Prepared for the Advisory Committee on Water Information Subcommittee on Ground Water

# Results of the Illinois-Indiana Pilot Study for the National Ground Water Monitoring Network

By Allen Wehrmann (Illinois State Water Survey), Jerry Unterreiner (Indiana Department of Natural Resources),
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Rick Cobb (Illinois Environmental Protection Agency), Dave Larson (Illinois State Geological Survey),
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## Introduction

Groundwater is the source of drinking water for more than 130 million Americans each day. Of the 83,300 million gallons per day (Mgd) of groundwater used in 2000, 68% was used for irrigation, about 23% was used for public supply and domestic use, 4% for industrial use, and the remainder for livestock, aquaculture, mining, and power generation (Hutson and others, 2004). About 35% of the Nation's irrigation water supply is obtained from groundwater. Although overall water use in the USA has been relatively steady for more than 20 years, groundwater use has continued to increase, primarily as a percentage of public supply and irrigation. In addition to human uses, many ecosystems are dependent on groundwater discharge to streams, lakes, and wetlands.

The Nation's groundwater resources are under stress and require increased interstate and national attention to assure sustainable use of the resource. State, Federal and local agencies have documented significant impacts to major and minor aquifers throughout the USA. Impacts include declining water levels and groundwater contamination from chemical use and waste disposal. In addition, climate change may result in increased flooding which could significantly affect groundwater quality and increased drought periods can significantly affect groundwater levels. Increased groundwater demand is expected in all sectors of the economy, including the heavy use sectors of agriculture, drinking water, and energy production. Increased biomass production will increase demand on groundwater for water supply to produce fuels and further degrade water quality as a result of increased agrichemical application and residuals disposal. These activities threaten the aquifers directly as well as groundwater dependent ecosystems and the baseflow of streams supported by groundwater discharge. Proposals for geologic sequestration of carbon dioxide present the potential to acidify groundwaters if migration of the carbon dioxide to adjacent aquifers occurs. Additionally, brackish and saline groundwaters are likely to be increasingly developed and treated in water deficient areas and may compete as locations for carbon sequestration. As groundwater use increases it is imperative to improve the overall management of the resource. An integrated local, State, Tribal, Federal partnership approach is needed to accommodate multi-jurisdictional issues, effective management of transboundary aquifers and promote stakeholder involvement.

Sustainable groundwater management is currently constrained by the lack of a nationally integrated groundwater monitoring network focused on providing water-level and water-quality data for regionally and locally important aquifers. The need for a national groundwater monitoring network has been recognized by numerous water resource agencies. To address this concern the Subcommittee on Ground Water (SOGW) was established in 2007 as an ad-hoc committee under the Federal Advisory Committee on Water Information (ACWI). The SOGW, which includes more than 70 people representing 55 different organizations, was charged with developing a framework that establishes and encourages implementation of a long-term groundwater quantity and quality monitoring network. This network is intended to provide data and information necessary for planning, management and development of groundwater supplies to meet current and future water needs, including ecosystem requirements. In June 2009, the SOGW issued a report entitled *A National Framework for Ground-Water Monitoring in the United States*. This report describes a framework for the establishment and long-term operation and use of a National Ground-Water Monitoring Network (NGWMN).

The NGWMN is envisioned as a voluntary, integrated system of data collection, management, and reporting that provides the data needed to help address present and future groundwater management questions raised by Congress, Federal, State and Tribal agencies and the public. The NGWMN will be comprised of a compilation of selected wells from existing State, Federal and Tribal groundwater monitoring programs. The focus of the network will be on assessing the baseline conditions and long-term trends in water levels and water quality. As proposed, the NGWMN will include two monitoring sub-networks: a sub-network that focuses on monitoring unstressed parts of principal aquifers and aquifer systems and a sub-network that targets areas of concern within aquifers and aquifer systems (typically contaminated areas and areas where water-level declines are of concern). Monitoring within the NGWMN will include four different categories: baseline monitoring, trend monitoring, surveillance monitoring, and special studies monitoring.

