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Abstract
Since 1990, various local, state, and federal agencies have funded 29 projects to collect new data aimed at improving our knowledge of the Mahomet aquifer that underlies 13 counties in east-central Illinois. Total funding for all of these projects exceeds $3.6 million. Through these projects, our understanding of the geology and hydrology of the Mahomet aquifer has been greatly enhanced since Kempton and others (Kempton et al., 1991) wrote their seminal paper on the Mahomet aquifer. In this paper, findings from some of these projects will be discussed.

Unusual results from two groundwater flow models, coupled with water level data from the “throat” of the aquifer in Piatt and DeWitt Counties, led to additional studies near Allerton Park (Piatt Co.). Using new technology (high-resolution seismic reflection), test drilling, and long-term aquifer testing, scientists were able to explain these unusual results. A hydraulic window connecting the Mahomet aquifer to the Sangamon River was identified in the glacial materials overlying the Mahomet aquifer. This connection allows Mahomet aquifer water to discharge to the river under normal conditions, but allows the Sangamon River to recharge the aquifer when the river is high or when the aquifer is pumped.

Our knowledge of the groundwater chemistry in the Mahomet aquifer also has improved tremendously in the last 10 years. Motivated by the need to assess the vulnerability of groundwater resources to contamination and to define the long-term sustainability of our aquifer, scientists have sampled and analyzed groundwater for many common and some unusual chemicals. These studies have shown that the age of the groundwater sampled in the Mahomet aquifer varies from less than 1,000 to about 12,000 years. The detection of trace amounts of pesticides in the Mahomet aquifer indicates that there may be areas where a small amount of younger groundwater is mixing with the older water. Arsenic has also been found in the Mahomet aquifer, at levels above accepted drinking water standards. Recent research suggests its presence is currently unpredictable, but controlled by natural geochemical processes.

BACKGROUND

Although the sand and gravel have been in place for hundreds of thousands of years, the "Mahomet aquifer" did not exist until the 1940s. During the 1940s, Leland Horberg named the buried bedrock valley and its sand and gravel deposits while studying the geologic deposits sampled from 3 wells near the Village of Mahomet. Horberg (1945) proposed that the Mahomet Bedrock Valley (MBV) was the western portion of a larger Mahomet-Teays Bedrock Valley that could be traced back to West Virginia (figure 1). The MBV connected to the Ancient Mississippi River Valley to the west. Later, using additional information, Kempton and coworkers suggested that the Mahomet-Teays Bedrock Valley was really 2 or 3 separate valleys. In addition, Kempton et al. (1991) revised the geologic map showing the main valley and its tributaries (figure 2).

Kempton and coworkers (1991) described the Mahomet aquifer and its bedrock valleys as follows:

- The Mahomet aquifer is the most important aquifer in east-central Illinois and is the only highly productive, nonalluvial sand and gravel aquifer in the southern three-fourths of Illinois.
- The Mahomet aquifer fills the deeper parts of the Mahomet Bedrock Valley and in the tributary Onarga and Kenney Valleys.
- The Mahomet aquifer averages close to 100 feet thick and may be as much as 200 feet thick locally.
- The Mahomet aquifer is composed primarily of clean sand and gravel with only minor amounts of fine-grained sediments. These materials tend to fine down valley (east to west) and upward. Sand predominates in the upper 50 feet along most of the valley.
- Most of the tributary valleys contain predominantly fine-textured, water–laid sediments that have lower hydraulic conductivity than sediments in the main valley.
- The Mahomet Bedrock Valley developed through Late Tertiary time (more than 1.5 million years ago) as part of a westward flowing drainage system with headwaters in NE Illinois and NW Indiana and has a complex erosional history.
- This drainage system was disrupted by early Pleistocene glaciation. During the Pleistocene, catastrophic, high-velocity floods further eroded the main valley, leaving hanging tributary valleys.

The geologic materials deposited above the bedrock are shown in figure 3. This stratigraphic column shows that the Mahomet Bedrock Valley was eroded in Pennsylvanian and older bedrock and is filled with geologic materials from the pre-Illinois Episode, the Illinois Episode, the Wisconsin Episode, and recent times. These materials include predominantly sand and gravel and fine-grained tills.

Since 1990, various local, state, and federal agencies have funded 29 projects to collect new data aimed at improving our knowledge of the Mahomet aquifer beneath east-central Illinois. Total funding for all of these projects exceeds $3.6 million. A list of these projects is available at www.MahometAquiferConsortium.org. Through these projects, our understanding of the geology and hydrology of the Mahomet aquifer has been greatly enhanced since Kempton and others (Kempton et al., 1991) wrote their seminal paper on the Mahomet aquifer. In this paper, the findings for some of these projects will be discussed.

Advances in Geology & Hydrology

Geology beneath McLean & Tazewell Counties

In the mid-1990s, the Long Range Water Plan Steering Committee funded a hydrogeologic study of the Mahomet and overlying aquifers for an 8-township area in McLean and Tazewell Counties. The goal of the study was to characterize the hydrogeology at the confluence of two bedrock valleys (Mackinaw and Mahomet Bedrock Valleys) and to identify potential sites for a well field capable of producing up to 15 million gallons per day (MGD). This study included a substantial effort to collect new geologic, geophysical, and geochemical data. One of the study's major findings was that the geometry and geology of the aquifer was more complex than previously thought (Herzog et al., 1995). The aquifer geometry was more complex because the bedrock surface included several hills that reduced the aquifer thickness, as shown in figure 4.

3D Mapping with GIS

In the mid-1990s, Soller et al. (1999) mapped the Quaternary deposits in east-central Illinois to develop and test new techniques for mapping geologic deposits in three dimensions. This project included all or portions of Champaign, DeWitt, Ford, Iroquois, Logan, Macon, McLean, Piatt, Sangamon, Tazewell, Vermilion, and Woodford Counties. Three-dimensional mapping included mapping the thickness and distribution of geologic materials both at the land surface and in the subsurface. This area provided an excellent geologic setting for developing and testing new mapping techniques because it has diverse Quaternary geology and thick, regional sand and gravel aquifers within a buried bedrock valley system, the Mahomet Bedrock Valley.

Geologists have traditionally used cross sections and fence diagrams to visualize geologic units in three dimensions. Portraying the three-dimensional nature of geologic materials in as much detail as possible is essential to an improved understanding of geologic maps and the geologic processes responsible for the distribution of deposits. This information is needed both during the iterative process of mapping and for the public's comprehension of map information.

