Sublayers	1	
LAYER 4 Silty Clay Input Parameters	Hydrodynamic Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.286	
	Density	1.9	g/cm^3
	Thickness	6.573	m
	Number of Sublayers	2	
LAYER 5 Lower Radnor Till Sand Input Parameters	Hydrodynamic Dispersion Coefficient	12.84	m^2/a
	Effective Porosity	0.3	
	Density	1.9	g/cm^3
	Thickness	0.8543	m
	Number of Sublayers	2	
LAYER 6 Radnor Till Input Parameters	Hydrodynamic Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.286	
	Density	1.9	g/cm^3
	Thickness	0.9906	m
	Number of Sublayers	2	
LAYER 7 Organic Soil Input Parameters	Hydrodynamic Dispersion Coefficient	0.526	m^2/a
	Effective Porosity	0.4	
	Density	1.9	g/cm^3
	Thickness	1.042	m
	Number of Sublayers	2	

OUTWARD

DIFFUSION = 0.00003 m^2/YR

DIFFUSION = 0.0158 m^2/YR

DIFFUSION = 0.0158 m^2/YR

DIFFUSION = 0.0158 m^2/YR

DIFFUSION = 0.0158 m^2/m

TABLE 812.316-7
INPUT VALUES FOR MODEL - MAHOMET SAND
Clinton Landfill No. 3

LAYER 8 Vandalia Till Input Parameters	Hydrodynamic Dispersion Coefficient	0.0158	m^2/a
	Effective Porosity	0.286	
	Density	1.9	g/cm^3
	Thickness	15.24	m
	Number of Sublayers	3	
	Vertical Darcy Velocity (Flux)	3.515E-03	m^2/a
LAYER 9 Mahomet Sand Aquifer Input Parameters	Hydrodynamic Dispersion Coefficient	0.0315	m^2/a
	Effective Porosity	0.3	
	Density	1.9	g/cm^3
	Thickness	30.48	m
	Number of Sublayers	3	
Times	Times for Simulation	5, 10, 15, ..., 145	a
Distances	Vertical Distance (total)	56.393	m
Integration Parameters	Laplace Transform	7, 20, 0, 2	

DIFFUSION = 0.0158 m²/YR

Notes:

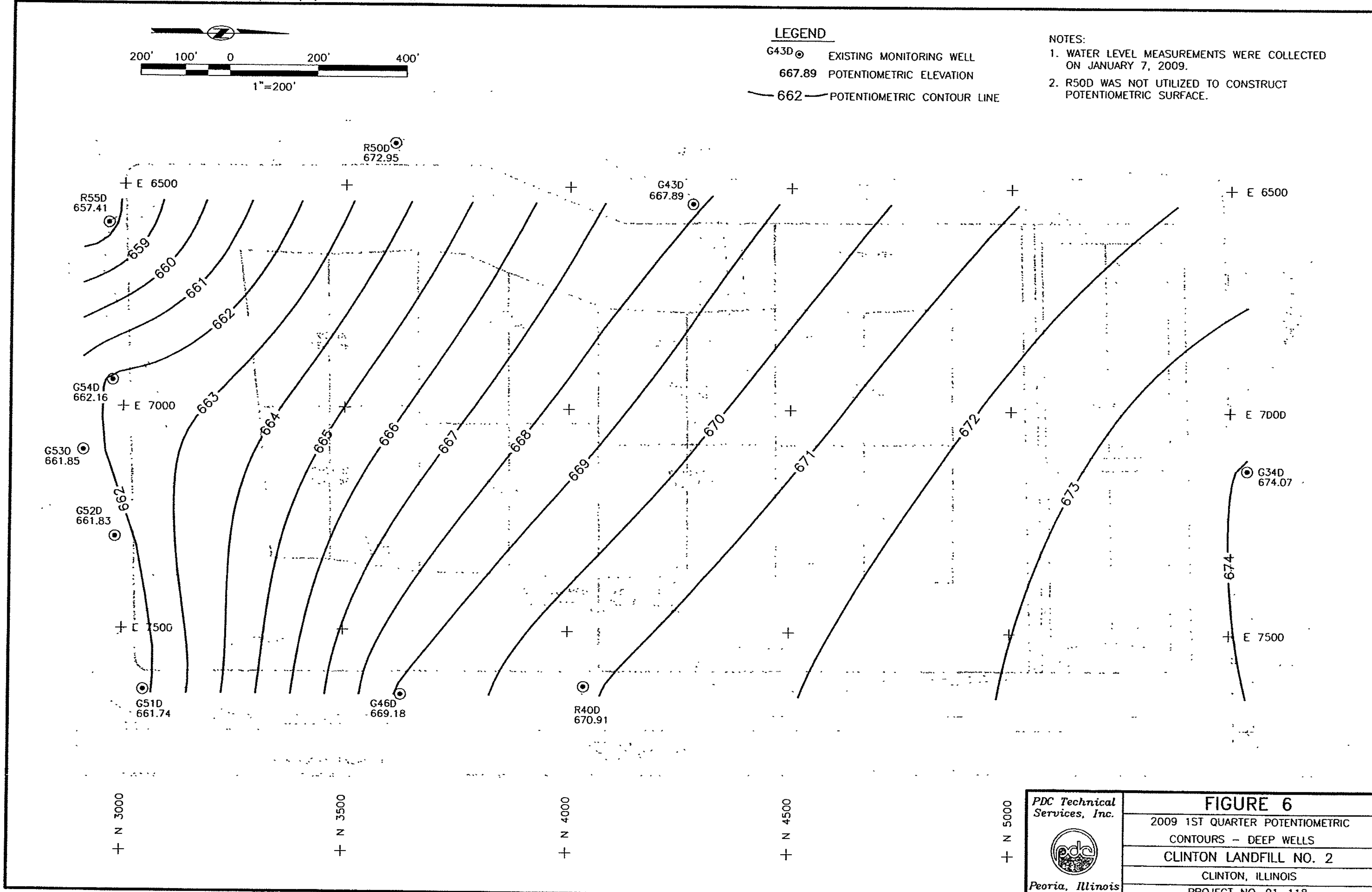
1) m = meters
2) mg/l = milligrams per liter
3) m^2/a = meters squared per year
4) m/a = meters per year
5) cm^3/g = centimeters cubed per gram
6) cm/g^3 = centimeters per cubic gram
7) a = year

ATTACHMENT 4

Clinton Landfill No. 2
2009 Potentiometric Maps
(Deep Wells)

Shaw

CAD DWG NO:911181601 EMPLOYEE NO: 90220 DATE/TIME: 06/21/10 11:43:00 ACAD-16



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CAD DWG NO:911181602 EMPLOYEE NO. 90220 DATE/TIME: 06/21/10 14:17 ACAD 16.

LEGEND

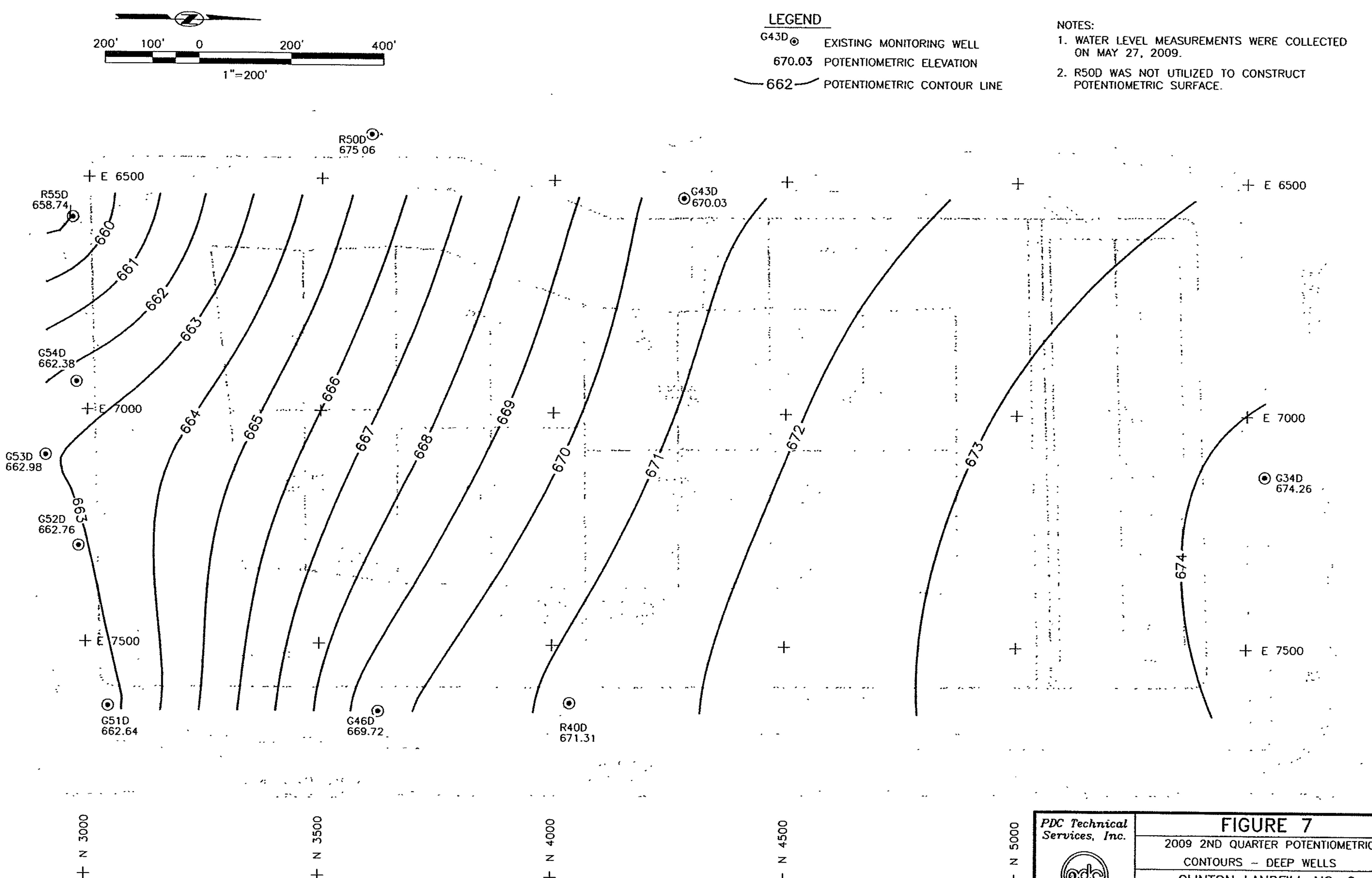
G43D ⊙ EXISTING MONITORING WELL

670.03 POTENTIOMETRIC ELEVATION

—662— POTENTIOMETRIC CONTOUR LINE

NOTES:

1. WATER LEVEL MEASUREMENTS WERE COLLECTED ON MAY 27, 2009.
2. R50D WAS NOT UTILIZED TO CONSTRUCT POTENTIOMETRIC SURFACE.



