An Introductory Guide to the Mahomet Aquifer and Natural Gas Storage in East-Central Illinois

Prepared by the Prairie Research Institute

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INTRODUCTION

Illinois has a great diversity of natural resources. One that is of particular importance in east-central Illinois is the Mahomet aquifer, the region's primary source of water that is essential for public water supply, power generation, and commercial, industrial, domestic, and agricultural uses. The Mahomet aquifer lies below approximately 2.5 million acres (3,940 square miles) throughout portions of 14 counties (Figure 1). Approximately 1,500 high-capacity wells draw from the aquifer, and an average daily groundwater withdrawal rate (not including power-generation uses) was estimated to be 210 million gallons a day (Roadcap et al., 2011). The Mahomet aquifer provides an estimated "53 million gallons per day (mgd) of drinking water to approximately 120 public water supplies and thousands of rural wells" that serve over 500,000 people in the region (USEPA, 2015).

One resource that Illinois does not contain is significant amounts of naturally occurring gas that can be used for electricity generation and heating. For that, Illinois relies significantly on natural gas that is transported to the state via interstate pipelines and stored below the ground in geologic formations.

Issues concerning the Mahomet aquifer and natural gas storage are particularly relevant given the recent establishment of the Mahomet Aquifer Protection Task Force (MAPTF) by Public Act 100-0403, which went into effect in August 2017. The task force was formed "to address the issue of maintaining the clean drinking water of the Mahomet Aquifer, the principal aquifer in east-central Illinois." The task

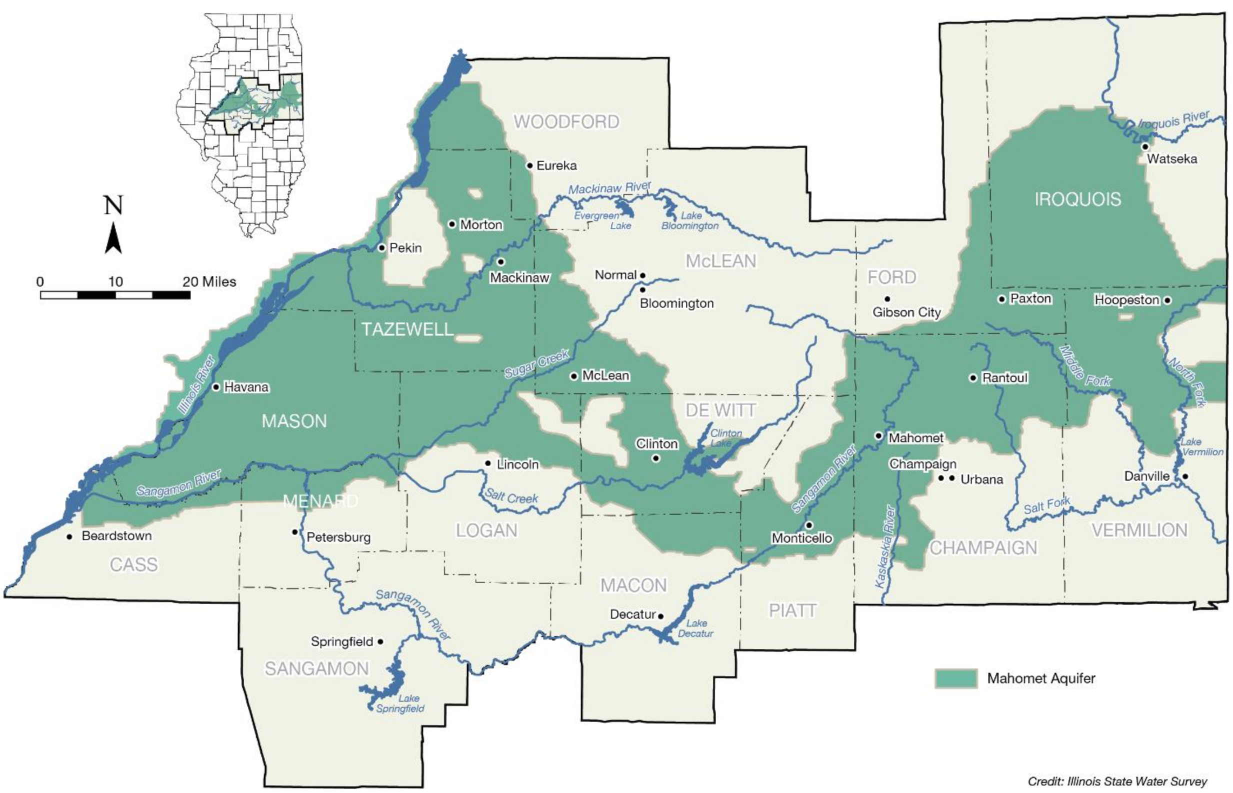

Figure 1: East-central Illinois regional water supply planning area (Roadcap et al., 2011).

force is charged with conducting “a study of the Mahomet Aquifer in furtherance of: (1) developing a State plan to maintain the groundwater quality of the Mahomet Aquifer; (2) identifying potential and current contamination threats to the water quality of the Mahomet Aquifer; (3) identifying actions that might be taken to ensure the long-term protection of the Mahomet Aquifer; and (4) making legislative recommendations for future protection of the Mahomet Aquifer.”

PRI geologists and hydrologists have studied topics such as aquifer formation and geometry, groundwater flow modeling, flow directions and recharge, water supply development, and water quality. Other PRI scientists have studied environmental monitoring, bedrock geology, oil production, storage of natural gas, and sequestration of carbon dioxide. PRI tapped into this unique assemblage of scientific expertise and formed a Natural Gas Working Group (NGWG) in October 2017 (see appendix A for additional information). One of the near-term tasks of the NGWG is to assist stakeholders in their responses to a natural gas leak that occurred from the Manlove natural gas storage field in northern Champaign County. Longer term, the NGWG is considering natural gas storage activities in Illinois as they relate to natural resource characterization, management, and protection issues.

This introductory guide was developed by the NGWG in coordination with colleagues across PRI to provide basic information about the Mahomet aquifer and natural gas storage in east-central Illinois. PRI is available to the task force as a technical resource and can draw on the expertise of PRI scientists and programs to help the task force meet its goals. PRI can also help identify additional data, reports, activities, or assessments that may be relevant to the task force. Requests for reports, presentations, and interactions are welcomed and can be prioritized based on needs of the task force and PRI.

Potential Aquifer Protection Issues to Consider

PRI scientists have provided technical guidance to many communities, water authorities, and stakeholder groups concerned with the use and management of the Mahomet aquifer. An important effort to address this topic is the ongoing Regional Water Supply Planning Committee that was formed by the Mahomet Aquifer Consortium and the Illinois Department of Natural Resources. In its reports (MAC, 2009 and 2015), the committee made numerous recommendations and identified key action items. Since then, PRI scientists have focused on some of those issues in their studies of the aquifer. Further, a short list of common issues that may have relevance to the task force is provided below. The list is not intended to be comprehensive, but it is provided as initial information that the task force may wish to consider and includes areas in which PRI has significant experience.