Computer software provides the opportunity to easily manipulate data to quickly view and evaluate subsurface deposits as maps are being developed iteratively. Software also allows the geologist to view and evaluate the deposits from more perspectives than would be efficient using traditional cartographic methods. When displayed on the computer as an animation, this series of maps provides a new, dynamic visualization of the distribution of geologic deposits through time. Computer-based, three-dimensional visualization offers a new opportunity for a more complete understanding of subsurface glacial sediments, both for the geologist and for other map users. Three-dimensional visualization of the Quaternary deposits beneath east-central Illinois can be viewed at http://pubs.usgs.gov/imap/i-2669/.

Improved Geophysical Techniques
Improvements in geophysical techniques have led to improved geologic interpretations. High resolution seismic reflection techniques using both compression (P-wave) and shear (SH-wave) waves have provided vital data for constructing realistic geologic maps and cross sections. These techniques are now more economical to apply and have been used to map two areas within the Mahomet aquifer region.

Conventional P-wave seismic methods required that geophones be planted in the ground at a 3 m spacing, which was labor intensive and thus expensive. To make data collection more efficient, a landstreamer system was developed and used (Pugin et al, 2004b). Instead of planting the geophones in the ground, geophones are mounted on small steel sleds that are towed in a line behind a car along the road (figures 5 & 6). The landstreamer also allows the geophysicists to efficiently collect SH-wave data. The SH wave avoids problems with a deep water table or biogenic gas (methane) that often plagues the conventional P-wave methods. We have found that the SH-wave reflection data provides extremely high resolution images of the Quaternary sediments.

<u>Allerton Park study area</u>
In the Allerton Park area, high resolution geophysical imaging included about 19 km of P-wave (conventional acquisition methods) and 7 km of SH-wave (landstreamer) seismic reflection, and 1.7 km of resistivity profiles (Pugin et al., 2003). Vertical sonic profiles and gamma logs were collected in 4 recently drilled and 2 available boreholes for calibration purposes. This data set was acquired during the fall 2001 and the summer 2002. Intriguing results of this study were associated with the sediments overlying the Banner sands. A 1 km wide and 50 m thick Illinois Episode sub-glacial valley, mainly filled with sand, was found to cut through (or replace) the Glasford till (figure 7). Similar deposits can be observed at the surface on the Illinoian till plain, 40 km farther south. The modern Sangamon River flows in a 30 m deep coarse-sediment channel that cuts through the Wedron till. Where these two channels cross, a hydraulic window connects the shallow aquifers, and possibly the Sangamon River, with the Mahomet aquifer.

<u>Fisher study area</u>
During the summer 2003, geophysical data were acquired along section line rural roads covering an area of approximately 20 square miles in northwest Champaign County, south of Fisher. This area corresponds to a place where the potentiometric surface of the Mahomet aquifer drops about 10 m (Wilson et al., 1998). The target of this research was to test whether a P-wave landstreamer could provide data needed to understand the geologic structure responsible for such a hydraulic discontinuity. A buried bedrock “cliff”, about 30 m high, was observed in several locations (figure 8, Pugin et al., 2004a). This bedrock feature caused a major thinning of the Mahomet aquifer which likely causes the 10 m drop in the potentiometric surface of the Mahomet aquifer.

SH-wave reflection data provides much better definition of the uppermost 30 m of sediment with much better vertical and horizontal resolution. In particular, many parts of the P-wave profiles were obscured by biogenic “drift” gas. In some areas however, the

SH-wave data were also obscured by coarse gravel that absorbs the shear wave energy. The presence of coarse gravel was confirmed with samples from boreholes. This coarse gravel appears to be part of a network of tunnel valleys present in the Illinoian tills (Pugin et al. 2003). These tunnel valleys facilitate the flow of water through the tills on a regional basis and provide hydraulic windows connecting the surface water with the Mahomet aquifer.

Groundwater Flow Modeling

A post-audit of an existing groundwater flow model of Decatur's two emergency wellfields has greatly altered our conceptual understanding of flow in the aquifer (Roadcap and Wilson, 2001). Decatur operates these emergency wellfields to supplement Lake Decatur during extended dry periods, which are expected to last for several weeks and occur 3 or 4 times a decade. These wellfields discharge to the Sangamon River. During an unusually dry period in the fall 1999 and the winter 2000, Decatur pumped 10 to 15 MGD from these wellfields over an 84-day period. This new stress on the aquifer was simulated. The principle finding was that the model overpredicted drawdowns at the wellfield directly adjacent to the river. Adding river cells to the model upstream of the wellfield allowed the drawdown to be accurately simulated (figure 9). While previously suspected, this connection has now been verified by the seismic studies discussed above, comparisons of groundwater and Sangamon River hydrographs, and a 30-day aquifer test with a new network of strategically placed observation wells.

A 3D MODFLOW model is being developed for the entire aquifer. The current model development activities are focused on the area around Champaign and the upper Sangamon River where the flow system is currently not well understood.

Advances in Geochemistry

In the late 1980s and early 1990s, Panno and coworkers (Panno et al., 1994) used major ion chemistry and isotope geochemistry to develop a conceptual model of groundwater flow and recharge in the Mahomet aquifer. They identified four areas with distinct groundwater quality (figure 10). Based on radiocarbon isotopic data, the relative age of the groundwater in these areas are also different (table 1), youngest in the confluence area and oldest in the Onarga Valley and the western end of the Mahomet aquifer. These data also indicate that groundwater from the underlying bedrock flows into the aquifer in Iroquois, Piatt, Macon, and DeWitt Counties (figure 11).