Groundwater level monitoring has been conducted for many decades in many states. Data from these networks have been used to help identify, develop, and manage groundwater supplies at the local and State level. Groundwater quality monitoring programs have been developed more recently in response to the focus on water quality that resulted from passage of the Safe Drinking Water Act; the Clean Water Act; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other environmental laws. As of 2007, 37 states operated statewide or regional groundwater monitoring networks and 33 states have at least one active groundwater quality monitoring program. The state monitoring networks are funded using a combination of State and Federal funds. The networks are operated by a variety of State agencies, many of them in cooperation with the United States Geological Survey (USGS). The networks operate under a variety of specific State / Tribal / local goals and objectives and are not necessarily focused on all of the important aquifers within a State or Reservation. As a result, it is very difficult to use these groundwater monitoring programs to evaluate water availability and rates of use on a regional or national basis. Because many aquifers support multiple jurisdictions, a focus on monitoring at the aquifer level rather than at a political subdivision is critical to facilitate sustainable groundwater use.

Based on statements of interest from numerous states and multi-state groups, the SOGW selected five pilot projects: Illinois-Indiana, Texas, New Jersey, Montana and Minnesota. These five pilots vary in scale from an intra-state monitoring network that covers only a portion of one individual state to an inter-state network where two States share an aquifer. Information obtained from Pilot Projects will help to better understand the current status, range of coverage, and level of coordination of groundwater monitoring networks in the U.S., and will serve as a foundation for developing an estimate of the number and type of resources needed for full-scale implementation of the national monitoring network. The five pilot projects have been conducted through cooperative efforts between the State monitoring network managers, the SOGW and the USGS.

### Purpose of Study

One of the three key recommendations included in A National Framework for Ground-Water Monitoring in the United States is to develop and conduct a limited number of pilot studies to: (a) test the NGWMN concepts and approaches detailed in the Framework document; (b) evaluate the feasibility and resources necessary to implement a national network; and (c) produce recommendations leading to full scale implementation. The pilot projects were initiated in early 2010 and are expected to be completed by March 2011 Each of the pilot projects proposed to address the following objectives:

1) evaluate the feasibility of designing network segments within one or more principal, major or other important aquifers, using conceptual groundwater flow models as the primary network design element,
2) determine methods to establish unstressed and targeted sub-networks within the target aquifer(s),
3) test the design of the NGWMN and its ability to provide water level and quality data to large-scale assessments of the groundwater resource,
4) determine the feasibility and design parameters of a central, web-based data portal that will allow NGWMN to gather and disseminate data, as well as promote data sharing among data providers and the public,
5) test and assess the effectiveness of coordination, cooperation and collaboration mechanisms among federal, state, regional and local, and tribal data collectors, providers and managers,
6) investigate methods to ensure that data collected by the data providers and, therefore, the NGWMN as a whole are comparable. Data elements, including site characteristics, well construction and details, the frequency of water-level measurements, water-quality analytes, water-level measurement procedures, water-quality sampling procedures, and written standard operating procedures, will all be evaluated and,
7) determine the timeframe and costs associated with adding, upgrading, or developing a state, tribal, or local well network and data management system that meets the criteria and needs of the NGWMN and its on-going implementation.

Each Pilot evaluated potential monitoring points within each principal, major or other important aquifer for potential inclusion in the NGWMN and identified a subset of proposed monitoring points as meeting NGWMN's "stressed" or "unstressed" sub-network design criteria. In addition, each Pilot identified all costs of potential participation in a NGWMN that are specific to the particular Pilot State on a total and per well basis, as appropriate, including historical costs for the development and maintenance of their existing network; one-time start-up costs; and capital, operational, and maintenance costs associated with filling data gaps. Each Pilot also interfaced with the NGWMN Data Portal under development by the USGS.

### The Mahomet-Teays Aquifer of Illinois/Indiana

The principal aquifer selected for the Illinois-Indiana Pilot is a regionally significant Quaternary sand and gravel aquifer that extends beneath portions of an 11-county area of east-central Illinois and beneath portions of 12 counties in north-central Indiana. Known as the Mahomet-Teays Aquifer (or more simply as the Mahomet Aquifer) in Illinois, and as the Teays-Mahomet Aquifer in Indiana, the aquifer occupies portions of the buried Teays-Mahomet bedrock valley (also called the Lafayette (Teays) bedrock valley in Indiana) detailed within the regional portion (HA-730K) of the U.S. Geological Survey (USGS) *Ground-Water Atlas of the United States* (Lloyd and Lyke, 1995) (Figure 1).