Water quantity and quality topics relevant to aquifer protection, include:

- sustainability of water supply development
    - resource exploration, delineation, and assessments;
    - system/well planning (e.g., evaluation of existing water quality, evaluation of potential impacts of planned withdrawals/interferences);
    - identification of recharge areas;
- measurements and monitoring of the resource;
- water withdrawal reporting;
- water quality reporting;
- assessments of land-use impacts from point and non-point sources;

- assessment and mitigation responses to contamination;
- water quality regulation (e.g., well permitting, groundwater classification, source water protection, sole source designation, resource impairment); and
- water quantity regulation (e.g., well permitting).

Further, in June 2017 PRI convened stakeholders for a workshop on the Mahomet aquifer. A report on that workshop has been published as ISGS Circular 594: The Future of the Science of the Mahomet Aquifer, and it contains a section on “Scientist – Stakeholder Relationships” that also raises a number of topics relevant to aquifer characterization and protection (Brown et al., 2018).

SHALLOW GEOLOGY AND THE MAHOMET AQUIFER

The geologic deposits within approximately 400 feet of the land surface include the glacial and postglacial deposits lying above bedrock, which contain important natural resources providing societal benefits to the region's citizens and economic prosperity. In the upper 5 feet, the modern soil is developed in windblown sand and silt (*loess*; see appendix B for glossary) and the *glacial till* (see glossary) that is the foundation for one of the most productive agricultural systems in the United States. Deeper in the subsurface, glacial sand and gravel deposits hold the region's most important supplies of drinking water. The Mahomet aquifer, the largest of these aquifers, is a part of the glacial legacy in the Upper Midwestern United States.

Regional Overview

Geological processes at work in the Earth's landforms and surfaces have shaped how the rocks and sediments are distributed in the area. These processes were active over various lengths of time, causing the erosion and deposition of geologic materials to form the landscape present today. During preglacial time, the composition and structure of the sedimentary bedrock strongly influenced development of surficial landforms. The landscape resembled the present-day Ozark Plateau. The preglacial landscape was further modified through erosion by water and glaciers. In east-central Illinois, bedrock was uplifted several hundred million years ago and then deeply incised to form the prominent Mahomet Bedrock Valley. This valley (Figure 2) is 8–20 miles wide and 200–300 feet deep, stretching from the Illinois River to the Indiana state line (Kempton et al., 1991; Soller et al., 1999). The bedrock valley once contained a medium to large river that drained westward to the Ancient Mississippi River. On multiple occasions, beginning about 2.6 million years ago, glaciers covered much of the Upper Midwestern United States (Killey, 2007). In east-central Illinois, the deposits left behind by the glaciers covered the preglacial landscape.

During the earliest glaciation of the area, the Mahomet Bedrock Valley contained rivers carrying sediment-laden meltwater. Deposits of sand and gravel accumulated in front of westward advancing ice, partially filling the bedrock valley. The remainder of the valley contains glacial tills and lake sediment (Herzog et al., 1995; Stumpf and Dey, 2012). By the end of the Illinois Episode glaciation, the Mahomet Bedrock Valley was buried. Deposits of the most recent glaciation form the surficial landforms found on the present landscape. For more information about the Ice Age and the study of glacial materials, see Killey (2007).

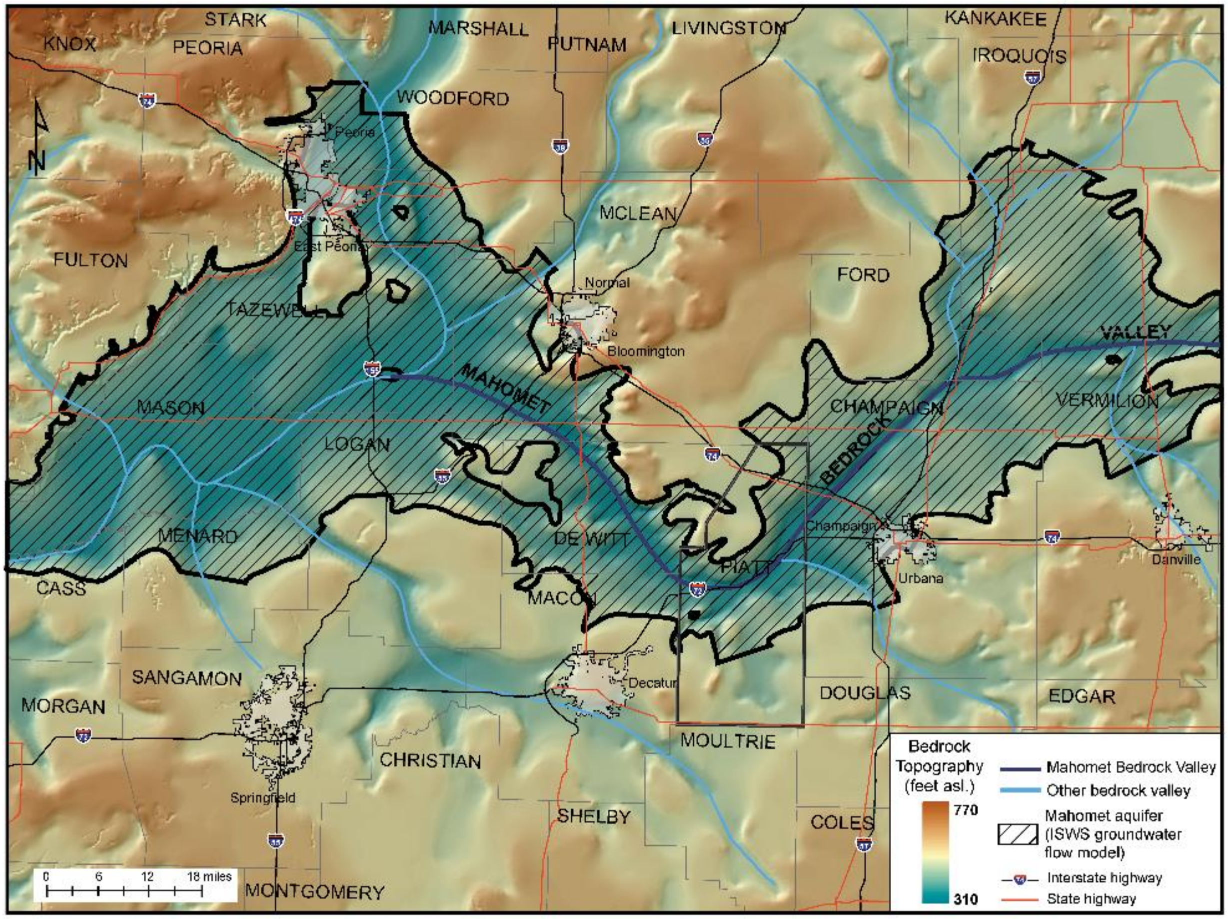

Figure 2: Map of east-central Illinois showing the boundary of the Mahomet Bedrock Valley. The boundary is shown over the bedrock surface (i.e., all the glacial sediment is removed). The topography of the surface is represented by a colored image (compiled from Herzog et al., 1994).