Table 1. Groundwater age as defined by isotope geochemistry (from Panno et al., 1994; Hackley, 2002)

Area	**Groundwater age (years)**
Onarga Valley	3,400 to 21,000
Central Mahomet Valley	1,400 to 5,000
Western Mahomet Valley	900 to 12,000
Confluence area	<1,700

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program is designed to look at the status and trends of our Nation's waters. Groundwater quality is determined primarily by chemical characteristics that tend to vary more spatially than temporally, making spatial characterization and transport processes a main focus in groundwater assessment. The Mahomet aquifer is one of over 60 aquifers included as part of this national study. Between 1996 and 1998, 30 wells were drilled and sampled to assess the recently recharged groundwater overlying the Mahomet aquifer, and 30 domestic wells were sampled within the aquifer. Analysis of the groundwater included over 300 chemical constituents, including pesticides, volatile organic compounds, trace elements, and radon. A key issue in some parts of the Mahomet aquifer is elevated arsenic concentration above background levels. The current arsenic drinking water maximum contaminant level is 10 μg/L (U.S. Environmental Protection Agency, 2001). Arsenic was found at elevated levels in the Mahomet aquifer, up to 84 micrograms per liter (μg/L). Samples from 83 percent of the domestic wells had arsenic detections (greater than 1 μg/L), and 43 percent had arsenic concentrations greater than 10 μg/L (Warner, 2001). A statewide geostatistical analysis of the arsenic concentrations in public and domestic supplies indicates the area of the Mahomet aquifer is one of various areas in Illinois with potentially high arsenic concentration (Warner et al., 2003). A subset of Mahomet aquifer wells with elevated arsenic concentrations was resampled in 1997 to determine arsenic speciation (arsenate and arsenite concentrations). Arsenite is more toxic than arsenate and was detected in higher concentrations in these wells. Total dissolved arsenic concentrations ranged from 50 to 100 percent arsenite. In the wells overlying the Mahomet aquifer, arsenic was detected in 24 percent of the samples, but none exceeded 10 μg/L.

To examine arsenic in the aquifer material, integrated samples of the aquifer material were collected from the ISGS core library. The solid-phase samples were analyzed by the USGS for bulk chemistry, X-ray diffraction, X-ray fluorescence, heavy mineral analysis, and potentially for selective extraction for arsenic species. Arsenic concentration in the Mahomet aquifer system material was related to the presence of pyrite (figure 12).

Pesticides were detected in low concentrations (up to 0.019 μg/L) in the initial NAWQA sampling in 1996 in 10 of 30 Mahomet aquifer wells. Atrazine was the most frequently detected pesticide in the Mahomet aquifer. Pesticides were detected in half of the samples from the recently recharged groundwater overlying the Mahomet aquifer. Mahomet aquifer wells with pesticide detections in 1996 were resampled in 1998. Pesticides were detected again in 4 of those 10 wells. Pesticides are a recent anthropogenic contaminant so the groundwater was analyzed for tritium to estimate the time since recharge. No tritium was detected in the groundwater with pesticide detections. These results indicate that the bulk of the water predates 1953 and small amounts of much younger water mixes with the older water. Uranium was not present in samples from the Mahomet aquifer, probably because of reducing conditions that may immobilize uranium. Radon was present (ranging from 110 to 730 pCi/L [picocuries per liter]) with higher concentrations observed in the recently recharged groundwater overlying the Mahomet aquifer (maximum of 1,300 pCi/L).

The USGS continues to assess water quality in the Mahomet aquifer. Five randomly selected wells in the Mahomet aquifer will be sampled every 2 years (begun in 2002) for over 300 chemical constituents to assess water quality trends over time. The entire USGS 30 well network in the Mahomet aquifer will be resampled in 2006. Finally, a study of the fate and transport of natural and anthropogenic contaminants to public water-supply wells in the Mahomet aquifer will begin in 2009.

Arsenic in the Mahomet aquifer—ISWS studies

In 2002, the ISWS collected samples from approximately 50 private wells in Tazewell County, an area with known arsenic contamination, and northwest Champaign County, an area with very few available arsenic data. Most wells were finished in the Mahomet aquifer, with roughly equal numbers of wells near the bottom, middle, and upper parts of the aquifer. In both counties, wells with high arsenic concentrations were spread throughout the study area. In Champaign County, 40% of the wells had nondetectable (<1 µg/L) arsenic, 90% had less than the maximum contaminant level (MCL) of 10 µg/L, and one well had more than 50 Fg/L. In Tazewell County, 25% of the wells had nondetectable arsenic, 55% had less than the MCL, and 10% had over 50 µg/L. In both counties, the spatial distribution of arsenic was complex. Wells with high concentrations were commonly located less than 1 mile from wells with nondetectable arsenic. In Tazewell County, the percentages of wells with arsenic concentrations above the MCL were roughly equal in the shallow, intermediate, and deep parts of the Mahomet aquifer. Based on relatively few samples from the overlying Glasford aquifer, there appeared to be a higher percentage of Glasford aquifer wells with arsenic concentrations exceeding the MCL than wells completed in the Mahomet aquifer.

In the central part of the Mahomet aquifer, arsenic concentrations were correlated with chloride and generally increased with depth, which suggested a bedrock source (Warner, 2001). However, in Tazewell and Champaign Counties, arsenic and chloride were not correlated. A low concentration of one solute was usually associated with a high concentration of the other. No trends with depth were observed. Therefore, the bedrock was not considered a significant source of arsenic in Champaign or Tazewell Counties (Holm et al., 2004).

In most samples, arsenite (As(III)) made up over 90% of the dissolved arsenic and particulate arsenic (retained by a 0.45 µm filter) made up less than 10% of the total. The arsenic speciation was consistent with thermodynamic calculations based on the measured pH and oxidation-reduction potential values. Although no strong correlations between arsenic and other analytes were found, high arsenic concentrations were associated with low sulfate concentrations and with high concentrations of bicarbonate, fluoride, and organic carbon.

Recommendations for Future Work

A great deal of research has been conducted to understand the geology, hydrology and geochemistry of the Mahomet aquifer and overlying sediments. Because of the current use and potential future demands for high-quality groundwater, additional work is still needed to address questions posed by planners and the general public--

- Additional geologic and geophysical studies are needed to understand the three-dimensional relationships of the aquifers and confining layers. High resolution seismic profiling and related geologic studies are effective in defining the complex geologic structure in the glacial sediments that comprise the Mahomet aquifer. All existing and new data should be compiled into a three-dimensional geologic model for the entire Mahomet aquifer and overlying materials.
- A detailed, three-dimensional groundwater flow model of the entire aquifer is needed to understand groundwater flow into and through the Mahomet aquifer. This flow model would also be useful to quickly evaluate the potential effects of future major water users.
- Additional groundwater quality data are needed to assess water quality over time and to assess known problems such as arsenic.
- A network of observation wells should be installed along the length of the Mahomet aquifer. This network should include wells in the Mahomet aquifer, overlying aquifers and possibly the underlying bedrock. The wells would provide hydraulic data to assess groundwater flow and recharge and samples for geochemical studies.
- Continued integration of data/information across geologic, geochemical, and engineering disciplines is highly recommended to unravel the secrets of the Mahomet aquifer.