The aquifer also is identified within the *Principal Aquifers of the United States* (U.S. Geological Survey, 2003) as the Pleistocene Series 112PLSC and Outwash 112OTSH.

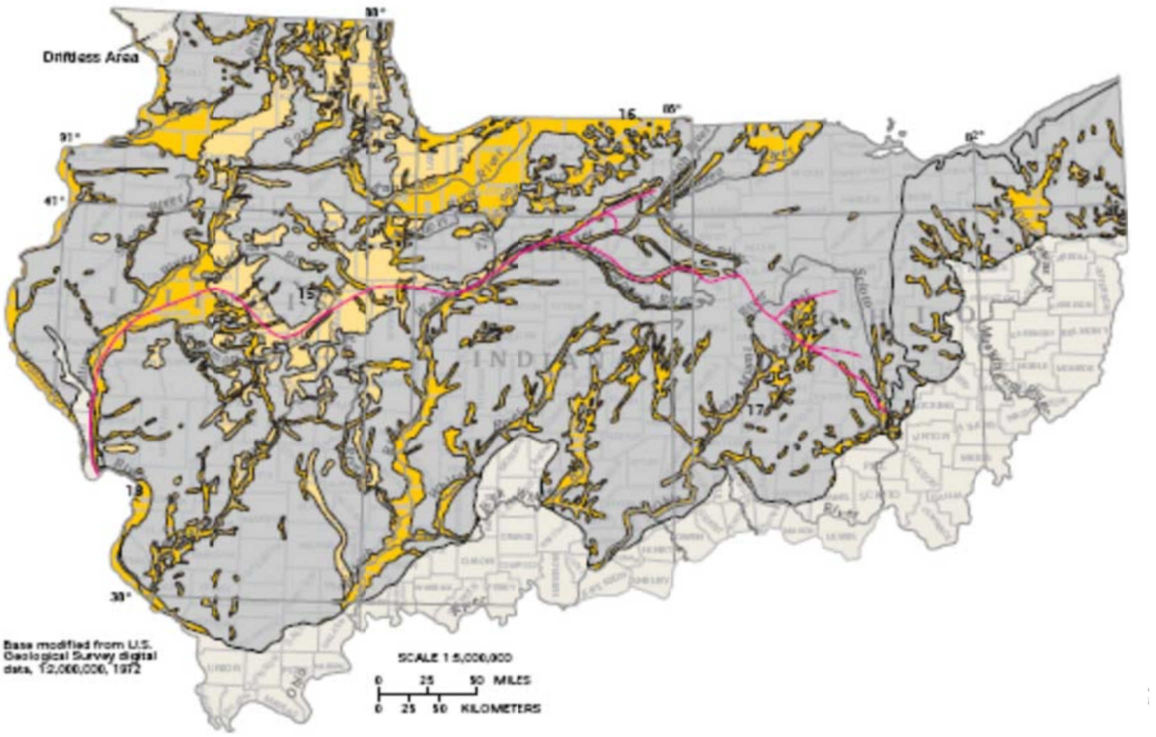

Figure 1. Aquifers in the unconsolidated deposits of the Central Lowland Province (from Lloyd and Lyke, 1995). The red line traces the thalweg of Teays bedrock valley.

The origin of the Teays bedrock valley, while subject to considerable debate, appears to have had its headwaters east of the Appalachian Mountains (Bleuer, 1989). From its headwaters it flowed westward through West Virginia, Ohio, Indiana, and finally into Illinois where it joined with the ancestral Mississippi River. The ancestral Teays bedrock valley was subsequently filled with Pleistocene glacial deposits and because the aquifer generally occupies the bottom of the valley, the aquifer varies in thickness from a feather-edge along the valley walls to 150 feet or more along the valley's central axis. In much of east-central Indiana the valley is gorge-like and confined to a width of one mile or less. In places the valley is over 300 feet below the surrounding bedrock uplands. In other areas, the valley broadens to a width of several miles, such as at Lafayette (IN) where the Anderson, Metea, Wildcat, and Tippecanoe bedrock valleys join with the Teays bedrock valley. A Geological Society of America symposium produced a Teays-Mahomet historical perspective including a series of technical papers (Melhorn and Kempton, 1991).