Mahomet Aquifer

Unconsolidated sediments from three glaciations (Wisconsin, Illinois, and pre-Illinois Episodes) cover the bedrock surface and have filled the preglacial valleys. The bottommost unit in the Mahomet Bedrock Valley includes sand and gravel (called the Mahomet Sand Member) deposited by rivers draining glaciers. In places, the sand and gravel are overlain by glacial till of the pre-Illinois glaciation (Figure 3). However, widespread erosion by ice and water during the subsequent (Illinois) glaciation removed much of this older sediment. The eroded landscape was then covered by glacial sand and gravel and till (Grigg tongue and Vandalia Member). A similar period of erosion also occurred later in the Illinois glaciation and at the beginning of the Wisconsin glaciation when the Pearl Formation and Ashmore Tongue were deposited. In some places, erosion during successive events occurred over the same area. This repetitive sequence of erosion and deposition has formed overlapping deposits of sand and gravel.

Brown et al. (2018) describes the complexity of how the Mahomet aquifer has been defined over time. It is important to recognize that the Mahomet aquifer has been defined in different ways for different (e.g., hydrogeologic, regulatory) purposes. Roadcap et al. (2011) used work from Soller et al. (1999) and identified the Mahomet aquifer in a hydrogeologic context as the lowermost deposits of preglacial and glacial sand and gravel (Mahomet Sand Member) in the Mahomet Bedrock Valley within the Banner

Formation (Figure 3). For a good, general resource about groundwater, aquifers, and associated topics, see Killey (2004).

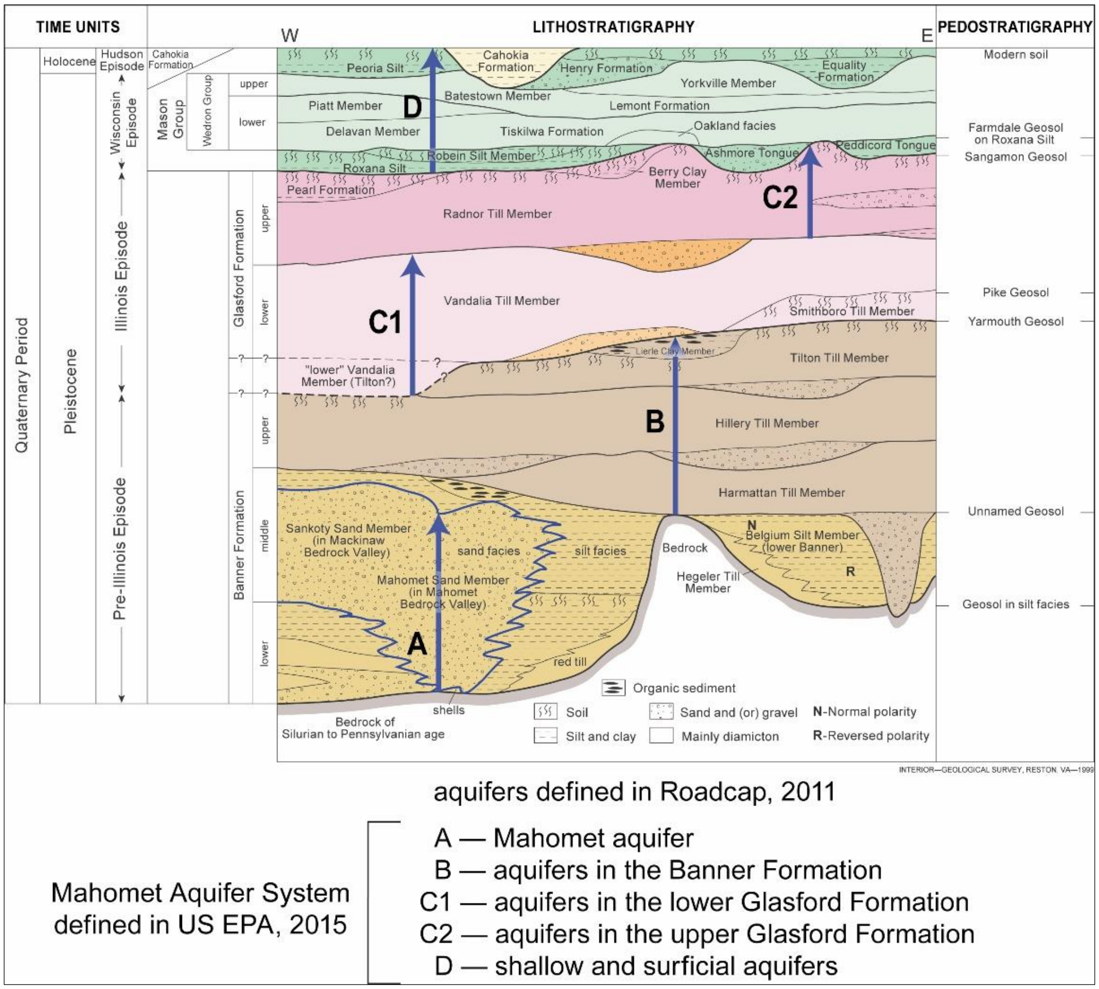

Figure 3: Diagrammatic stratigraphic column and correlation of glacial deposits (lithostratigraphic units), as shown in Soller et al., 1999. Hydrogeologic framework depicted as the Mahomet aquifer (A), aquifers in the Banner Formation (B), aquifers in the lower Glasford Formation (C1), aquifers in the upper Glasford Formation (C2), and shallow and surficial aquifers (D) recreated from Roadcap et al., 2011. The Sole Source Aquifer designation of the Mahomet aquifer, the Mahomet aquifer system (US EPA, 2015), includes all of the hydrogeologic units of Roadcap et al., 2011. The Mahomet Sand Member and the Sankoty Sand Member of the Banner Formation (lithostratigraphic units) are outlined in blue.