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Figure 1. Map of the Mahomet-Teays bedrock valley proposed by Horberg (1945)

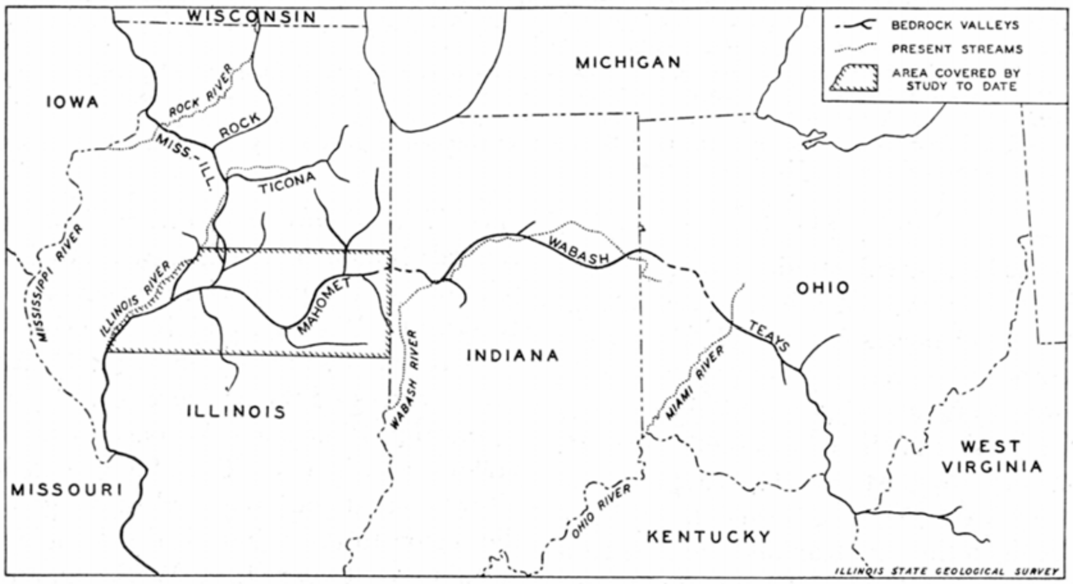

FIG. 1.—Map showing area studied in Illinois and proposed Teays drainage system. (Adapted in part after Fidlar, Tight, and Ver Steeg.)

Figure 2. Map of the principal bedrock valleys as mapped by Kempton et al. (1991). Solid lines denote the main channel.

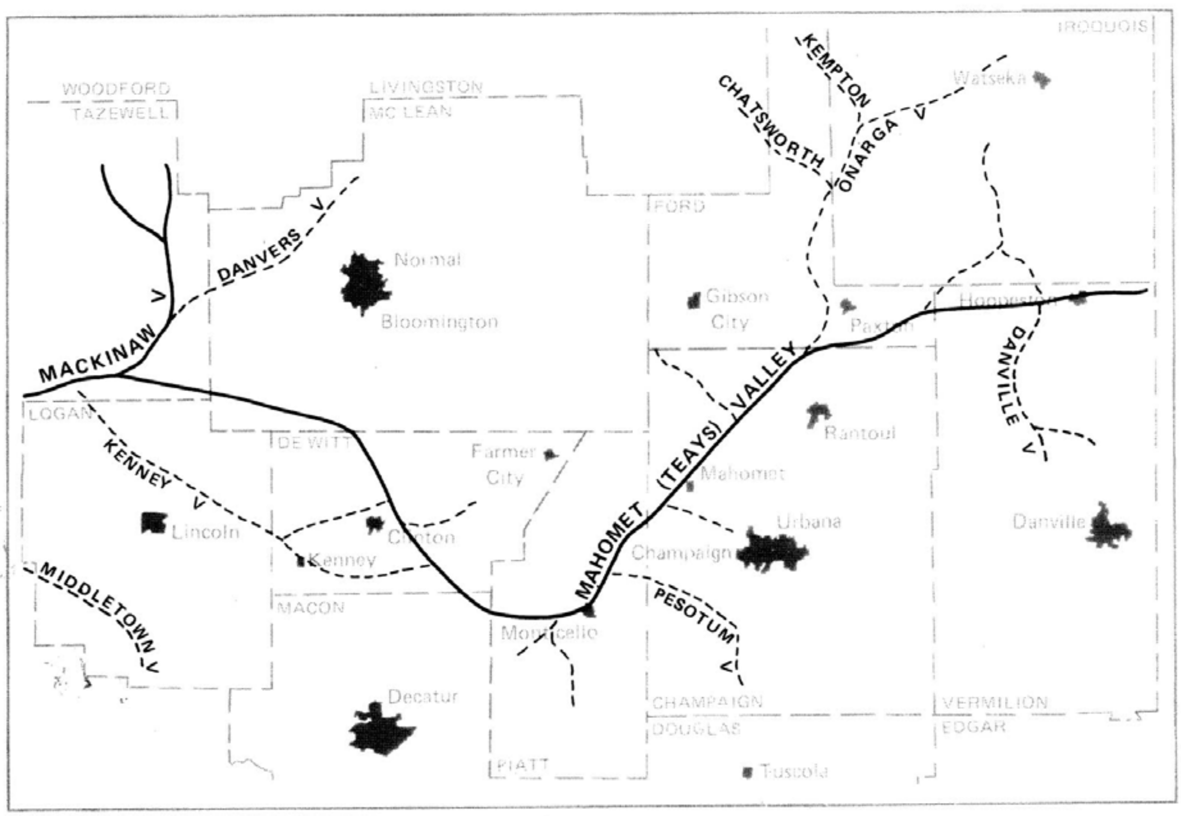

Figure 3. Stratigraphic column for Quaternary materials in east-central Illinois (Soller et al., 1999). Sand and gravel deposits are highlighted.