PDC Technical Services, Inc.
Peoria, Illinois

FIGURE 7

2009 2ND QUARTER POTENTIOMETRIC CONTOURS – DEEP WELLS

CLINTON LANDFILL NO. 2

CLINTON, ILLINOIS

PROJECT NO. 91-118

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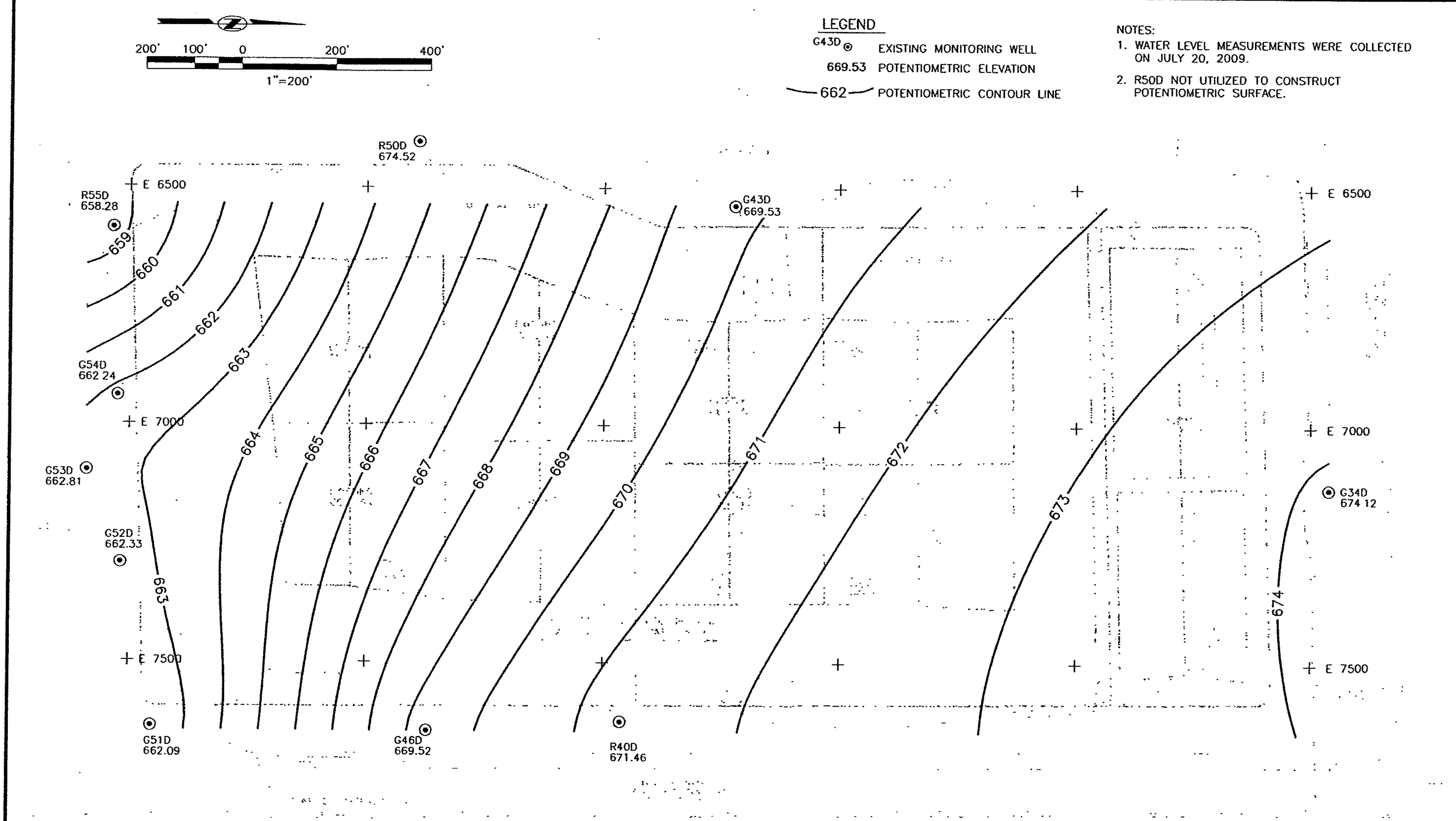


NOTES:

1. WATER LEVEL MEASUREMENTS WERE COLLECTED ON JULY 20, 2009.
2. R50D NOT UTILIZED TO CONSTRUCT POTENTIOMETRIC SURFACE.

PDC Technical Services, Inc.

Peoria, Illinois

FIGURE 8

2009 3RD QUARTER POTENTIOMETRIC CONTOURS – DEEP WELLS

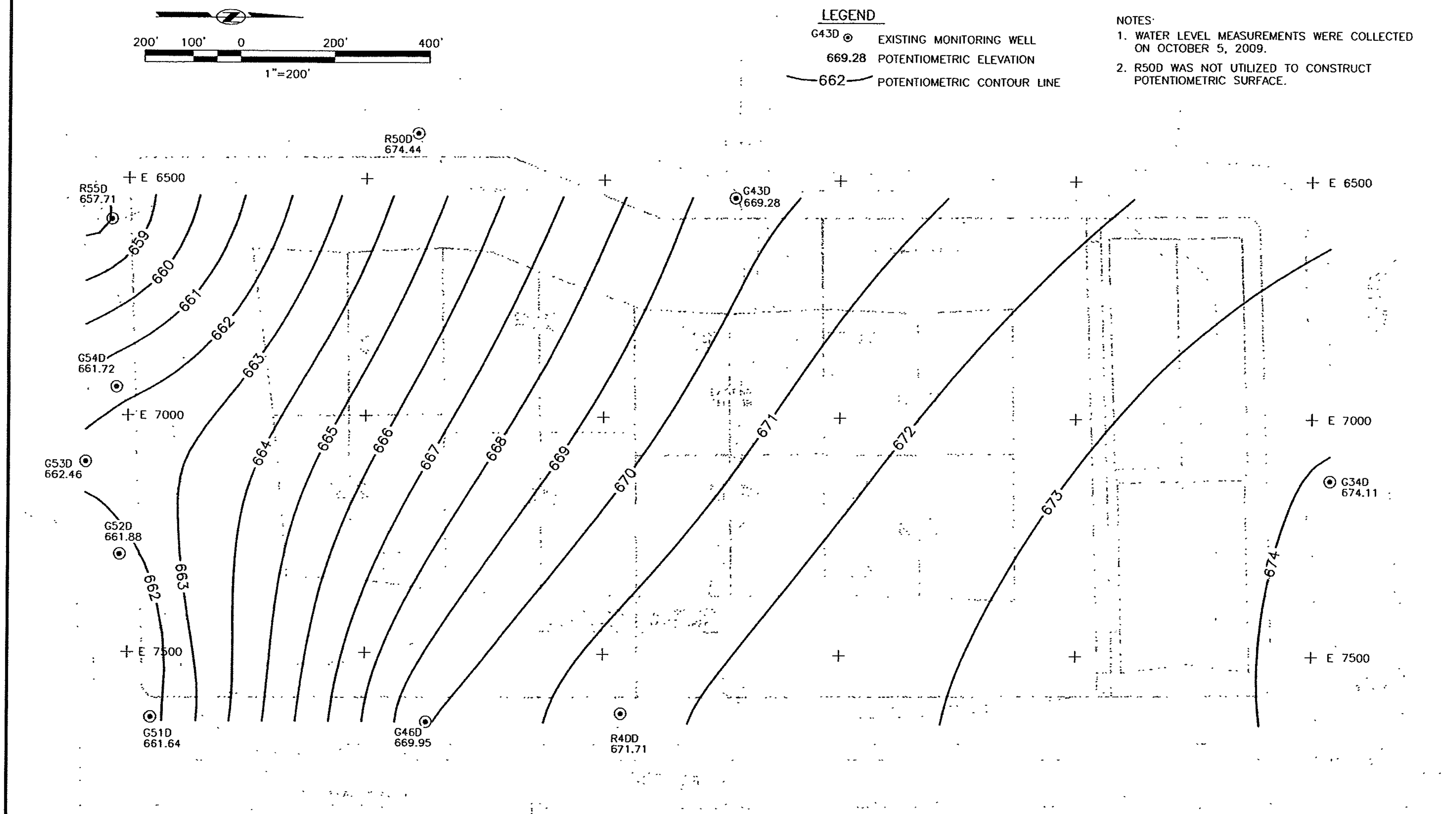
CLINTON LANDFILL NO. 2

CLINTON, ILLINOIS

PROJECT NO. 91-118

G:\Landfills\91-118 Clinton Landfill\s\Piez. cont\dwg\WELL DATA FILES\Clinton #2\2009\911181603.dwg, Model, 7/7/2010 12:28:13 PM, 11x17, 1:200

CAD DWG NO 911181604 EMPLOYEE NO 90220 DATE/TIME: 06/21/10 15:08 ACAD-16.