The Mahomet-Teays Aquifer extends across east-central Illinois from the Indiana border near Hoopeston to the Illinois River near Havana (Figure 2). In Illinois, the aquifer provides an estimated 220 Mgd to communities, industry, agriculture, and rural wells (of which 71 Mgd was for municipal use). In Indiana, the aquifer extends from Adams County at the Ohio state line westward through the state and into Illinois (e.g., Visocky and Schicht, 1969; Kempton et al., 1991; Holm, 1995; Wilson et al., 1998; Hollinger et al., 2000; Roadcap and Wilson, 2001; Burch, 2008; Bruns and Steen, 2003); a portion of the aquifer also falls within the federally-funded USGS Lower Illinois River Basin (LIRB) NAWQA study area (Warner and Schmidt, 1994).

A goal of the Illinois-Indiana Pilot is to increase information accessibility and awareness of the Mahomet-Teays Aquifer System across state lines. Heightened monitoring and sharing of information not only between Illinois and Indiana, but nationally as well, will increase awareness and ensure this regional aquifer system remains an important drinking water supply and a pivot point for economic sustainability and development.

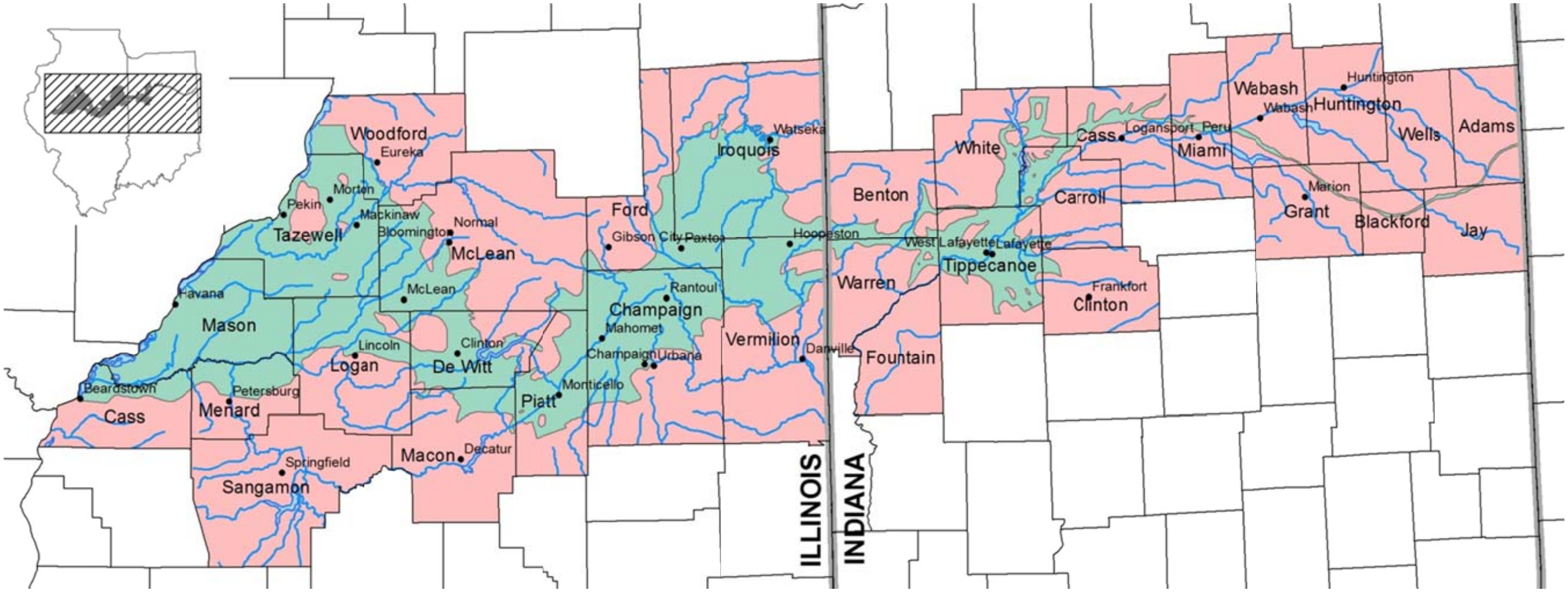

Figure 2. The Mahomet-Teays aquifer region (shaded in green) within Illinois and Indiana.