HYDROGEOLOGY AND MODELING

A hydrologic conceptual model of flow in the Mahomet aquifer system was developed by Roadcap et al. (2011) from previous studies, analyses of new data, and the construction of a groundwater flow model. The conceptual model (Figure 4) is a generalized representation of the different flow processes within the Mahomet aquifer system that are represented in greater detail within the numerical groundwater flow model used to actually calculate flows. The aquifer exhibits a wide range of hydraulic behaviors due to the complex geometry and composition of the glacial deposits, and the variable interconnections between the deposits, the land surface, and streams. These behaviors affect how the aquifer responds to variations in precipitation, streamflow, and pumpage from high-capacity wells. Hydrologic conditions for almost the entire Mahomet aquifer and for the thicker portions of the overlying Lower Glasford aquifer are suitable for the development of high-capacity wells. Shallower or thinner sand layers can still be considered aquifers because they can provide useful quantities of water to small community systems, private wells, and springs.

The eastern portion of the aquifer is under confined conditions (i.e., *a confined aquifer*; see glossary), because it is deeply buried and overlain by low-permeability glacial tills and lake sediment. The fine-grained sediments act as confining layers that pressurize the aquifer and cause the water in a well to rise to a level above the top of the sand. To recharge the confined portions of the Mahomet aquifer, water

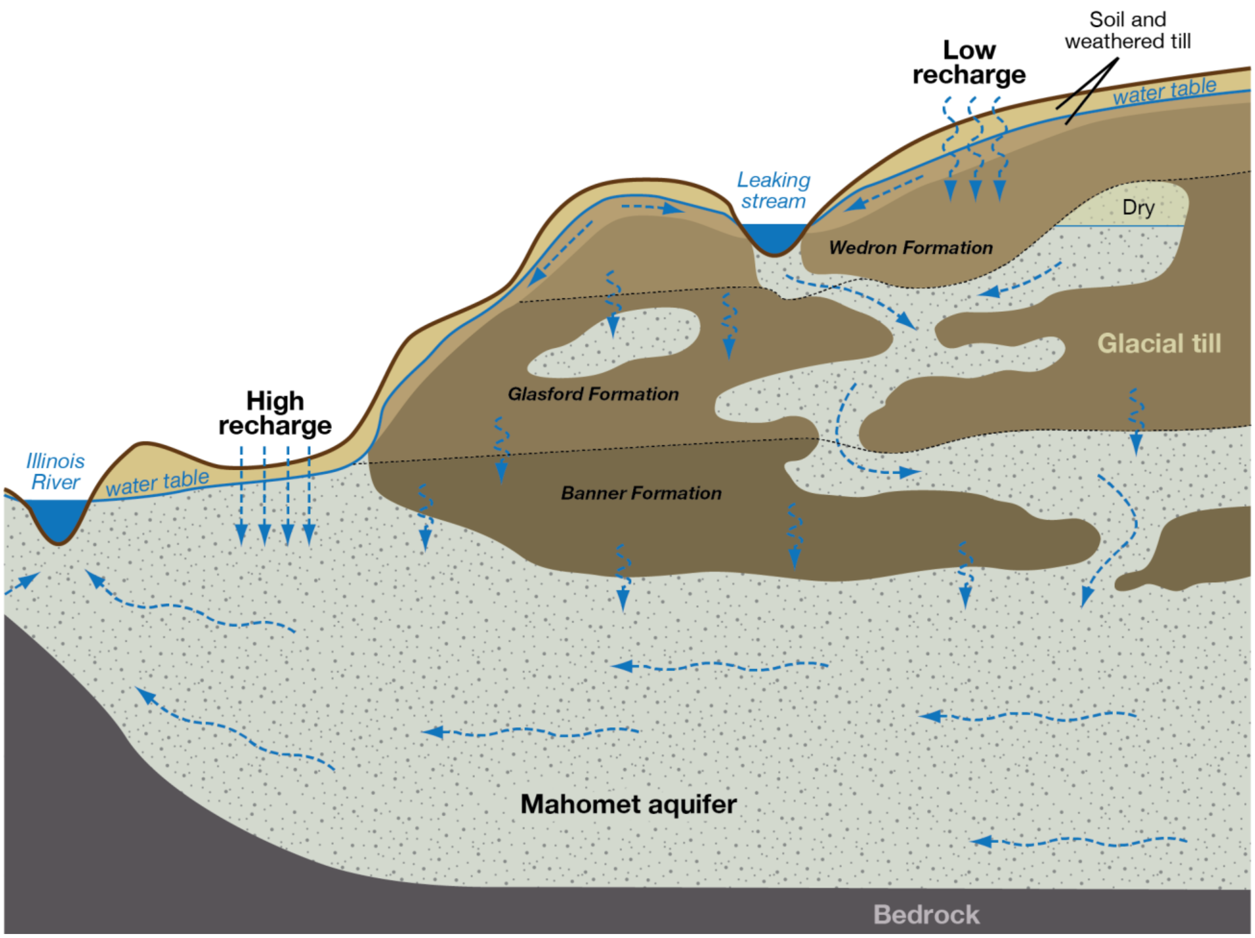

Figure 4: Conceptual model of flow in the Mahomet aquifer (not to scale; Roadcap et al., 2011).

must flow either downward through the confining layers or laterally through water-bearing zones that are connected at a distance to the surface or to other sources of water. The rate of recharge cannot be directly measured; rather, it is calculated through mass balance calculations in the groundwater flow model constructed for the Mahomet aquifer system. In the northern Champaign County region, the recharge rates calculated by the model are less than 1 inch per year, or only 3% of the average yearly rainfall. Important recharge areas may occur in the shallower deposits of glacial sand and gravel along a "leaky" stream where there is a downward gradient and an interconnection to the deeper aquifers. Leaky stream segments have been found along the Sangamon River in Piatt County (Roadcap and Wilson, 2001), and connections likely occur along the Sangamon River north of Fisher and along Salt Creek near Rantoul (Roadcap et al., 2011).

The ISWS collects data from an observation well "network" of more than 180 wells at more than 140 sites, largely composed of wells especially built for monitoring water levels. Water level observations generally are collected on a monthly or quarterly basis, with selected wells containing data loggers recording water levels as often as hourly. Numerous local and state entities have funded cooperative ISWS/ISGS drilling and monitoring efforts.