NOTES:

1. WATER LEVEL MEASUREMENTS WERE COLLECTED ON OCTOBER 5, 2009.
2. R50D WAS NOT UTILIZED TO CONSTRUCT POTENTIOMETRIC SURFACE.

PDC Technical Services, Inc.

Peoria, Illinois

FIGURE 9

2009 4TH QUARTER POTENTIOMETRIC CONTOURS – DEEP WELLS

CLINTON LANDFILL NO. 2

CLINTON, ILLINOIS

PROJECT NO. 91-118

G:\Landfills\91-118 ....on Landfills\Piez. cont\dwg\WELL DATA FILES\Clinton #2\2009\911181604.dwg, Model, 7/7/2010 12:27:17 PM, 11x17, 1:200

ATTACHMENT 5

Technical Review:
Proposed Chemical Waste Unit
at the Clinton Landfill No. 3
Dewitt County, Illinois

Shaw

Technical Review:

Proposed Chemical Waste Unit at the Clinton Landfill No. 3 Dewitt County, Illinois

By

Craig H. Benson, PhD, PE
Madison, WI 53706

27 September 2009

1. INTRODUCTION

This report describes a technical review of the proposed Chemical Waste Unit (CWU) at Clinton Landfill No. 3 in Dewitt County, Illinois. The proposed CWU would accept non-hazardous industrial wastes, including wastes containing up to 500 ppm of PCBs. Because PCB wastes would be disposed, the proposed CWU must comply with regulations imposed by the Toxic Substances Control Act (TSCA). Additionally, disposal of other non-hazardous industrial wastes requires that the landfill meet the requirements of Subtitle D of the Resource Conservation and Recovery Act (RCRA) and any other regulations specific to Illinois for non-hazardous solid waste disposal.

The review addressed the following issues: (i) whether the proposed CWU complies with TSCA regulations, (ii) whether the proposed containment system will protect the Mahomet Aquifer, (iii) whether the containment system will protect shallow ground water units beneath the proposed CWU, and (iv) the long-term threat to the environment imposed by the proposed CWU and whether the proposed CWU is protective of the public health, welfare, and safety. The review was conducted using the documentation contained within Volumes I-IV of the report entitled "Application to Develop and Operated a Chemical Waste Unit Within the Permitted Clinton Landfill No. 3" as well as the report entitled "Additional Information for the Chemical Waste Unit at the Clinton Landfill No. 3." Both reports were prepared on behalf of Clinton Landfill Inc. by Shaw Environmental of St. Charles, Illinois.

This report consists of six sections, including this introduction (Section 1). Section 2 describes the TSCA regulations relevant to the containment systems for the proposed CWU and an assessment of whether the proposed CWU complies with these regulations [see (i) in preceding paragraph]. Sections 3-5 address each of the other three issues cited in the preceding paragraph. Section 6 provides a conclusion.

2. TSCA AND RCRA REGULATIONS

The technical requirements for a TSCA landfill for disposal of PCBs and PCB Items are contained in Subpart D (Storage and Disposal) as described in 40 CFR 761.75 (Chemical Waste Landfills). These requirements can be segregated into siting requirements, surface and ground water monitoring requirements, liner and leachate collection system requirements, operations requirements, and facilities requirements.

Each of these requirements is described in the following subsections. The final subsection compares the proposed CWU to these requirements.

2.1 TSCA Siting Requirements

The landfill must be sited so that the following conditions are met:

- Siting in a geologic environment consisting of a thick and relatively impermeable clayey formation. If a natural geologic environment with a thick and relatively impermeable clayey layer does not exist, then the landfill should be sited on a soil having the following characteristics:

  - In place soil thickness ≥ 4 ft or compacted soil liner thickness ≥ 3 ft.
  - Hydraulic conductivity less than 10^{-7} cm/s.
  - Percent fines at least 30%.
  - Liquid limit at least 30 and plasticity index at least 15.

- Base of landfill shall be at least 50 ft above historic high ground water table.

- Ground water recharge areas should be avoided.

- Floodplains should be avoided. Structures for diversion shall be provided if the landfill is within the 100-yr flood plain. Otherwise, diversion structures shall divert runoff from at 24-hr 25-yr storm.

- The landfill area shall have low to moderate relief to minimize erosion and ensure stability.

2.2 Surface and Ground Water Monitoring

The surface and ground water monitoring programs must satisfy the following:

- Surface and ground water monitoring shall be conducted in adjacent water bearing units. Monitoring systems and programs must include:

  - Sampling of surface and ground waters prior to commencing landfill operations.
  - Designated surface water courses shall be sampled monthly during operations.
  - Designated surface water courses shall be sampled semi-annually after closure.
  - For relatively impermeable subsurface conditions, three ground water monitoring wells shall be provided that are equi-spaced along the predominant axis of ground water flow.
  - Water samples will be analyzed for PCBs, pH, specific conductance, and chlorinated organics.

2.3 Liner and Leachate Collection Systems

The landfill liner and leachate collection system must satisfy the following:

- Synthetic membrane liners shall be used if the hydrologic or geological conditions require such a liner to provide a hydraulic conductivity at least equivalent to the clayey layers cited in Section 2.1. The synthetic liner must be at least 30-mil thick and be chemically compatible with PCBs.

- Leachate collection/monitoring system shall be installed and monitored monthly for quantity and chemical characteristics of the leachate. The leachate collection system can be one of the following three systems:

  - Gravity flow drain field placed directly above the liner.
  - Gravity flow drain field and additional liner placed directly above the liner.
  - Suction lysimeter network.

2.4 Operations

The following operations conditions must be met:

- An operations plan shall be developed that describes operational issues, record keeping, surface water management, and waste burial information.

- Items shall be placed in the landfill in a manner that will prevent damage to containers or articles containing PCB items.

- Wastes incompatible with PCBs and PCB items shall be segregated from PCBs.

- If the facility accepts liquid PCB wastes, the operations plan shall include procedures to stabilize the liquid to a non-flowing form and determine if the concentration is less than 500 ppm.

- Ignitable wastes shall not be disposed in the landfill.

2.5 Supporting Facilities

The following supporting facilities and operations must be satisfied:

- A 6-foot barrier (wall, fence, etc.) shall be place around the facility to present unauthorized persons and animals from entering.

- Roads shall be maintained that are adequate to support operations and maintenance without safety or nuisance problems or hazardous conditions.

- The site shall be operated in a manner that prevents safety problems associated with spilled liquids or windblown materials.

2.6 Assessment of Proposed CWU at Clinton Landfill No. 3

The proposed CWU was compared to the technical requirements in TSCA that are described in 40 CFR 761.75. A summary of the elements that were compared is shown in Table 1. This comparison showed that the proposed CWU meets or exceeds TSCA technical requirements in all cases. A summary of the comparison follows.

Siting. The proposed CWU will be constructed in a geological environment consisting primarily of thick fine-grained soil layers that will greatly restrict movement of contaminants that might emanate from the CWU. Separation between the base of the CWU and the Mahomet aquifer greatly exceeds the required 50 ft minimum separation, and the location is not within an Illinois regulated recharge area or the 100 yr flood plain. The topography of the area has modest to low relief, which will minimize erosion and promote stability.

Ground Water and Surface Water Monitoring. An extensive monitoring network is planned that exceeds the requirements in TSCA. This system, coupled with the existing network for the other units on site, will provide adequate monitoring. The monitoring well design standards planned for the site are consistent with Illinois requirements, which exceed those stipulated in 40 CFR 761.75(b). Sampling of the wells will occur on regular intervals and will include all constituents required in 40 CFR 761.75(b). Surface runoff will be sampled and analyzed in a manner consistent with 40 CFR 761.75.

Liner and Leachate Collection Systems. Given the thick fine-grained layers beneath the proposed CWU, an engineered liner system is not required according to 40 CFR 761.75(b). Nevertheless, a highly redundant engineered liner system is proposed that consists of three geomembranes (synthetic liners), a geosynthetic clay liner, a compacted clay liner, and an internal drainage layer. This highly redundant system, combined with the favorable geological environment, will effectively control migration of contaminants from the proposed CWU. Field tests conducted on site as well as tests and analyses conducted on similar soil by the Illinois State Geological Survey and the University of Illinois at Urbana-Champaign have shown that the soil used for the compacted clay liner can be compacted to low hydraulic conductivity (< 10^{-7} cm/s) and is an excellent barrier to contaminant transport. A leachate collection system is also included that meets the criteria for both the 'simple leachate collection system' and 'compound leachate collection system' described in 40 CFR 761.75(b).

Operations. An operations plan has been proposed that deals with the management and recordkeeping issues stipulated in 40 CFR 761.75(b). This plan also stipulates methods for waste placement, segregation, stabilization, and monitoring of PCB concentrations that are consistent with 40 CFR 761.75(b).

Supporting Facilities. The proposed CWU includes provisions for security via fencing, installation and maintenance of roads to ensure safe access, and training to ensure the safety of personnel and others at the facility.