## Conceptual Model of the Mahomet-Teays Aquifer System

Hydrogeologic sections somewhat typical of the Mahomet-Teays valley in Indiana, in places, are shown in Figure 3and Figure 4 (Bruns and Steen, 2003). These sections simply portray a complex glacial setting of diamictons and intertill aquifers of varying potential commonly overlying the basal Mahomet-Teays aquifer. Given the complexity of the glacial setting, a conceptual model of water movement into and within the aquifer has been developed but continues to evolve as new data are collected and analysed (Figure 5). For the purposes of this report, reference to the Mahomet-Teays aquifer system includes the Mahomet-Teays and overlying aquifers.

Recharge to the aquifer is predominantly by vertical movement of water downward from infiltration of precipitation over the land surface within the aquifer boundaries. The eastern portion of the aquifer, including that portion of the aquifer within Indiana, is confined by as much as 200 feet of diamicton (glacial till). Average recharge to the aquifer is fairly low (from 6 inches/year to less than 0.5 inch/year) and comes predominantly through sparse interconnections to shallower coarse-grained materials and streams. Toward the western end of the aquifer, nearer to the Illinois River in Mason and Tazewell Counties, the land surface elevation falls substantially as the Illinois River is approached. Here the confining layers are absent and permeable aquifer sands occur at land surface. The aquifer becomes unconfined and recharge is quite rapid (exceeding 12 inches/year).

A map of the aquifer potentiometric surface within Illinois (Figure 6) shows that within Illinois, groundwater flow is predominantly down-valley from east to west discharging to the Illinois River and several interconnected streams such as the Sangamon and Mackinaw Rivers. Discharge to other surface outlets on the eastern perimeter (Iroquois River to the northeast, Wabash River to the east, and Middle Fork Vermilion River to the southeast) also is apparent. A similar potentiometric surface of the aquifer within Indiana suggests hydrogeologic similarities to that in Illinois with groundwater discharge from the Mahomet-Teays to surface streams like the Wabash River and various tributary streams such as the Eel and Tippecanoe Rivers, and Wildcat Creek (Bruns and Steen, 2003).

A large cone of depression in the Champaign area has substantially altered the natural down-valley movement of groundwater, such that a groundwater divide now exists west of Champaign beneath Piatt County. Groundwater withdrawals from the Mahomet-Teays at Champaign currently average 24 Mgd. Groundwater in that area now moves eastward into the Champaign cone. Groundwater level monitoring in the shallower Glasford sands shows that the cone of depression at Champaign is affecting groundwater levels in those units. Continued monitoring will provide critical information on the long-term impact of such pumping on the availability of source bed leakage.