Groundwater flow directions and areas of recharge and discharge for the eastern segment of the Mahomet aquifer can be determined from a contour map of water level measurements from the 141 wells, known as a *potentiometric surface* map (Figure 5; see glossary). Similar to water on the land surface, groundwater flows from high areas (lighter shading) to low areas (darker shading). The map

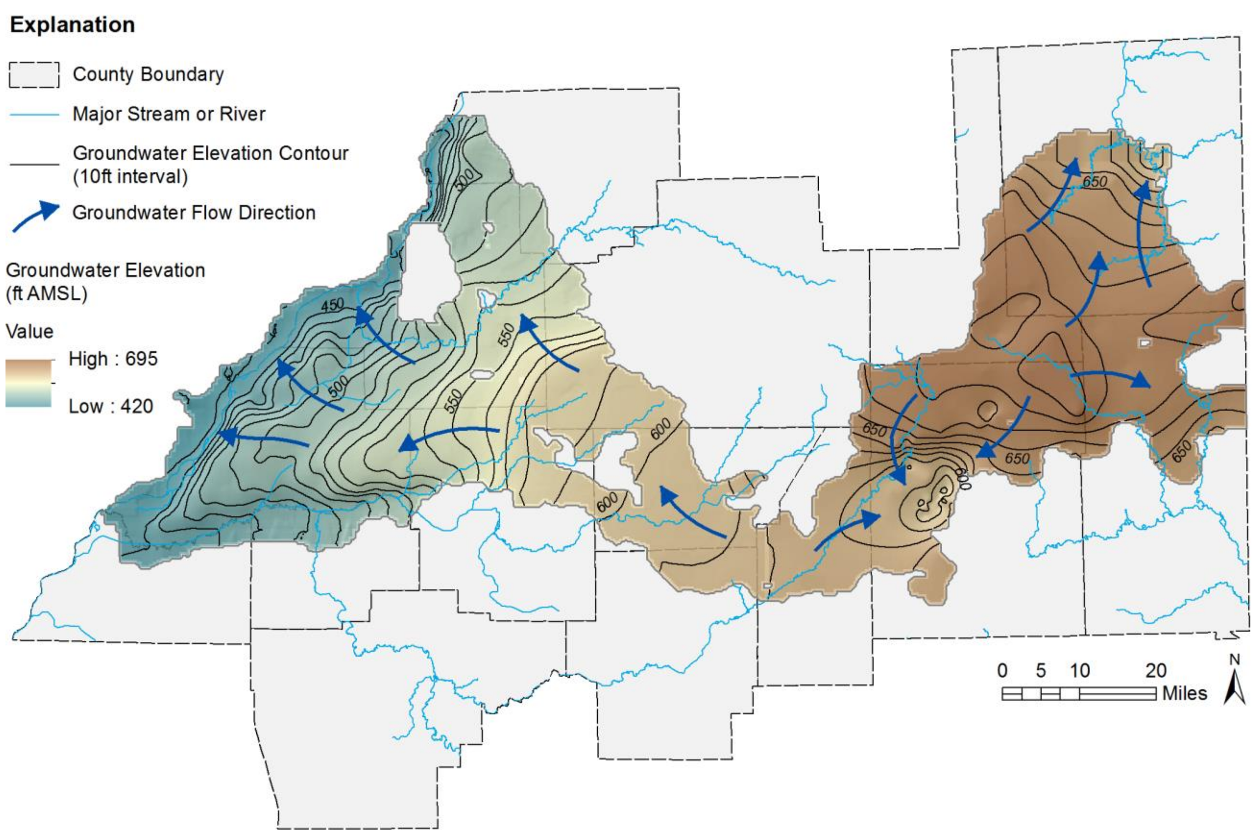

Figure 5: Composite potentiometric surface map of the Mahomet aquifer based on measurements from 1990 to 2009.

shows that groundwater flow is divided into several sub-regional flow systems with two prominent features: a high in the potentiometric surface near Paxton in Ford County and a large *cone of depression* (see glossary) at Champaign. Pumpage in Champaign-Urbana averages around 23 million gallons per day (mgd), which has lowered water levels by up to 100 feet and caused a reversal of flow in Piatt and western Champaign Counties. All of the groundwater withdrawn at Champaign is balanced by local precipitation and stream leakage.

WATER QUALITY

Water quality in the Mahomet aquifer system is generally very good. The water tends to be hard due to high concentrations of naturally occurring calcium and magnesium, a common issue in aquifers in Illinois. Naturally occurring iron is also abundant in the Mahomet aquifer. Neither hardness nor iron are considered human health risks, but they can be a nuisance. Unless treated, hard water can cause the buildup of scale in pots and water pipes and iron can discolor ceramic fixtures. Thus, it is common for well owners in east-central Illinois to treat their well water with softening and iron-removal systems.

Because low-permeability deposits up to 200 feet thick cover much of the aquifer, it is generally protected from contaminants originating at the land surface. There are, however, some naturally occurring contaminants in the Mahomet aquifer and shallower aquifers in the region, the most important being arsenic. Concentrations of arsenic above the drinking water standard (10 micrograms per liter, µg/L) are found in both the Mahomet aquifer and the shallower Glasford aquifers. In the Mahomet aquifer, there are two primary areas of elevated arsenic concentrations: 1) Tazewell County (western part of the aquifer) and 2) deep, central parts of the aquifer along bedrock valley walls in Piatt, DeWitt, and Macon Counties (Figure 6). Wells in the Glasford aquifers with elevated arsenic concentrations are found throughout the Mahomet bedrock valley region. Arsenic concentrations in the Mahomet and Glasford aquifers vary significantly; wells less than a mile apart can have much different arsenic concentrations. Geochemical conditions within the aquifers control arsenic concentrations. For example, arsenic concentrations are low in wells also containing sulfate, and high only in wells where sulfate is absent or at very low concentrations. Further, wells containing elevated arsenic concentrations often contain naturally occurring methane in addition to high organic carbon and ammonium concentrations.

Chloride is another common constituent in the Mahomet aquifer (Figure 7). Although it is not toxic to humans and does not have a primary drinking water standard, too much chloride can cause water to taste salty. In most of the aquifer, chloride is derived from natural sources. In the eastern part of the aquifer, chloride concentrations are extremely low. Near the border between Champaign and Piatt Counties, chloride concentrations abruptly increase, due to the natural discharge of brine from older bedrock into the aquifer from below. Chloride concentrations then decrease gradually to the west as the briny water mixes with more dilute water. In the extreme western part of the region, the Mahomet aquifer goes from being covered by a continuous layer of fine-grained glacial sediment (i.e., a confined aquifer) to the confining layer being absent, thin, or discontinuous (i.e., an *unconfined aquifer*; see glossary). In this unconfined region (Mason and western Tazewell Counties), surface activities have a greater potential to impact water quality. Elevated chloride concentrations in the East Peoria and Pekin areas are probably due to road salt runoff from those urban areas. Some wells in this region also have elevated nitrate-nitrogen concentrations, primarily due to fertilizer applied to agricultural farmland.