RCRA Compliance. The containment system for the proposed CWU has the same or more robust engineering features than the adjacent municipal solid waste (MSW) landfill that has been permitted under Illinois rules, which supersede those stipulated in RCRA. Thus, the proposed CWU meets RCRA criteria as well as TSCA criteria.

3. PROTECTION OF THE MAHOMET AQUIFER

The Mahomet Aquifer is an outwash aquifer consisting of sands and gravels up to 150 ft thick that rest on top of shale and sandstone bedrock. Ground water in this aquifer is a water supply for the region and is the primary water source for the City of Clinton, IL and nearby Weldon Springs. Because this regional aquifer is an important water supply, protecting the aquifer from contamination is a necessity to protect the health, safety, and welfare of the public.

Long-term protection of the Mahomet Aquifer is provided naturally by the overlying fine-grained soils in the Berry Clay and the Radnor Till. The silt and clay fractions of these units and the stress imposed by the overlying overburden render these natural units nearly impermeable, with hydraulic conductivities in the low 10^{-8} and 10^{-9} cm/s range. Under such conditions, chemical diffusion becomes the predominant mechanism for contaminant transport, which is ideal in terms of protecting underlying ground water. When diffusion controls contaminant transport, the rate at which contaminants move and their flux into surrounding units is at a minimum.

The liner system for the proposed CWU will provide additional redundant protection above and beyond that provided naturally by the Berry Clay and the Radnor Till. The liner system is more extensive than normally required at modern MSW landfills, and includes internal redundancy exceeding that required for US hazardous waste landfills. The base of the liner consists of a composite barrier comprised of 3 ft of compacted clay overlain by a 60-mil geomembrane. A similar barrier system is commonly used for MSW landfills in the US. The composite liner is overlain with a geocomposite drainage layer, and then a three-layer sandwich consisting of a second geomembrane, a geosynthetic clay liner (GCL), and third geomembrane. In addition, the geocomposite drainage layer located between the upper three-layer liner sandwich and the lower composite liner will provide a means to evaluate the efficacy of the lining systems during landfill operation and after closure.

Two ground water impact analyses (GIA) were conducted to evaluate the potential for contamination of ground water resources by contaminants released from the landfill. The first GIA was conducted as part of the application for the adjacent MSW landfill rather than specifically for the CWU. Consequently, the simulations considered only a single composite liner (geomembrane over compacted clay liner) employed for the MSW landfill rather than the highly redundant multiple liner for the proposed CWU. This simplification added another level of conservatism to the GIA when applied to the proposed CWU. The second GIA focused specifically on transport of PCBs from the CWU.

The first GIA consisted of a computer simulation to predict contaminant transport through the landfill liner and the underlying geological formations. The simulation assumed that lateral transport in more permeable strata between the base of the landfill and the Mahomet Aquifer was negligible (e.g., all contaminants were directed downward to the Mahomet Aquifer). The analysis also assumed that sorption was negligible. As a result, the GIA was a conservative analysis (i.e., predicted higher concentrations than would actually occur). The analysis showed that drinking water quality standards would not be exceeded in the Mahomet Aquifer, even for the contaminant with the lowest permissible concentration when the leachate concentration was at the highest concentration theoretically possible (a very unlikely scenario). Accordingly, drinking water quality standards for all other contaminants would not be exceeded. The conclusion from this conservative analysis is equally valid for the MSW landfill and proposed CWU, which will contain industrial waste with modest total contaminant concentrations (e.g., ≤ 500 ppm for PCBs). Moreover, the first GIA is even more conservative when applied to the proposed CWU because of the multiple liner system that will be installed.

The second GIA considered PCB transport through a simplified version of the lining system proposed for the CWU. This simplified lining system consisted solely of 3 ft of compacted clay; the other barriers (geomembranes and GCL) in the proposed liner were not included. The leachate concentration (aqueous concentration) was conservatively assumed to equal the maximum permissible total concentration in the waste (500 ppm), even though leachate data from analogous landfills containing PCBs indicated that leachate (aqueous) concentrations are either very low (low ppb) or undetectable. The leachate concentration was assumed to remain constant throughout the analysis and sorption onto the organic carbon fraction was accounted for using conventional methods. The model predictions showed that the PCBs were extremely immobile, and never migrated through the entire thickness of the liner over a 1000-year period despite the very conservative assumptions used in the analysis. In fact, concentrations even 1 ft into liner were predicted to be orders of magnitude below detectable levels.

Both of these very conservative analyses illustrated that the liner design for the proposed CWU will be protective of the Mahomet Aquifer.

4. PROTECTION OF SHALLOW GROUND WATER UNITS

Hydrogeological investigations conducted for the proposed CWU and other disposal units at Clinton Landfill No. 3 identified three shallow ground water units between the base of the landfill and the Mahomet Aquifer: the Upper Radnor Till Sand, the Lower Radnor Till Sand, and the Organic Soil. These units are thin and moderately permeable. None of these units is used as a major source of drinking water in the region.

The first GIA (for the adjacent MSW landfill and reviewed in Section 3 of this report) evaluated whether ground water in these shallow units would be impacted by contaminants released by the landfill. The simulation for the Upper Radnor Till Sand assumed that leachate would be released directly to the sand beneath the landfill. Simulations for the Lower Radnor Till Sand and the Organic Soil were similar to those conducted for the Mahomet Aquifer. In all analyses, sorption to solids and lateral transport in ground water units above the unit in question were ignored. As a result, the analyses were conservative.

These analyses showed that the design proposed for the MSW landfill units is protective of the Upper Radnor Till Sand, the Lower Radnor Till Sand, and the Organic Soil (i.e., concentrations of contaminants were below applicable ground water quality standards). Because the proposed CWU will employ a more protective liner system and will contain industrial wastes with modest concentrations, the conclusions from the GIA for the MSW landfill pertaining to the shallow ground water units are valid for the proposed CWU. That is, the proposed CWU will be protective of the shallow ground water units.

A similar conclusion can be drawn from the second GIA conducted specifically for PCB transport from the CWU. Despite the conservative assumptions that were employed in the analysis, PCBs did not migrate through the liner over a 1000-year period. Thus, contamination of the shallow ground water units will not occur

5. LONG-TERM THREAT TO THE ENVIRONMENT AND PROTECTION OF PUBLIC HEALTH, WELFARE, AND SAFETY

PCBs in the industrial waste to be contained in the proposed CWU will persist for a very long time. Consequently, the proposed CWU will be a potential long-term threat to the environment. However, the proposed CWU has been designed with several features that mitigate this threat and ensure protection of public health, welfare, and safety. These features include:

- siting on thick fine-grained geologic strata,
- a multiple layer liner employing three geomembranes, a geosynthetic clay liner, a compacted clay liner, and two levels of leachate collection and removal,
- waste monitoring and placement procedures to ensure that concentrations in the waste are below maximum permissible limits and that the waste is placed in a manner that ensures protection and long-term stability of the containment system,
- filling and build out geometry that will ensure physical stability during operation and after closure,
- capping with a final cover with a composite barrier layer and lateral drainage layer that will limit percolation into the waste and consequent leachate generation after closure,

- a detailed construction quality assurance plan to ensure that all elements of the proposed CWU are constructed to specification,
- monitoring of shallow ground water units to provide an early detection system for potential contamination of the Mahomet Aquifer, which serves as a major source of drinking water for local communities,
- monitoring of storm water runoff and air quality,
- fencing to prevent humans and animals from intruding on the site,
- a perpetual post closure monitoring and care program to ensure that the containment and monitoring systems continue to function so long as the proposed CWU poses a potential risk to the environment, and
- financial assurance to ensure closure and post-closure monitoring/care of the landfill in perpetuity.

Contamination of ground water is the most significant potential threat posed by the proposed CWU. This threat is negligible, as both GIAs illustrate that ground water beneath the proposed CWU will be protected despite the use of very conservative assumptions in the analysis. This level of containment is possible because of the redundancy afforded by the multiple liner system, the secure geological environment, and the relative immobility of PCBs in a matrix of soil and sediment such as that anticipated in the proposed CWU.

Adequate protection of ground water will depend in part on the liner system remaining intact during operation and after closure of the proposed CWU. This is a very likely scenario, as the materials selected for the liner system are the most durable materials currently available for containment of wastes, especially when deployed in multiple layers in an environment with elevated stress that is nearly anoxic. The drainage layer within the liner will also serve as a long-term sentinel of liner failure and excessive discharge of contaminants. Thus, if a liner failure occurs, the failure would be detected rapidly, permitting corrective action before a significant impact occurs to the surrounding environment.

6. CONCLUSION

This review addressed whether the proposed CWU complies with TSCA and RCRA regulations and ensures protection of the Mahomet Aquifer and shallow ground water units beneath the proposed CWU. The review also provided a qualitative assessment of the long-term threat to the environment and public health, welfare, and safety imposed by the proposed CWU. The following conclusions are formed based on the review:

- the proposed CWU complies with and exceeds the technical requirements in TSCA for disposal facilities,

- the geological setting, the redundant multiple liner system for the proposed CWU, and the final cover ensure isolation of the waste and protection of the Mahomet Aquifer and shallow ground water units beneath the proposed CWU,

- the design of the containment system, the construction quality assurance program, and the monitoring plan for leachate, ground water, surface water, and air will mitigate threats to the environment, and

- the perpetual post-closure care and monitoring program will ensure that the threats to the environment are properly managed so long as the waste remains a potential risk, thereby ensuring protection of the public health, welfare, and safety.

Table 1. Proposed CWU design and operation relative to TSCA requirements.