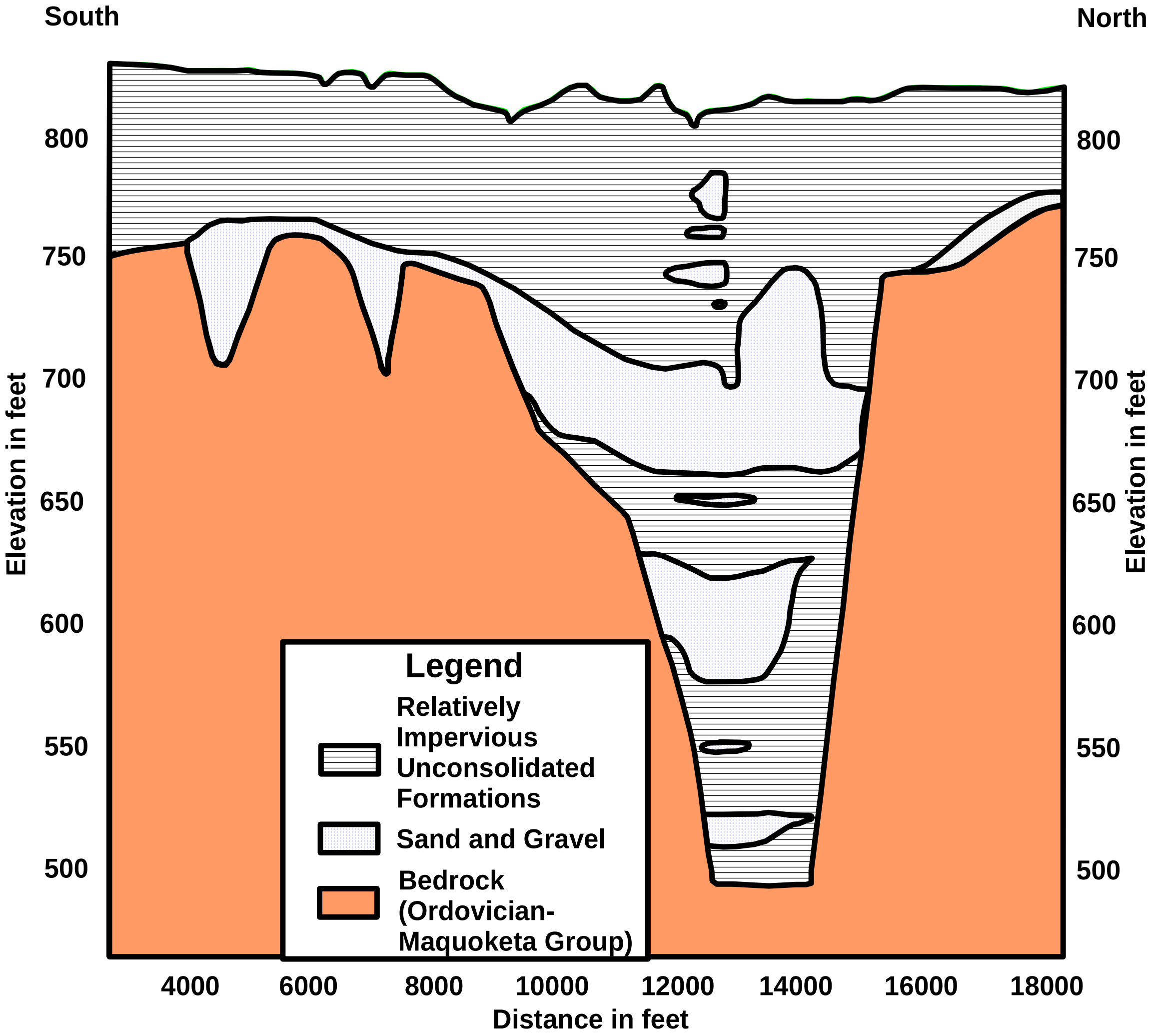

Figure 3. Generalized cross section of the Teays valley near the Indiana-Ohio state line (from Bruns and Steen, 2003).