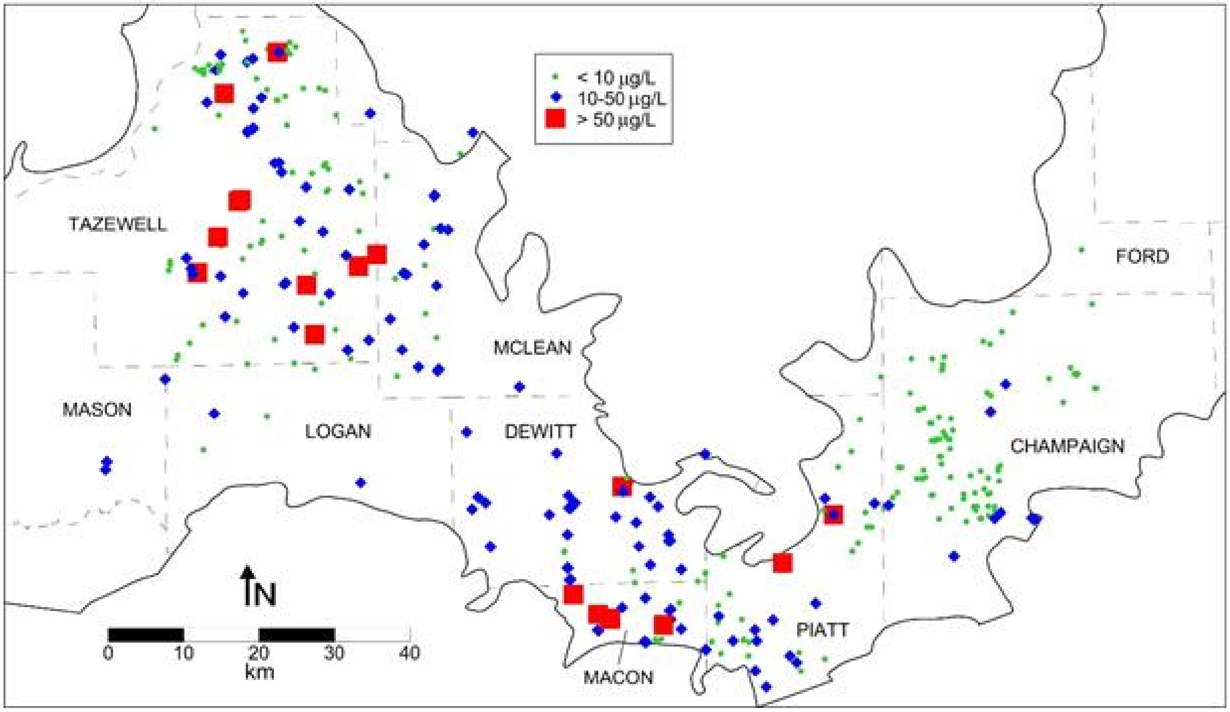

Figure 6: Arsenic concentrations in the Mahomet aquifer. The drinking water standard is 10 µg/L (Kelly et al., 2005).

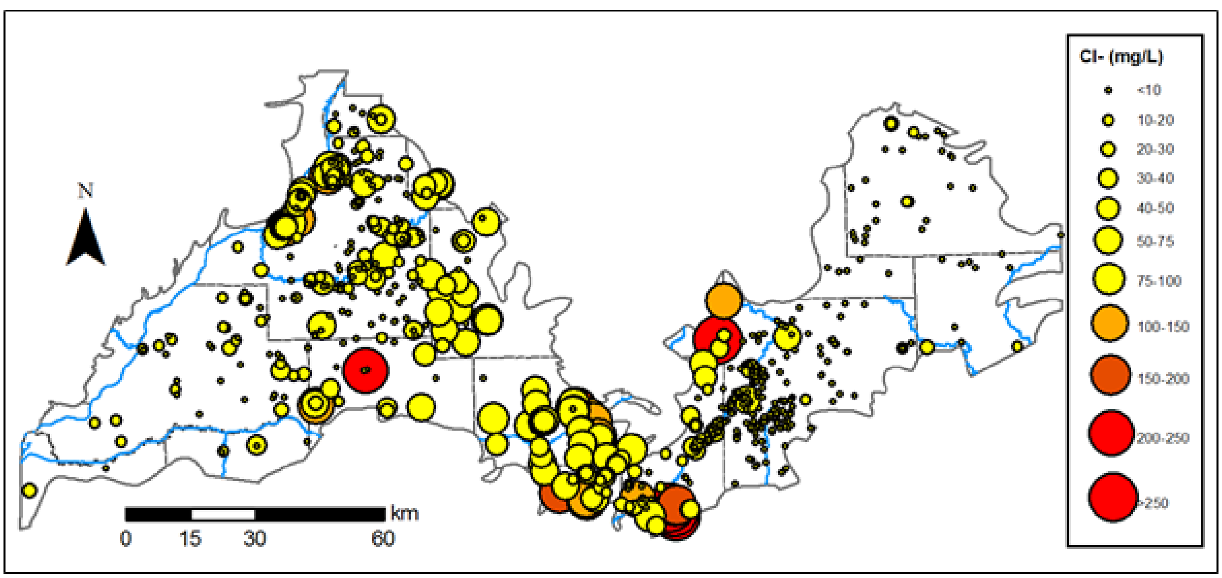

Figure 7: Chloride concentrations in the Mahomet aquifer. Elevated chloride in the central part of the aquifer is from natural bedrock discharge. Elevated chloride in the East Peoria/Pekin region in the west is probably due to road salt runoff (Kelly et al., 2012).

KEY POLICY AND REGULATORY REFERENCES

As the task force performs its duties pursuant to P.A. 100-0403, the members should take into account the Illinois Groundwater Protection Act (415 ILCS 55 *et seq.*, hereafter "IGPA"), which declares:

> "…it is the policy of the State of Illinois to restore, protect, and enhance the groundwaters of the State, as a natural and public resource. The State recognizes the essential and pervasive role of groundwater in the social and economic well-being of the people of Illinois, and its vital importance to the general health, safety, and welfare. It is further recognized as consistent with this policy that the groundwater resources of the State be utilized for beneficial and legitimate purposes; that waste and degradation of the resources be prevented; and that the underground water resource be managed to allow for maximum benefit of the people of the State of Illinois."

To fulfill that policy, the IGPA "responds to the need to manage groundwater quality by emphasizing a prevention-oriented process. The IGPA is a comprehensive law that relies upon a state and local partnership. Although the IGPA directs toward protection of groundwater as a natural and public resource, special provisions target drinking water wells. The IGPA responds to the need to protect groundwater quality and establishes a unified groundwater protection program by:

- Setting a groundwater protection policy;
- Enhancing cooperation;
- Establishing water well protection zones;
- Providing for surveys, mapping, and assessments;
- Establishing authority for recharge area protection;
- Requiring groundwater quality standards; **and**
- Requiring technology control regulations.