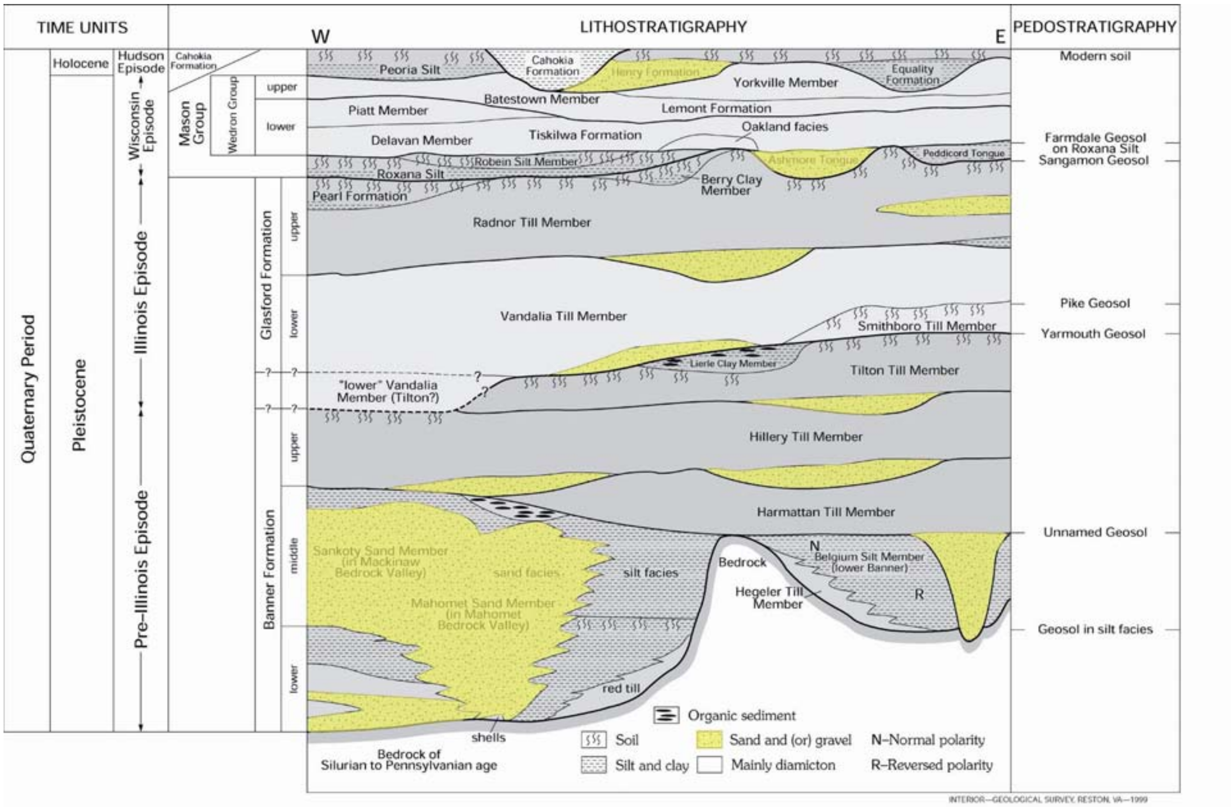

Figure 7.—Diagrammatic stratigraphic column of glaciogenic sediments in east-central Illinois. The Cahokia Formation was deposited mostly during the Hudson Episode. Geologic and stratigraphic names and intervals used in this figure are those accepted by the ISGS.

Figure 4. Bedrock topography beneath McLean and Tazewell Counties as defined by Kempton and Visocky (1992) (top) and Herzog et al. (1995) (bottom). New data revealed a more complex bedrock surface, especially around Hopedale, Minier and Stanford.

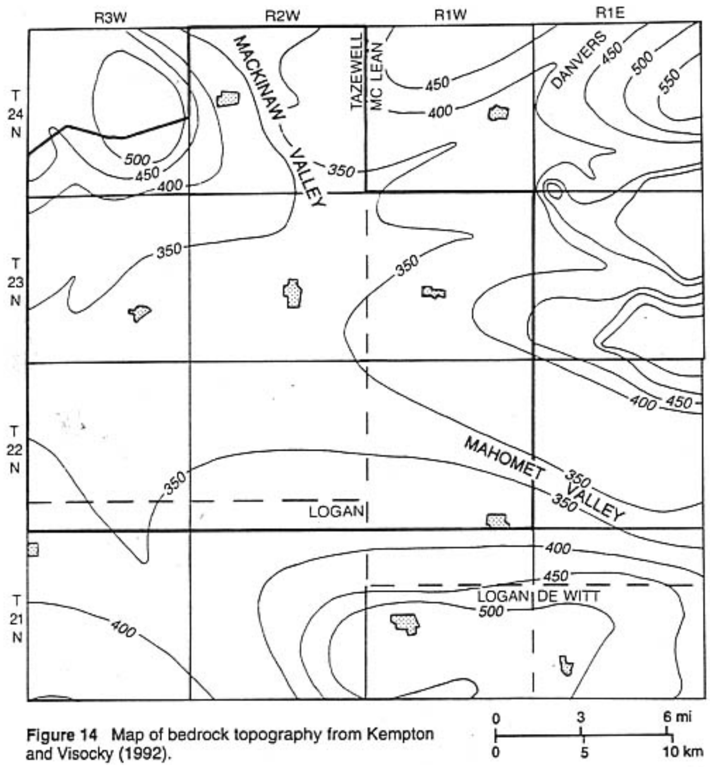

Figure 14 Map of bedrock topography from Kempton and Visocky (1992).

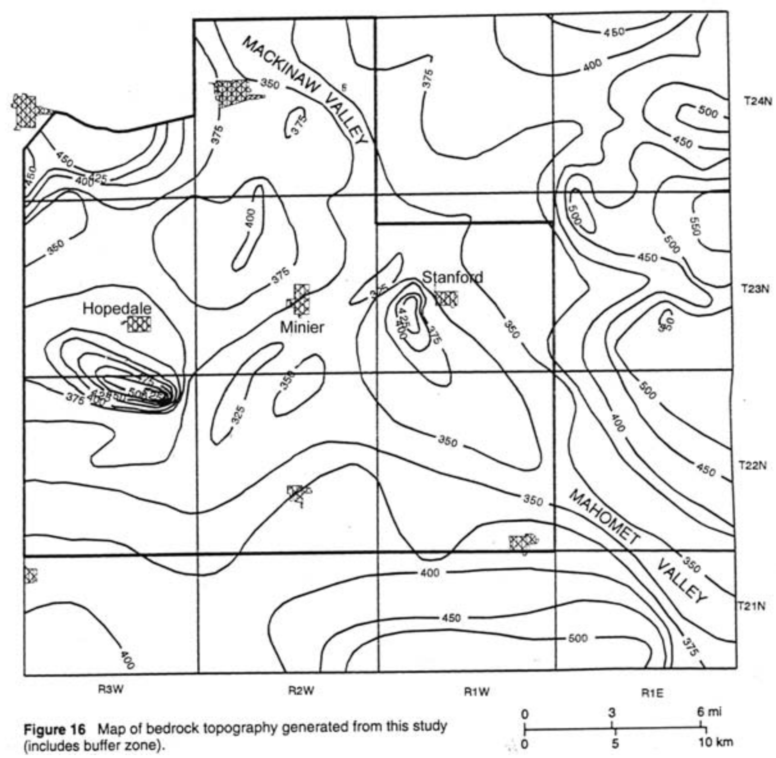

Figure 16 Map of bedrock topography generated from this study (includes buffer zone).