Requirement	Regulatory Evaluation	Comments
Siting		
Geological environment	Satisfied	Landfill and major water supply aquifer separated by approximately 170 ft of fine-grained soils
50 ft. ground water separation	Satisfied	> 50 ft separation from Mahomet aquifer, which is primary water source in area. < 50 ft separation for Upper and Lower Radnor sands and for Organic Soil, but these are local ground water units and not water supply
Ground water recharge	Satisfied	Not located above sole source aquifer or regulated recharge area
Flood plains	Satisfied	Outside 100 yr flood plain, and approved storm water plan
Topography	Satisfied	Location in central IL has modest to low relief
Surface and Ground Water Monitoring		
Pre-operations	Satisfied	Site is already operating adjacent disposal units that monitoring surrounding ground water and surface water. Ground water monitoring designed specifically for CWU.
Designated water courses	Satisfied	There are no known designated surface water courses at this time. Surface runoff will be sampled and analyzed at storage basin.
Ground water monitoring wells	Satisfied	The proposed ground water monitoring system greatly exceeds the required three-well network. The network includes 6 wells immediately down gradient of the CWU.
Water analysis	Satisfied	Monitoring well network will be sampled quarterly for pH, specific conductance, and PCBs and annually for SVOCs and VOCs, including (but not limited to) chlorinated compounds.
Liner and Leachate Collection Systems		
Synthetic liner	Satisfied	Because unit is located on thick fine-grained soils, a synthetic liner is not needed. However, CWU includes three synthetic liners, a geosynthetic clay liner, and a compacted soil liner.
Leachate collection system	Satisfied	Proposed system meets the criteria stipulated in 40 CFR 761.75(b).
Leachate monitoring	Satisfied	Leachate samples will be collected and analyzed monthly for pH, specific conductance, PCBs, SVOCs, and VOCs

Table 1. Proposed CWU design and operation relative to TSCA requirements (con't.).

Requirement	CWU Satisfactory?	Comments
Operations		
Operations plan	Satisfied	An operations plan is proposed that addresses each of the issues in 40 CFR 761.75(b)
Placement methods	Satisfied	The waste placement plan indicates PCB wastes will be placed in a manner that prevents damage to containers or PCB Items.
Waste segregation	Satisfied	The waste placement plan indicates PCB wastes will be segregated from other incompatible wastes.
PCB concentration monitoring	Satisfied	Acceptance testing limits PCB concentration to < 500 ppm.
Liquid PCB stabilization	Satisfied	A solidification program near the active face has been proposed. Liquid wastes to be solidified must have PCB concentration < 500 ppm.
Supporting Facilities		
Barrier/fence	Satisfied	The facility is fenced. The Inspection and Maintenance Plan ensures that the fence is maintained.
Roads	Satisfied	The Inspection and Maintenance Plan ensures that the roads are maintained for safe access.
Safe operations	Satisfied	The Personal Training and Hazard Prevention programs provide for safe operations.

ATTACHMENT 6

Resume for Dr. Craig Benson

Shaw

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EDUCATION

BSCE, Lehigh University - 1985
MSE, University of Texas at Austin – 1987 (Civil Engineering, Geotechnical/Geoenvironmental)
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REGISTRATION

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ACADEMIC EXPERIENCE

Wisconsin Distinguished Professor, University of Wisconsin, Madison, Wisconsin, July 2007 to present.

Chairman, Geological Engineering, University of Wisconsin, Madison, Wisconsin, July 2007 to July 2008, August 2009-present.

Director, Recycled Materials Resource Center, University of Wisconsin, Madison, Wisconsin, August 2007-present.

Chairman, Dept. of Civil & Environmental Engineering, University of Washington, Seattle, Washington, July 1, 2008 to July 31, 2009.

A.H. Fuller Chair in Civil and Environmental Engineering, University of Washington, Seattle, Washington, July 1, 2008 to July 31, 2009.

Associate Chairman for Environmental Science and Engineering, Dept. of Civil & Environmental Engineering, University of Wisconsin, Madison, Wisconsin, July 2004 to June 2007.

Professor, University of Wisconsin, Madison, Wisconsin, February 2000 to June 2007.

Associate Professor, University of Wisconsin, Madison, Wisconsin, May 1995 to January 2000.

Assistant Professor, University of Wisconsin, Madison, Wisconsin, January 1990 to May 1995.

HONORS AND AWARDS

Research

Diplomate, Geotechnical Engineering, Academy of Geo-Professionals, 2009
Academy of Distinguished Alumni, University of Texas at Austin, 2009
Croes Medal, American Society of Civil Engineers, 2008
Alfred P. Noble Prize, American Society of Civil Engineers, 2008
IJOG Excellent Paper Award, Intl. Assoc. Computer Methods & Advances in Geomechanics, 2008
Second Paper Award, Global Waste Management Symposium, 2008
Third Paper Award, Global Waste Management Symposium, 2008
Kellet Mid-Career Research Award, University of Wisconsin, 2005
Walter L. Huber Civil Engineering Research Award, ASCE, 2000
Croes Medal, American Society of Civil Engineers, 1998
Casagrande Award, American Society of Civil Engineers, 1995
Middlebrooks Award, American Society of Civil Engineers, 1995
Collingwood Prize, American Society of Civil Engineers, 1994
Distinguished Young Faculty Award, U.S. Department of Energy, 1991
Presidential Young Investigator, National Science Foundation, 1991

Teaching

Polygon Outstanding Instructor Award, College of Engr., Univ. of Wisconsin, 1991, 93, 97
Outstanding Professor Award, ASCE Wisconsin Student Chapter, 1992
Top 100 Educators Award, Wisconsin Students Association, Univ. of Wisconsin, 1991

Academics

John A. Focht Endowed Presidential Scholarship in Civil Engr., Univ. of Texas at Austin, 1988
Dawson Endowed Presidential Scholarship in Civil Engr., Univ. of Texas at Austin, 1986
Engineering Foundation Fellowship, University of Texas at Austin, 1985
John B. Carson Prize in Civil Engineering, Lehigh University, 1985
Phi Beta Kappa, Chi Epsilon, and Tau Beta Pi

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SPONSORED RESEARCH

Waste Containment Systems

Coupling Effects of Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers, US Nuclear Regulatory Commission

Predicting the Long-Term Performance of Surface Barriers for LLRW Containment, US Department of Energy, Consortium for Risk Evaluation with Stakeholder Participation

Effectiveness of Engineered Covers: From Modeling to Performance Monitoring, US Nuclear Regulatory Commission

Bentonite-Polymer Nanocomposites for Geoenvironmental Applications, National Science Foundation, with T. Edil and C. Shackelford

Prion Transport in Porous Media: Influence of Electrostatic and Non-DLVO Interactions, National Science Foundation, with J. Pedersen and J. Aiken

Effect of Stress, Hydration, and Ion Exchange on the Hydraulic Conductivity of Geosynthetic Clay Liners, Colloid Environmental Technologies Corporation

Innovative Methods for Natural Restoration of Final Covers for Mill Tailings, US Dept. of Energy, with W. Albright and J. Waugh

Evaluating Long-Term Impacts on Final Covers - Exhumation of the ACAP Test Sections, National Science Foundation, US Environmental Protection Agency, Environmental Research and Education Foundation, with D. Fratta and W. Albright

Toxin/Pathogen Inactivation and Disposal of Intentionally Contaminated Foods, National Center for Food Protection and Defense, US Dept. of Homeland Security, with D. Noguera

Predictive Tools for Sustainable Solid Waste Management Using Bioreactor Landfills, National Science Foundation, with M. Barlaz

The State of Municipal Solid Waste Bioreactor Landfills-II, US Environmental Protection Agency, with M. Barlaz

VOC Transport Through Composite Landfill Liners, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

VOC Transport in Lined Containment Facilities, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

Hydrology of the Monticello Water Balance Cover, Stollar Corporation and US Dept. of Energy.

Effect of Freeze Thaw on Compacted Soil Liners and Covers, University of Wisconsin Graduate School.

Fate and Transport of Chronic Waste Disease Prions in Municipal Solid Waste Landfills, US Environmental Protection Agency, with J. Pedersen and J. Aiken.

Evaluation of VOC Contamination of Groundwater from Lined Landfills in Wisconsin, Groundwater Research Advisory Council, State of Wisconsin.

Hydrologic Modeling of Covers Used for Mine Waste Containment, US Environmental Protection Agency, with C. Shackelford.

Bioreactor Landfills: State of the Practice, US Environmental Protection Agency, with D. Lane and M. Barlaz.

Field Performance of Alternative Covers, US Environmental Protection Agency.

Integrated Long-Term Stewardship for Low-Level Radioactive Waste, US Department of Energy and Flour Fernald, Fernald, Ohio.

Chemical Interactions Between Mine Waste Liquids and Geosynthetics, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

Long-term Chemical Compatibility of Geosynthetic Clay Liners, National Science Foundation, with C. Shackelford.

Hydraulic Conductivity Testing Protocols for Paper Sludges, National Council of the Pulp and Paper Industry for Air and Stream Improvement.

Dry Barriers for Waste Containment, National Science Foundation, with S. Kung

Alternative Cover Assessment Program, United States Environmental Protection Agency, with W. Albright (Desert Research Institute) and Glendon Gee (Battelle PNNL).

Large-Scale Verification of a VOC Transport Model for Composite Liners, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

Field Assessment of Geosynthetic Clay Liners in Final Covers, United States Environmental Protection Agency.

Unsaturated Hydraulic Properties of Alternative Cover Soils, Waste Management, Waste Connections, Bluestem Solid Waste Authority, and Marina Solid Waste Management District

Alternative Covers for Waste Containment in Southern California, San Bernardino County, CA.

Equivalency of Subtitle D and Alternative Earthen Covers, City of Glendale, Arizona.