"The groundwater policy sets the framework for management of groundwater as a vital resource. The law focuses upon uses of the resource and establishes statewide protection measures directed toward potable water wells. In addition, the IGPA provides an opportunity to local governments and citizens to perform an important role for groundwater protection in Illinois." (IEPA, 2018a)

In addition to the IGPA, Title 35 of the Illinois Administrative Code includes the following groundwater rules and regulations (IEPA, 2018a):

- Subtitle F, Chapter I, Part 615: Existing Activities In A Setback Zone Or Regulated Recharge Area
- Subtitle F, Chapter I, Part 616: New Activities In A Setback Zone Or Regulated Recharge Area
- Subtitle F, Chapter I, Part 617: Regulated Recharge Areas
- Subtitle F, Chapter I, Part 620: Groundwater Quality
- Subtitle F, Chapter I, Part 670: Minimal Hazard Certifications
- Subtitle F, Chapter I, Part 671: Maximum Setback Zone for Community Water Supply Wells

With respect to natural gas storage, the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) exercised its federal authority to regulate underground natural gas storage facilities (USDOT-PHMSA, 2016) and has incorporated by reference American Petroleum Institute (API) Recommended Practices 1170 and 1171 by law (49 CFR 191 and 192). These API recommended practices, now mandatory, are intended to serve as a foundation for minimum standards for both inter- and intra-state underground gas storage facilities. Additional information is available from the PHMSA website (https://primis.phmsa.dot.gov/ung/index.htm).

SUBSURFACE GEOLOGY OF NATURAL GAS STORAGE

In Illinois, natural gas is used by over 80 percent of households as their primary source of heat. Natural gas is also an increasingly important source of fuel for electric power generation because of the ongoing retirement of older coal-fired power plants. However, Illinois has no significant sources of natural gas and must rely on other states, such as Oklahoma, Texas, and Louisiana to supply this fuel by using long-distance pipelines. Illinois households use approximately 44% more heat than the national average. Demand for natural gas varies significantly throughout the year, and as a result, Illinois has the largest amount of natural gas storage in *saline formations* (see glossary) in the nation (Figure 8; 780 billion cubic feet total) to meet the volume and timing of the demand.

In Illinois, utilities have been storing natural gas in the subsurface for over 50 years. One of these gas storage fields, Manlove Field, partially lies within the Mahomet aquifer boundary.

Natural gas storage projects must be located in areas that have the proper geologic conditions. Three primary geologic components of underground natural gas storage include a reservoir, a caprock, and a geologic trap. In Illinois, natural gas underground storage sites primarily use saline formations as reservoirs (Figure 9). In addition, there are important facility and operational requirements in order to safely and effectively store and retrieve the injected gas.

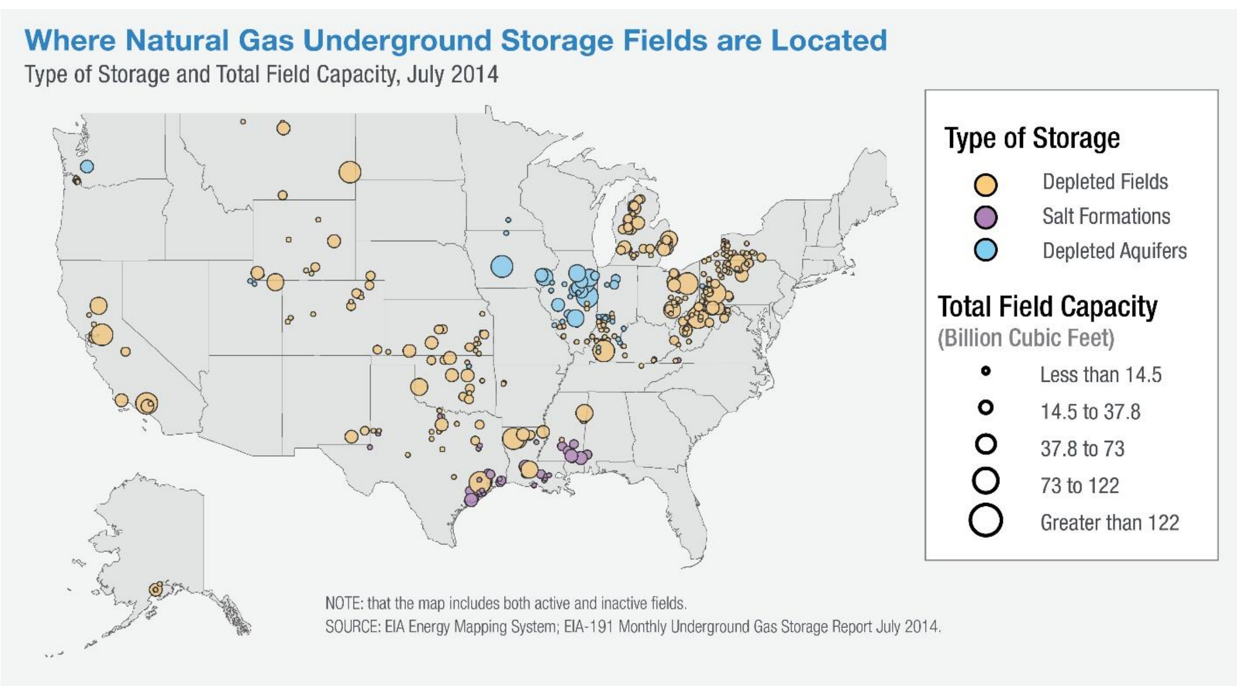

Figure 8: Distribution of natural gas underground storage throughout the United States. Note: The term "depleted aquifers" is analogous to "saline formations" used in this document.

Reservoir

A natural gas reservoir is a porous and permeable geologic formation in which natural gas is stored. Adequate *porosity* (void space; see glossary) and *permeability* (connectivity of the void spaces; see glossary) are needed in order to allow for injection, storage, and withdrawal of the natural gas to occur at sufficient rates to meet the dynamics of supply and demand. In northern Illinois, for example, the Mt. Simon Sandstone is commonly used for natural gas storage because of its relatively high porosity and permeability. It is also a thick and widespread geologic unit in the area.

Caprock

A caprock is a laterally continuous geologic unit or units above the storage reservoir that has a much lower permeability to impede the upward movement of natural gas above the reservoir under storage pressure. In Illinois, caprocks typically contain a significant component of shale, a very low permeability geologic rock.