Figure 5. P-wave landstreamer in use at the Fisher field site.
A. The geophones are attached to steel sleds and towed behind the car at 3 m intervals.
B. One version of the system uses a weight-drop source attached to an ATV.
C. In another version of the system, the weight drop is mounted on a trailer that also tows the landstreamer sleds. (from Pugin et al. 2004 a&b)

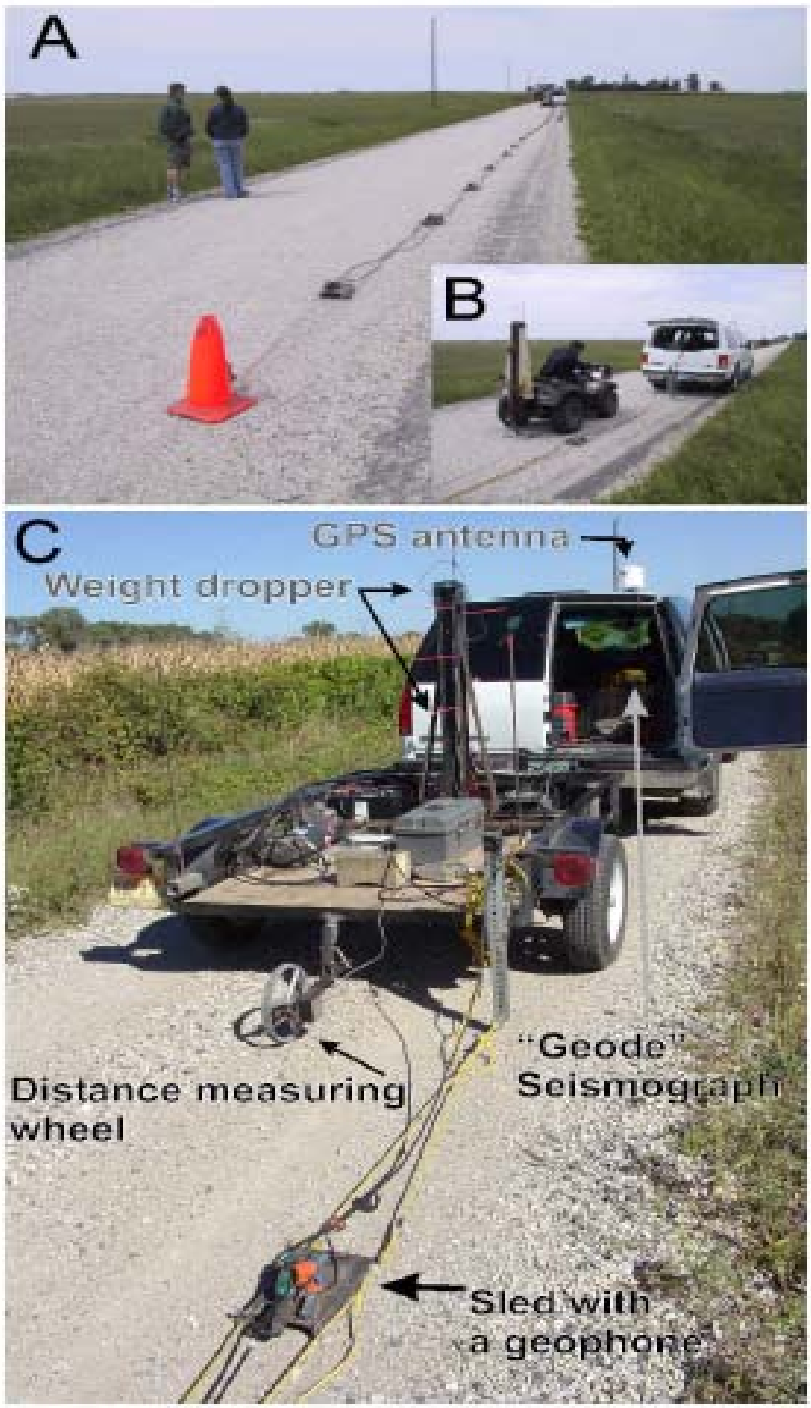

Figure 6. The SH-wave landstreamer in use at Allerton Park. Horizontal geophones are attached to sleds towed behind the car. Inset: the source is a 1-kg hammer striking a plate held under the rear wheel of the car. (from Pugin et al. 2003).

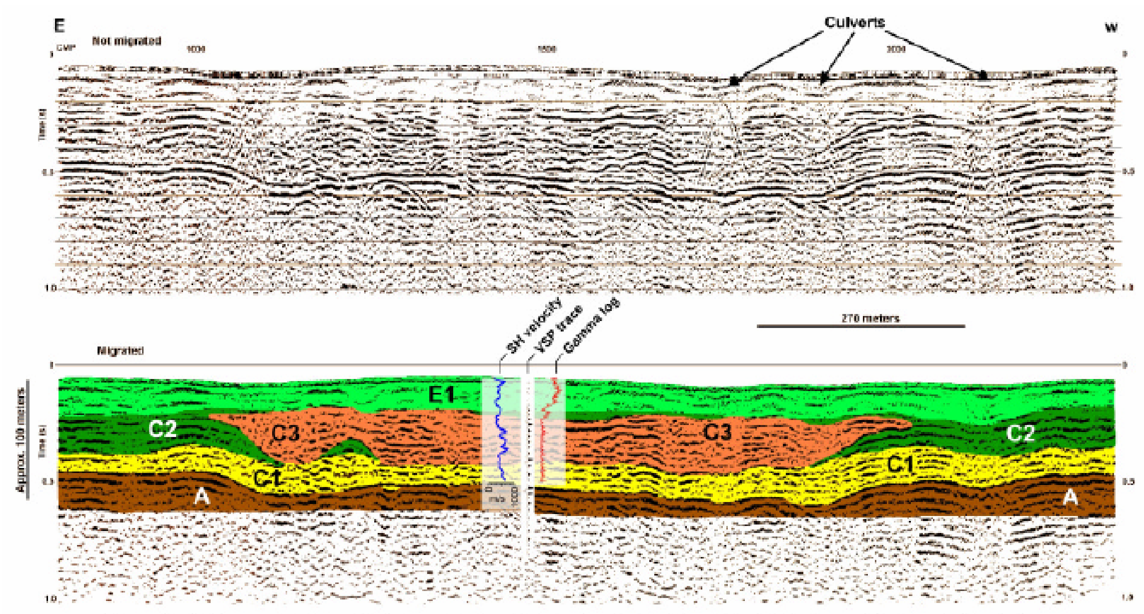

Figure 7. SH-wave results at Allerton Park showing the presence of a buried tunnel-valley in the Illinoian sediments. This tunnel valley has eroded through the fine-grained till units to the top of the Mahomet Sand. Just north of this location, coarse sediments in the Sangamon River valley cross this tunnel valley so that a vertical pathway of coarse sediment is present from the Sangamon River directly to the Mahomet Sand. (from Pugin et al., 2003)