Development of *Win*UNSAT-H, a Windows Implementation of UNSAT-H, WMX Technologies, Inc.

Hydraulic Characterization of Mine Rock Backfill for the Flambeau Mine, Flambeau Mining Company, Ladysmith, WI

Hydraulic Characterization of Mine Rock Backfill for the Flambeau Mine: II-In Situ Verification, Flambeau Mining Company, Ladysmith, WI

Field Hydraulic Conductivity Assessment of the NCASI Test Plots, National Council of the Paper Industry for Air and Stream Improvement

Effect of Freeze-Thaw on the Hydraulic Conductivity of Compacted Papermill Sludge, the National Council of the Paper Industry for Air and Stream Improvement.

Engineering Properties of Paper Sludges Used for Hydraulic Barriers in Landfill Covers, Solid Waste Research Program, State of Wisconsin.

Shear Strength of Municipal Solid Waste, WMX Technologies, Inc., with T. Edil.

Evaluating the Effectiveness of Landfill Liners, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

Laboratory and Field Evaluation of the Effects of Freeze-Thaw on Barrier Materials, United States Environmental Protection Agency.

Field-Evaluation of Geoinsulation-A Geosynthetic Insulation Material, Envotech Limited Partnership, with P. Bosscher

Hydraulic Conductivity Assessment of Compacted Soil Liners, Waste Management of North America, Inc.

Rational Construction Quality Control Criteria for Compacted Soil Liners, University of Wisconsin Graduate School.

Final Cover Hydrologic Evaluation, Waste Management of North America, Inc.

Evaluation of Freezing and Thawing on the Hydraulic Conductivity of a Test Pad, Waste Management of Wisconsin, Inc.

Improved Design Methods for Landfill Final Covers, National Science Foundation.

Quality Assurance and Hydraulic Conductivity Assessment of Compacted Soil Liners, Waste Management of North America and Chemical Waste Management, Inc.

Hydrologic Analysis of a Co-Composting Landfill, Solid Waste Research Council, State of Wisconsin.

Sustainable Construction

Engineering Behavior of Recycled Unbound Materials, US Dept. of Transportation Pooled Fund, with T. Edil.

Recycled Materials Resource Center, Federal Highway Administration and United States Environmental Protection Agency, with K. Gardner

Assessing Environmental Impacts Associated with Bases and Subgrades Stabilized with Coal Combustion Products, Center for Freight and Infrastructure Research and Education, US Department of Transportation, with T. Edil.

User Guidelines for Waste and By-Product Materials in Highway Pavements, US Environmental Protection Agency, with A. Graettinger and J. Jambeck

Gravel Equivalency of Fly Ash Stabilized Reclaimed Roads, Minnesota Local Roads Research Board, with T. Edil

In Situ Stabilization of Gravel Roads with CCPs, Combustion Byproducts Recycling Consortium, US Dept of Energy, with T. Edil

Leaching of Heavy Metals from Gray-Iron Foundry Slags Used in Geo Engineering Applications, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Monitoring and Analysis of Leaching from Subbases Constructed with Industrial Byproducts, FHWA Recycled Materials Research Center, with T. Edil.

Ash Utilization in Low Volume Roads, Minnesota Department of Transportation, with T. Edil

Integrated Approach for Assessing Groundwater Impacts from Fly Ash Stabilized Soils, Alliant Energy, with T. Edil.

Geoenvironmental Assessment of Soft Soils Stabilized with High Carbon Fly Ashes, Solid Waste Research Program, State of Wisconsin, with T. Edil.

Are High Carbon Fly Ashes Effective Stabilizers for Soft Organic Soils?, National Science Foundation, with T. Edil.

Consortium for Beneficial Reuse of Fly Ashes, Alliant Energy, Northern States Power, and Mineral Solutions, Inc., with T. Edil.

Reuse of Fly Ash for Soil Stabilization, US Dept. of Energy, with T. Edil.

Field Demonstration of Earth Structures Constructed with Soil-Tire Chip Mixtures, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Use of Foundry Sands in Hot Mix Asphalt, University Industrial Relations, with H. Bahia

Fly Ash Stabilization of Soft Subgrades, US Dept. of Energy, Mineral Solutions, Inc., and Alliant Power, with T. Edil.

Field Demonstration of Beneficial Reuse of Foundry Byproducts in Highway Subgrade, Wisconsin Department of Transportation, with T. Edil.

Properties of Foundry Sand Relevant to Design of Embankments and Retaining Wall Backfill, State of Wisconsin, Recycling Market Development Board, with T. Edil.

National Practice Survey: Beneficial Re-use of Waste Foundry Sands, State of Wisconsin Recycling Market Development Board, with T. Edil.

Using Waste Foundry Sands as Hydraulic Barriers, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Field Assessment of Barrier Layers Constructed with Foundry Sands, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Use of Shredded Waste Tires in Highway Construction, United States Environmental Protection Agency, with T. Edil.

Sub-base Replacement with Waste Foundry Sands, State of Wisconsin, Recycling Market Development Board, with T. Edil.

Using High Carbon Class F Fly Ash as a Lining Material: I-Laboratory Study, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Using High Carbon Class F Fly Ash as a Lining Material: II-Field Verification, Solid Waste Research Council, State of Wisconsin, with T. Edil.

Reinforcement of Soils with Shredded Waste Tires, Solid Waste Research Council, State of Wisconsin, with P. Bosscher.

Use of Reclaimed Waste HDPE as Soil Reinforcement, Solid Waste Research Council, State of Wisconsin.

Groundwater Remediation and Monitoring

Sorption and Transport of Polycyclic Aromatic Hydrocarbons in Organoclays used for Permeable Adsorptive Barriers, CH2M Hill Inc. and Union Pacific Inc.

Environmental Impacts of Engineered Nanomaterials, Nanoscale Science and Engineering Center, National Science Foundation, with J. Pedersen and R. Hammers

Gray-Iron Foundry Slags as a Reactive Medium for Removing Arsenic from Ground Water and Drinking Water, Groundwater Research Advisory Council, State of Wisconsin, with D. Blowes.

Innovative Treatment of COPR Wastes in Costal Areas, US Dept. of Transportation, with T. Edil.

Development of Large-Scale Application for Remediation of Chromium Ore Processing Residue, University Industrial Relations, University of Wisconsin, with T. Edil.

An Integrated Approach to Evaluating Environmental Impacts from Soils Stabilized with Fly Ashes, State of Wisconsin Recycling Program and Alliant Energy, Inc.

Uncertainty Based Design of Permeable Reactive Barriers, Wisconsin Ground Water Research Advisory Council, with G. Eykholt

Innovative Groundwater Treatment: Reactive Walls Constructed with Excess Foundry Sand, Wisconsin Groundwater Research Advisory Council, with G. Eykholt.

Development of Integrated Decision Support System for Wellhead Protection, Wisconsin Water Resources Council, State of Wisconsin.

Reducing Uncertainty in Subsurface Characterization, U.S. Department of Energy.

Ultrasonic Probe to Evaluate the Integrity of Borehole Seals, Federal Highway Administration, with T. Edil.

Field Assessment of Monitoring Well Seal Integrity, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

A Tool For Evaluating the Integrity of Monitoring Well Seals, Groundwater Research Advisory Council, State of Wisconsin, with T. Edil.

Characterization of Air Plumes and Modeling Mass Removal During In Situ Air Sparging, Groundwater Research Advisory Council, State of Wisconsin, with G. Eykholt.

Other Topics

Wisconsin-Puerto Rico Partnership for Research and Education in Materials [Wi(PR)EM], US National Science Foundation, with J. de Pablo, J. Pedersen, et al.

Fate and Transport of Chronic Waste Disease Prions in Waste Water Treatment Plants, US Environmental Protection Agency

A Modular Geoenvironmental Curriculum, National Science Foundation, with other faculty from Wisconsin, Northwestern, Michigan, and Argonne National Laboratory.

Stiffness and Stress State in Unsaturated Soils, Minnesota Department of Transportation, with T. Edil.

Thermal Conditions Below Highway Pavements During Winter, Wisconsin Department of Transportation, with P. Bosscher.

Design Protocols for Cellular Confinement with Geoweb, University Industrial Relations and Presto Products, Appleton, WI, with T. Edil.

Equivalency of Subgrade Improvement Methods, Wisconsin Department of Transportation, with T. Edil.

Reinforcement of Soft Subgrades with Geosynthetics, Wisconsin Department of Transportation, with T. Edil.

Evaluation of the DCP and SSG for Subgrade Evaluation, Wisconsin Department of Transportation, with T. Edil.

Shear Strength of Granular Backfill Materials, Wisconsin Department of Transportation, with T. Edil.

Correlating Index Properties and Engineering Behavior of Wisconsin Soils, Wisconsin Department of Transportation, with T. Edil.

Incorporating Alternative Subgrade Improvement Methods in Pavement Design, Wisconsin Department of Transportation, with T. Edil.

GRADUATE STUDENTS SUPERVISED

PhD Students

Breitmeyer, R., Dissertation Topic: Hydrology of Bioreactor Landfills, expected 2010, co-advised with T. Edil, expected 2010.

Bareither, C., Dissertation Topic: Settlement of Bioreactor Landfills, co-advised with T. Edil, expected 2010.

Komonweeraket, K., Dissertation Topic: Mechanisms Controlling Release of Trace Elements from Soils Stabilized with Fly Ash, co-advised with T. Edil, expected 2008.

Park, M., Dissertation Topic: Transport of VOCs in Composite Landfill Liners, co-advised with T. Edil, expected 2009.