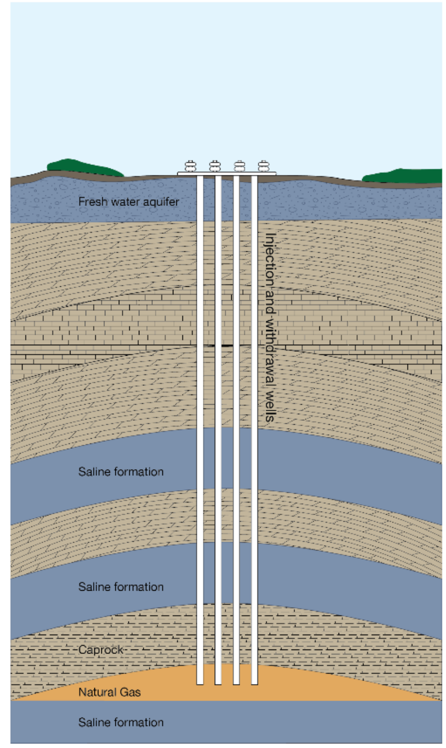

Figure 9: Conceptual illustration of a gas storage field using a domed geologic trap (not to scale). The area shaded in orange would be the zone within a reservoir that is used to store natural gas. The gas is trapped in the lowermost saline formation by the caprock.

Geologic Trap

A geologic trap is a structural feature in the subsurface that impedes upward migration of fluids (e.g., natural gas) so they are confined within a reservoir. One type of trap that is formed by folding rocks upward is called a dome (Figure 9). When gas is injected into the saline formation, or reservoir, the gas displaces briny water that occurs naturally in pore spaces of deeply buried rocks. The shape of the rock layers then constrains the movement of the stored gas and allows the accumulation of gas in the upper portion of the saline formation.

FEDERAL REPORT ON GAS STORAGE

In October 2016, a federal task force produced a report titled "Ensuring Safe and Reliable Underground Natural Gas Storage" (Interagency Task Force on Natural Gas Safety, 2016). The federal task force was established to "analyze California's Aliso Canyon natural gas leak and make recommendations on how to reduce the likelihood of future leaks from underground natural gas storage facilities across the country." In its 2016 report, the federal task force provided more than 40 recommendations across three principal research areas, including minimizing the risk of well failures; reducing health and environmental impacts of major leak incidents; and understanding energy reliability implications. As excerpted from the 2016 report, key recommendations of the federal task force included:

- "Gas storage operators should begin a rigorous evaluation program to baseline the status of their wells, establish risk management planning and, in most cases, phase-out old wells with single-point-of-failure designs."

- "Advance preparation for possible natural gas leaks and coordinated emergency response in the case of a leak can help manage and mitigate potential health and environmental impacts of leaks when they do occur."
- "Power system planners and operators need to better understand the risks that potential gas storage disruptions create for the electric system."

The PRI Natural Gas Working Group is collaborating with the Illinois Department of Natural Resources - Office of Oil and Gas Resource Management, the Illinois Environmental Protection Agency, and other stakeholders to evaluate the federal task force recommendations in the context of Illinois' natural gas storage. While the PRI Natural Gas Working Group is in the initial stages of its work, the federal task force recommendations have already helped identify topics of greatest importance where state-level efforts should be focused.

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APPENDIX A: PRAIRIE RESEARCH INSTITUTE NATURAL GAS WORKING GROUP

The Prairie Research Institute (PRI) Natural Gas Working Group was formed in October 2017 by the PRI Executive Director's office. The purpose of the group is to be an objective, technical working group that 1) assists stakeholders in their responses to address the natural gas leak that occurred from Manlove Field near Fisher, Illinois, and its associated natural resource impacts, and 2) consider natural gas storage activities in Illinois as they relate to natural resource characterization, management, and protection issues. The working group's point of contact is Trish Barker (tlbarker@illinois.edu; 217-300-2327), and the facilitator is Randy Locke. The tasks below show the current scope of the working group. For additional information, see https://prairie.illinois.edu/content/natural-gas-working-group.

Near-Term Tasks

1.1. Develop a list of key reports and data generated or maintained by PRI that can be used as a basis for the sound scientific characterization of the local geology, hydrology, water chemistry, and related natural resources associated with the gas leakage from Manlove Field.

1.2. Assist stakeholders, including state agencies and offices (e.g., Illinois Department of Natural Resources, Illinois Environmental Protection Agency, Attorney General's Office, Illinois Emergency Management Agency), in their responses to the gas leakage from Manlove Field. PRI assistance may include technical review of information based on areas of expertise of PRI staff, especially related to natural resource characterization, management, and protection.

Longer-Term Tasks

1.3. Review natural gas storage activities in Illinois as they relate to natural resource characterization, management, and protection issues. As appropriate, make recommendations for improving the safe and reliable operation of natural gas storage in Illinois in the context of existing state and federal requirements.

Members

Name	Role	Area of Expertise
Trish Barker	**Member, Point of Contact**	**External Communications**
Randy Locke	**Member, WG Facilitator**	**Environmental Monitoring**
Sallie Greenberg	Member	Stakeholder Engagement
Walt Kelly	Member	Aqueous Geochemistry
Hannes Leetaru	Member	Bedrock Geology
George Roadcap	Member	Groundwater Flow Modeling
Andrew Stumpf	Member	Glacial Geology
Jason Thomason	Member	Hydrogeology, Geophysics
Steve Whittaker	Member	Gas Storage Operations
Rick Winkel	Member	Policy

APPENDIX B: GLOSSARY

Note: Killey (2007) was used as a basis for the hydrogeologic definitions below.

Aquifer: a body of saturated rock or sediment that yields useful quantities of groundwater to wells or springs.

Aquitard: a body of saturated rock or sediment of low permeability that slows water transmission to or from an aquifer.

Caprock: a laterally continuous geologic unit above a reservoir that impedes the upward movement of fluids above the reservoir under storage pressure.

Cone of depression: a lowering of the water table (unconfined aquifer) or the potentiometric surface (confined aquifer) that resembles the shape of a cone and is created by pumping water from a well.

Confined aquifer: an aquifer bounded by aquitards above and below it.

Geologic trap: a structural feature in the subsurface that impedes upward migration of fluids (e.g., natural gas) so they are confined within a reservoir.

Glacial till: unsorted and unconsolidated material deposited directly by glaciers.

Loess: windblown silt and fine sand having a porous and crumbly character that usually contains carbonate minerals.

Permeability: the capacity or property of a rock, sediment, or soil to transmit fluid.

Porosity: the volume of empty space in a rock or sediment, such as cracks, pores, or other types of voids, in relation to the total volume.

Potentiometric surface: a surface represented by the level to which water will rise in tightly cased wells. The water table is the potentiometric surface for an unconfined aquifer.

Reservoir: a subsurface formation with sufficient porosity and permeability to store and transmit fluids.

Saline formation: a subsurface geologic unit with pore spaces that are filled with fluids with high concentrations of dissolved minerals (e.g., brine).

Unconfined aquifer: an aquifer that rests on top of an aquitard but that is not bounded on top by a confining layer. The water table indicates the top of the aquifer.