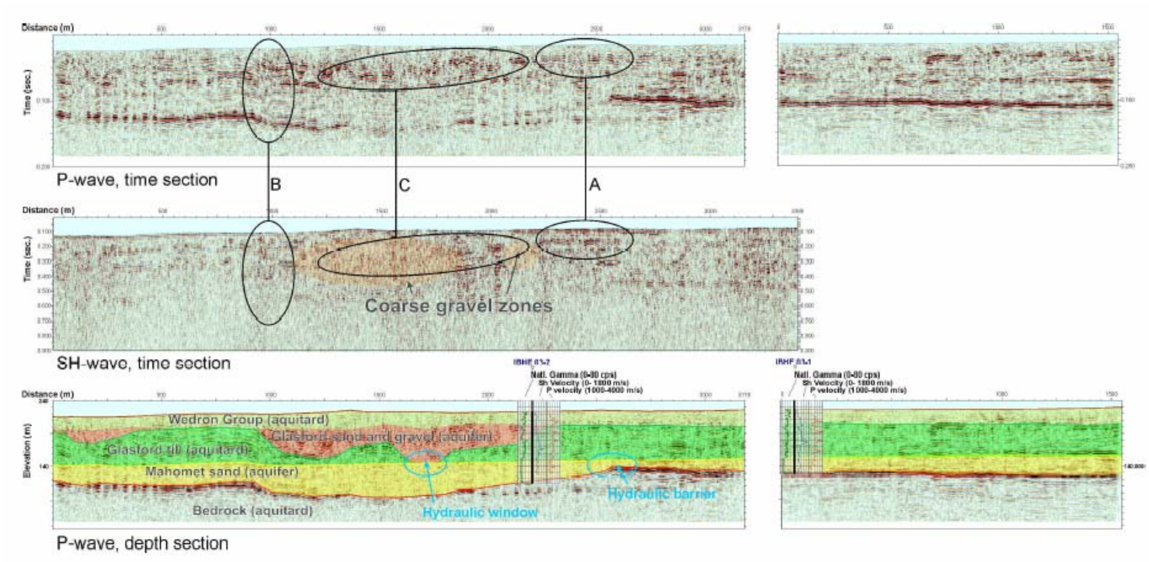

Figure 8. Examples of both P-wave and SH-wave landstreamer data from the Fisher area (Pugin et al., 2004a). Notice in particular, the difference in elevation of the strong bedrock reflection from the right to the left side of the section. The resulting thinning of the overlying sand is probably the cause of an abrupt decrease in potentiometric surface in the area.

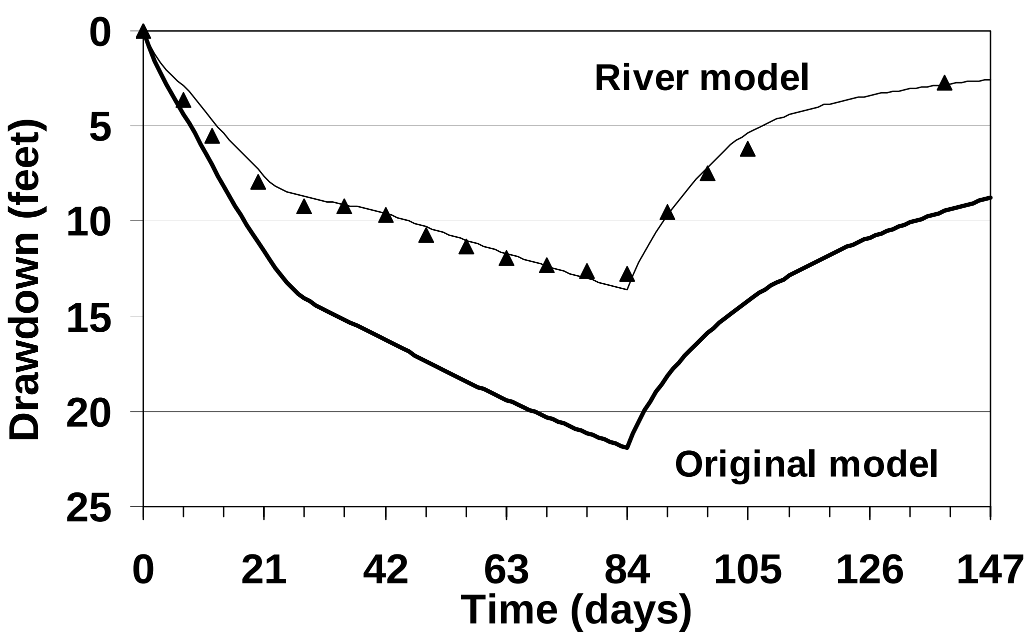

Figure 9. Observed drawdowns (triangles) at the Decatur wellfield versus calculated drawdowns from the original and the modified (with the added rivers cells) models