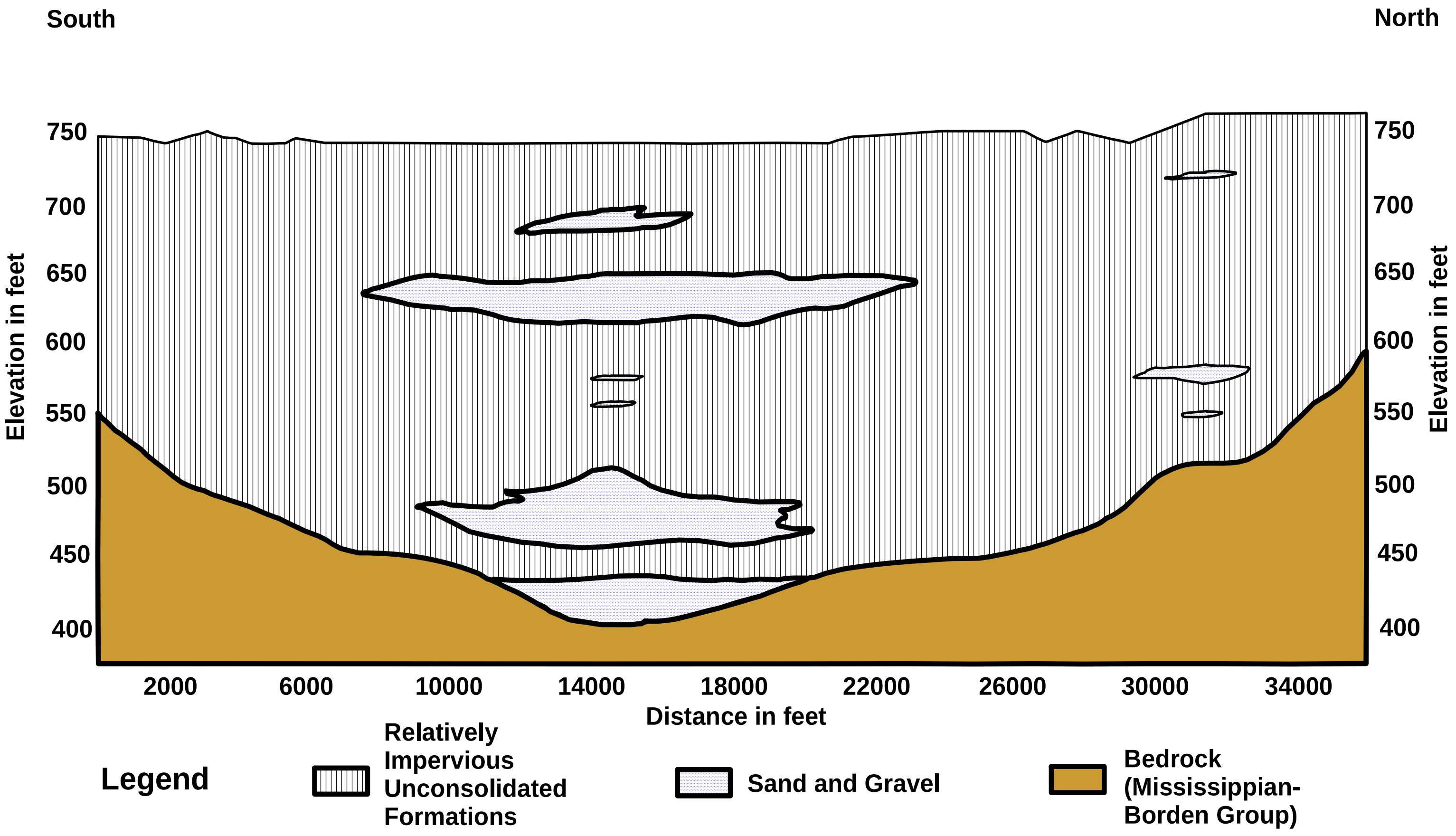

Figure 4. Generalized cross section of the Teays valley near the Illinois-Indiana state line (from Bruns and Steen, 2003).