Apiwantragoon, P., Dissertation Topic: Alternative Covers: Field Performance and Modeling Methods, 2007.

Tinjum, J., Dissertation Topic: Innovative Remedial Treatment of Chromium Ore Processing Residues, co-advised with T. Edil, 2006.

Albright, W., Dissertation Topic: Field Performance of Landfill Covers, 2005.

Lin, L., Dissertation Topic: Impacts of Mineralogical Fouling of Permeable Reactive Barriers in Heterogeneous Environments, 2004.

Chang, P., Dissertation Topic: Geophysical Characterization of Water and Solute Movement in an Arid Climate, 2003, co-advised with D. Alumbaugh.

Kim, W., Dissertation Topic: Alternative Subgrades Stabilization with Geosynthetics, 2003, co-advised with T. Edil.

Gulec, S., Dissertation Topic: Compatibility of Geosynthetics and Mine Waste Liquids, 2003, co-advised with T. Edil.

Tanyu, B., Dissertation Topic: Equivalency of Alternative Subgrade Stabilization Methods, 2003, co-advised with T. Edil.

Jo, H., Dissertation Topic: Fundamental Factors Affecting Interactions Between Bentonite and Inorganic Liquids, 2003.

Bin-Shafique, S., Dissertation Topic: Leaching of Heavy Metals from Fly Ash Stabilized Soils, 2002, co-advised with T. Edil.

Chalermyanont, T., Dissertation Topic: Reliability Analysis of Mechanically Stabilized Earth (MSE) Walls, 2002.

Lee, T., Dissertation Topic: Using Waste Foundry Sands as Reactive Media in Permeable Reactive Barriers, 2002.

Albrecht, B., Dissertation Topic: Passive Dry Barriers: Air Circulation and Mass Transfer, 2001.

Elder, C., Dissertation Topic: Effect of Heterogeneity on Performance of Permeable Reactive Barriers, 2000.

Kim, H., Dissertation Topic: Oxygen Transport Through Multi-layer Caps Over Mine Waste, 2000.

Abichou, T., Dissertation Topic: Hydraulic Properties of Foundry Sands, 1999, co-advised with T. Edil.

Tachavises, C., Dissertation Topic: Flow Rates Past Vertical Groundwater Cut-Off Walls: Influential Factors and Their Impact on Wall Selection, 1998.

Foose, G., Dissertation Topic: Leakage Rates and Chemical Transport Through Composite Landfill Liners, 1997, co-advised with T. Edil.

Khire, M., Dissertation Topic: Field Hydrology and Water Balance Modeling of Earthen Final Covers for Waste Containment, 1995.

Yesiller, N., Dissertation Topic: Ultrasonic Evaluation of Cased Borehole Seals, 1994, co-advised with T. Edil.

Othman, M., Dissertation Topic: Effect of Freeze/Thaw on the Structure and Hydraulic Conductivity of Compacted Clays, 1992.

MS Students

Schlicht, P., Thesis Topic: Weathering-Induced Alterations in the Hydraulic Properties of Final Covers for Waste Containment, 2009, co-advised with J. Tinjum.

Scalia, J., Thesis Topic: Hydraulic Conductivity of Geosynthetic Clay Liners Used in Composite Final Covers, 2009.

Bradshaw, S., Thesis Topic: Effects of Stress, Hydration, and Ion Exchange on Geosynthetic Clay Liners, 2008.

Camargo, F., Thesis Topic: Equivalency of Fly-Ash Stabilized RPM and Gravel Base Course, 2008, co-advised with T. Edil.

Rauen, T., Thesis Topic: Effect of Bioreactor Leachate on Geosynthetic Clay Liners, 2007.

Cope, D., Thesis Topic: Treating TCE-Contaminated Groundwater with Gray-Iron Slag, 2007.

Metz, S., Thesis Topic: Gray-Iron Slags as a Reactive Medium for Arsenic Treatment, 2007.

Eberhardt, M., Thesis Topic: Leaching of Heavy Metals from Gray-Iron Slags with and without Carbonation, 2008.

Baugh, J., Thesis Topic: Fly Ash Stabilization of Gravelly Soils, 2008, co-advised with T. Edil.

Rosa, M., Thesis Topic: Effect of Freeze-Thaw Cycling on Resilient Modulus of Fly-Ash Stabilized Subgrade Soils,2006, co-advised with T. Edil.

Klett, N., Thesis Topic: Evaluation of VOC Discharges to Groundwater from Engineered Landfills in Wisconsin, 2005, co-advised with T. Edil.

Bareither, C., Thesis Topic: Geological Controls on the Shear Strength of Wisconsin Sands, 2006, co-advised with T. Edil.

Bohnhoff, G., Thesis Topic: Predicting the Water Balance of Alternative Covers Using UNSAT-H, 2005.

Sauer, J., Thesis Topic: Leaching of Heavy Metals from Organic Soils Stabilized with High Carbon Fly Ashes, 2005, co-advised with T. Edil.

Tastan, O., Thesis Topic: Stabilizing Organic Soils with High Carbon Fly Ashes, 2005, co-advised with T. Edil.

Trzebiatowski, B., Thesis Topic: Effect of Pedogenesis on Soil Water Characteristic Curves of Cover Soils, 2004.

Meer, S., Thesis Topic: Effects of Ion Exchange and Desiccation on GCLs used in Final Covers, 2003.

Gurdal, T., Thesis Topic: Unsaturated Hydraulic Properties of Alternative Cover Soils, 2003.

Kim, K., Thesis Topic: Water Content Reflectometer Calibrations for Final Cover Soils, 2002.

Camacho, L., Thesis Topic: Analysis of Landfill Failure Using Three-Dimensional Limit Equilibrium Methods, 2002, co-advised with T. Edil.

Roesler, A., Thesis Topic: Field Hydrology and Model Predictions for Final Covers in the Alternative Assessment Program, 2002.

Acosta, H., Thesis Topic: Stabilization of Soft Subgrade Soils Using Fly Ash, 2002, co-advised with T. Edil.

Lanier, A., Thesis Topic: VOC Transport in Geosynthetic Clay Liners, 2002.

Marchesi, I., Thesis Topic: Simulating the Hydrology of Alternative Covers with *SoilCover*, 2002.

Mergener, E., Thesis Topic: Assessing Clogging of Permeable Reactive Barriers in Heterogeneous Aquifers Using a Geochemical Model, 2002.

Rochford, W., Thesis Topic: Effectiveness of Geomembrane and Soil-Bentonite Cut-Off Walls, 2002.

Thorstad, P., Thesis Topic: Field Performance of a Geosynthetic Clay Liner (GCL) Used as the Hydraulic Barrier Layer in a Landfill Cover in Southwestern Wisconsin, 2002.

Nelson, M., Thesis Topic: Laboratory Hydraulic Conductivity Testing Protocols for Paper Sludges in Barrier Layers, 2001.

Lau, W., Thesis Topic: Use of Geocells in Flexible Pavements Over Poor Subgrades, 2001, co-advised with T. Edil.

Simon, D., Thesis Topic: Comparison of Three Geophysical Imaging Techniques for Characterization of an IAS Plume, 2001, co-advised with D. Alumbaugh.

Kolstad, D., Thesis Topic: Hydraulic Conductivity and Ion Exchange in GCLs Permeated with Multispecies Inorganic Solution, 2000.

Mengelt, M., Thesis Topic: Effect of Cellular Confinement on Soil Stiffness Under Dynamic Loads, 2000, co-advised with T. Edil.

Maxwell, S., Thesis Topic: Geosynthetic Reinforcement of Soft Subgrades, 1999, co-advised with T. Edil.

Jo, H., Thesis Topic: Chemical Compatibility of Non-Prehydrated GCLs and Inorganic Liquids, 1999.

Lee, T., Thesis Topic: Physical Modeling of Vertical Groundwater Cut-Off Walls,1999.

Gibson, S., Thesis Topic: Geoelectric Methods to Evaluate Borehole Seals, 1999, co-advised with T. Edil.

Winkler, W., Thesis Topic: Thickness of Monolithic Covers in Arid and Semi-arid Climates, 1999.

Chen, C., Thesis Topic: Meteorological Conditions for Design of Monolithic Alternative Earthen Final Covers (AEFCs), 1999.

Vasko, S., Thesis Topic: Hydraulic Conductivity of Prehydrated Geosynthetic Clay Liners Permeated with Calcium Chloride Solutions, 1999.

Dingrando, J., Thesis Topic: Beneficial Reuse of Foundry Sands in Controlled Low Strength Material, 1999, co-advised with T. Edil.

Beurmann, S., Thesis Topic: Dielectric Sensor for Measuring Suction in Dry Soils, 1999.

Chiang, I., Thesis Topic: Effect of Fines and Gradation on Soil Water Characteristic Curves of Sands, 1998.

Christman, M., Thesis Topic: Annular Well Seals: A Geophysical Study of Influential Factors and Seal Quality, 1999, co-advised with T. Edil.

Lin, L.C., Thesis Topic: Effect of Wet-Dry Cycling on Swelling and Hydraulic Conductivity of Geosynthetic Clay Liners, 1998.

Goodhue, M., Thesis Topic: Reuse of Foundry Sands in Reinforced Earthen Structures, 1998, co-advised with T. Edil.

Jong, D., Thesis Topic: Load Limit Timings for Roadways Exposed to Frost, 1997, co-advised with P. Bosscher.

Suwansawat, V., Thesis Topic: Using TDR for Moisture Movement in Clays, 1997.

Akpinar, M., Thesis Topic: Interface Shear Strength of Geomembranes and Geotextiles at Different Temperatures, 1997.