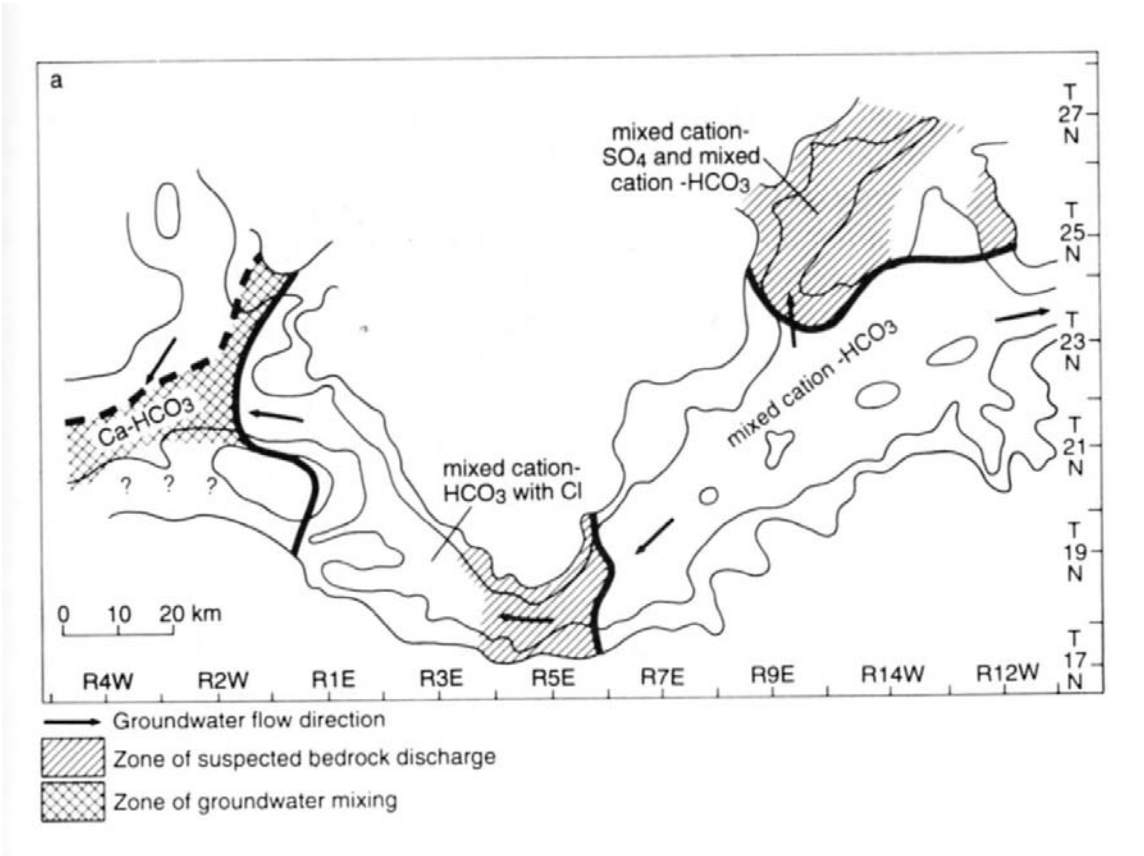

Figure 10. Map of geochemically distinct areas of the Mahomet aquifer (from Panno et al., 1994) showing zones of suspected bedrock discharge into the Mahomet aquifer.

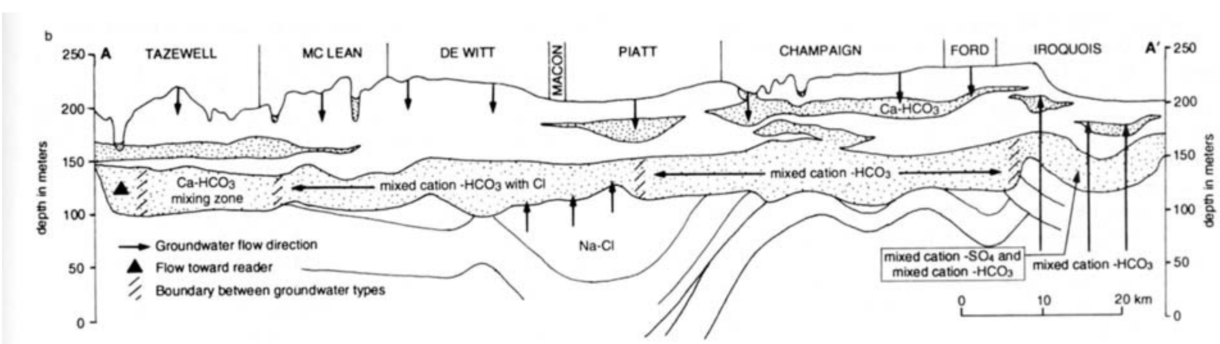

Fig. 8. Conceptual model of the MVA showing ground-water types, ground-water flow directions, areas of suspected leakage from bedrock, and the zone of ground-water mixing at the confluence of the MAK and MVA Aquifers: a = aerial view; b = longitudinal cross section A-A′.

Figure 11. Conceptual model of groundwater geochemistry and flow within the Mahomet aquifer (shown in a cross-section along the valley) (from Panno et al., 1994).

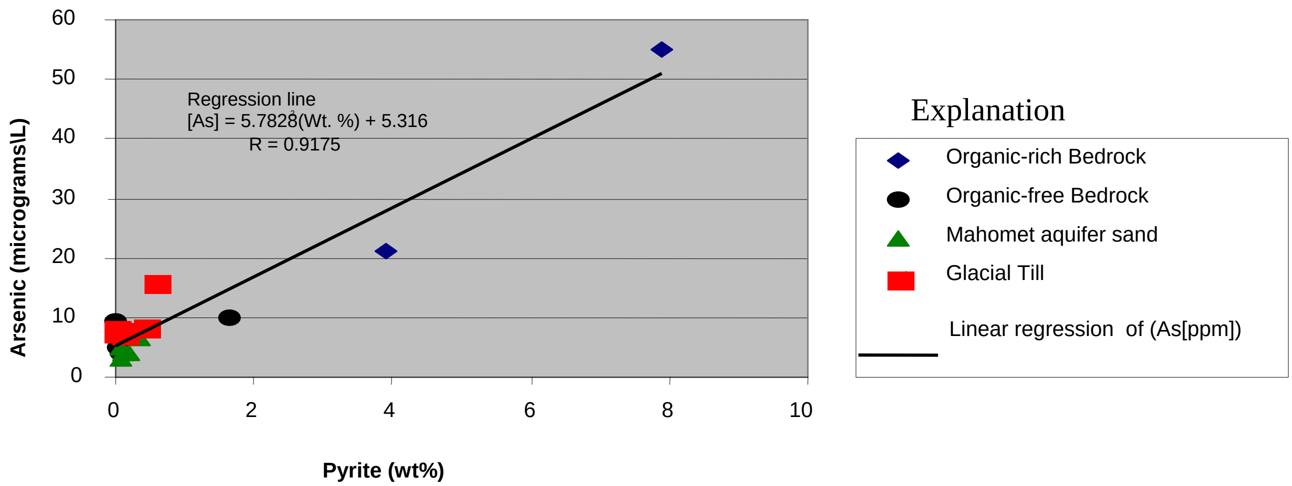

Figure 12. The relation between arsenic and pyrite in Mahomet aquifer materials (Warner, 2001).