Gavin, M., Thesis Topic: Physical and Chemical Effects of Electroosmosis on Kaolinite, 1997, co-advised with T. Edil.

Kircher, J., Thesis Topic: Modeling Chemical and Physical Effects of Electro-osmosis on Kaolinite, 1997, co-advised with T. Edil.

Kleven, J., Thesis Topic: Mechanical Properties of Excess Foundry System Sand and an Evaluation of its use in Roadway Structural Fill, 1997, co-advised with T. Edil.

Hill, T., Thesis Topic: Field and Laboratory Hydraulic Conductivity of Compacted Mine Waste Rock, 1997.

Elder, C., Thesis Topic: Modeling Mass Transfer During In Situ Air Sparging, 1996.

Baker, D., Thesis Topic: Physical Modeling of In Situ Air Sparging, 1996.

Klima, J., Thesis Topic: Field Assessment of Monitoring and Water Supply Well Seals, 1996, co-advised with T. Edil.

Tinjum, J., Thesis Topic: Soil Water Characteristic Curves for Compacted Fine Grained Soils, 1995.

Payne, L., Thesis Topic: Use of Pulsating Electro-Osmosis in Barrier Applications, 1995, co-advised with T. Edil.

Tatlisoz, N., Thesis Topic: Using Tire Chips in Earthen Structures, 1995, co-advised with T. Edil.

Palmer, B., Thesis Topic: High Carbon Class F Fly Ash for Reactive Barrier Landfill Liners, 1995, co-advised with T. Edil.

Albrecht, B., Thesis Topic: Effect of Desiccation on Hydraulic Conductivity of Compacted Clays, 1995.

Harrick, M., Thesis Topic: Permeable Reactive Walls in Wisconsin, 1994.

Abu Hassanein, Z., Thesis Topic: Using Electrical Resistivity Measurement as a Quality Control Tool for Compacted Clay Liners, 1994.

Meerdink, J., Thesis Topic: Unsaturated Hydraulic Conductivity of Barrier Soils Used for Final Covers, 1994.

Pekarun, O., Thesis Topic: Evaluation of Hydraulic Significance of Defects in Annular Well Seals, 1994, co-advised with T. Edil.

Kraus, J., Thesis Topic: Hydraulic Conductivity of Papermill Sludges, 1994.

Wang, X., Thesis Topic: Evaluating Suction Head at the Wetting Front During Infiltration in Compacted Clays, 1993.

Foose, G., Thesis Topic: Shear Strength of Sand Reinforced with Shredded Waste Tires, 1993.

Cooper, S., Thesis Topic: An Evaluation of How Subsurface Characterization Using Soil Classifications Affects Predictions of Containment Transport, 1993.

Bashel, M., Thesis Topic: Flow Rates in Composite Landfill Liners, 1993.

Trast, J., Thesis Topic: Field Hydraulic Conductivity of Thirteen Compacted Clay Liners, 1993.

Genthe, D., Thesis Topic: Shear Strength of Two Pulp and Paper Mill Sludges with Low Solids Content, 1993.

Sajjad, M., Thesis Topic: Effect of Electro-Osmosis on Hydraulic Conductivity of Compacted Clay, 1993.

Abichou, T., Thesis Topic: Field Evaluation of Geosynthetic Insulation for Protection of Clay Liners, 1993.

Bahner, E., Thesis Topic: Soil Nailing Case Histories in Wisconsin, 1993.

Hardianto, F., Thesis Topic: Representative Sample Size for Hydraulic Conductivity of Compacted Clay, 1993.

Lane, D., Thesis Topic: Hydrologic Observations and Modeling Assessments of Landfill Covers, 1992.

PATENTS

Apparatus and Method for Testing the Hydraulic Conductivity of Geologic Materials, United States Patent No. 6,178,808.

Pressure Plate Extractor, United States Patent No. 6,718,835.

CONSULTING ENGINEERING EXPERIENCE

Dr. Benson has served as a consultant on more than 90 projects for government and industry in the United States and abroad. His consulting work includes specialty design and analysis, peer review, prototype and field testing of new technologies, forensic engineering, and litigation support. References provided on request.

RECENT INVITED LECTURES

Final Covers for Waste Containment: Lessons Learned from a Nationwide Field Experiment. Sowers State-of-the-Art Lecture, 12th Annual George F. Sowers Symposium, Georgia Institute of Technology, Atlanta, Georgia, May 2009.

Chemical Alterations and Their Impact on the Hydrologic Properties of Bentonite, Monash University, Melbourne, Victoria, Australia, December 2008.

Hydrology and Settlement in Bioreactor Landfills, *Cutting Edge Technological Advances in Design and Operation, Reducing Leachate Quantity, Spatial Needs, and Costs, and Accelerating Landfill Gas Recovery Rates*, World Bank, Washington, DC, November 2007.

Modeling Unsaturated Flow and Atmospheric Interactions, Keynote Speaker, *Second International Conference on Mechanics of Unsaturated Soils*, Weimar, Germany, March 2007.

Geosynthetic Clay Liners for Waste Containment: Panacea or Future Problem?, Geosynthetic Research Institute, Drexel University, Philadelphia, November 2005.

Effects of Heterogeneity on Mineral Fouling of Permeable Reactive Barriers, 2nd International Conference on Reactive Barriers, Belfast, Northern Ireland, March 2004.

Lessons Learned from North American Failures, Keynote Speaker, *Fifth International Conference on Environmental Geotechnics*, ISSMGE, Rio de Janeiro, Brazil, August 2002.

Waste Containment Systems: Strategies and Performance, Keynote Speaker, *GeoEnvironment 2002*, Australian-New Zealand Geomechanics Society, Newcastle, NSW, Australia, Nov. 2001

Engineered Barriers, Keynote Speaker, National Academy of Sciences, Washington, DC, July 2001.

Are Geosynthetic Clay Liners Effective Barriers for Waste Containment?, Desert Research Institute, Reno, Nevada, January 2001.

Solid Waste Containment Systems, Keynote Speaker (with M. Manassero), *GeoEng2000*, Melbourne, Australia, November 2000.

Liners and Covers for Waste Containment, Keynote Speaker, Fourth Kansai International Geotechnical Forum, Creation of a New Geo-Environment, Japanese Geotechnical Society, Kyoto, Japan, June 2000

EDITORSHIPS

Editor-in-Chief, ASCE *Journal of Geotechnical and Geoenvironmental Engineering*, 2004-2006

Editor, ASCE *Journal of Geotechnical and Geoenvironmental Engineering*, 1996-99

Editor, *Journal of Geotextiles and Geomembranes*, 2009-present.

Co-Editor, *Waste Containment and Remediation*, GSP No. 142, ASCE, A. Alshawabkeh et al., co-editors, 2005.

Editor, *Risk-Based Corrective Action and Brownfields Restorations*, GSP No. 82, ASCE, J. Meegoda, R. Gilbert, and S. Clemence, co-editors, 1998

Co-Editor, Environmental Geotechnics Section, *Geotechnical News*, 1994-96

DIRECTORSHIPS AND CHAIRMANSHIPS

Chair, Independent Technical Review Committee for On-Site Disposal Facilities, US Department of Energy, March 2007-present.

Director, Wisconsin Geotechnics Laboratory, University of Wisconsin-Madison, December 2000-present.

Co-Director, Consortium for Fly Ash Use in Geotechnical Engineering, University of Wisconsin-Madison, with T. Edil, December 1999-present.

SOCIETY MEMBERSHIPS

Geo-Institute of the American Society of Civil Engineers
- Board of Governors (2007-present)
- Geoenvironmental Engineering Committee (1990-Present, chair 1996-99)
- Technical Publications Committee (1993-99, 2004-2006)
- TPCC Subcommittee on Policies for Specialty Conferences (1997-99)
- Editor-in-Chief, *JGGE*, 2004-06, Editor *JGGE*, 1996-99
- G-I Magazine Task Force (1997-99)
- Awards (chair, 1999-2001)

American Society for Testing and Materials (ASTM)
- D18 Executive Committee (2006-present)
- D18.04 - Hydrologic Properties of Soil & Rock (1991-Present, chair 1996-2006)
- D18.19 - Frozen Soil & Rock (1992-Present)

American Geophysical Union
British Geotechnical Association
Canadian Geotechnical Society
International Geosynthetics Society
National Ground Water Association
North American Geosynthetics Society
Soil Science Society of America

UNIVERSITY SERVICE

Chairman, Geological Engineering, (2007-2008, 2009-present)
Academic Council, Dept. of Civil and Environmental Engineering (1994-99, Chair 1997-99)
Admissions Chairman, Geo Engineering Program (1990-2006)
Associate Chair of Civil and Environmental Engineering - Environmental Science and Engineering Division (2004-2007)
Becker Award Committee (chair), Civil and Environmental Engineering (2002-04)
Byron Bird Award Committee (1995)
Civil and Environmental Engineering Salary Committee (1998, 2002, 2004-2006)
College of Engineering Academic Planning and Curriculum Committee (1996-99)
College of Engineering Advisory Board for Geological Engineering (1990-2008)
College of Engineering Curriculum Committee (1997-99, 2002-04)
College of Engineering Diversity Committee (2002-04)
Conflict of Interest Oversight Committee, University of Wisconsin (2000-02)
Graduate Committee, Geological Engineering (1999-present, Chair 1999-2001, 2003-2006)
Scholarship Committee, Dept. of Civil and Environmental Engineering (1998-2002)
Search Committee for Geo Engineering Position (Chairman, 2004-present)
Search Committee for Engineering Geophysics Position (Chairman, 1997-98, 2003-04)
Undergraduate Committee, Geological Engineering (Chairman, 2002-2008)