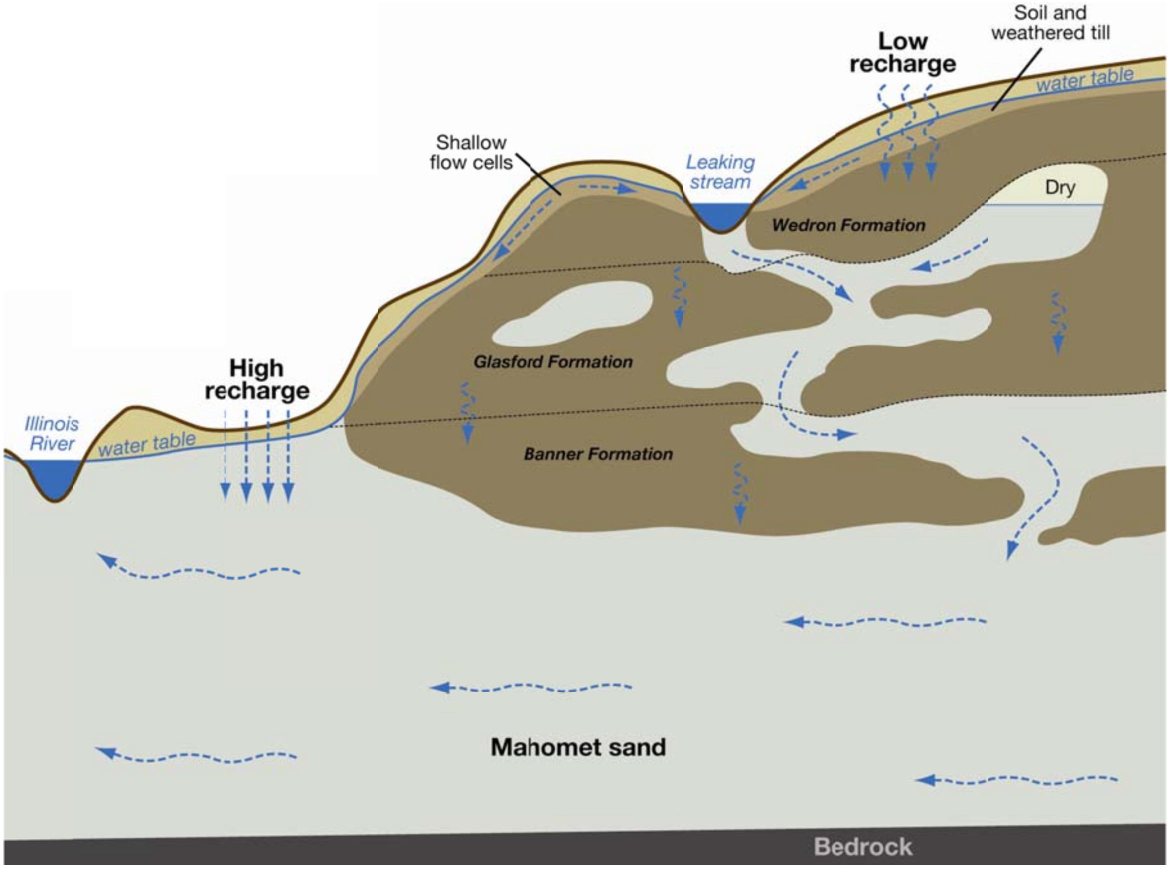

Figure 5. Conceptual framework for groundwater movement into and within the Mahomet-Teays aquifer.

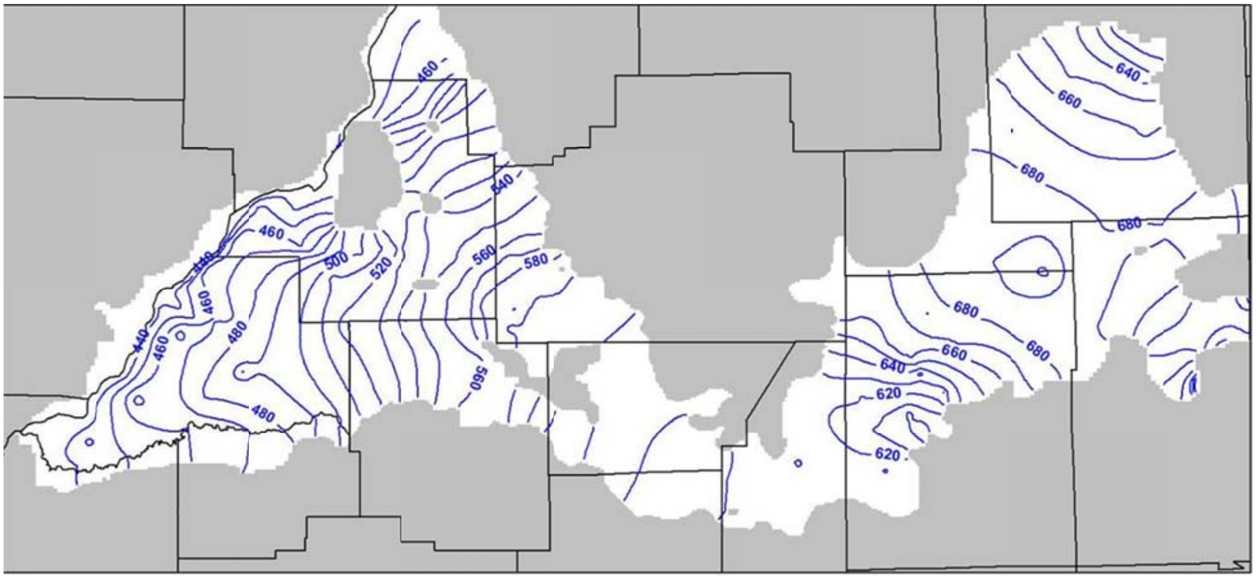

Figure 6. Potentiometric surface of the Illinois portion of the Mahomet-Teays aquifer, July 2009 (unpublished).

The degree of confinement, expressed via feet of available potentiometric head above the top of the Mahomet-Teays aquifer (Figure 7), along with a firm understanding of the geology and hydrogeology of the aquifer system (the aquifer and overlying units), gives credence to the conceptual model portrayed in Figure 5: confined conditions on the eastern portion of the Mahomet-Teays (stretching back into Indiana) and unconfined conditions beneath the western portion of the aquifer system.

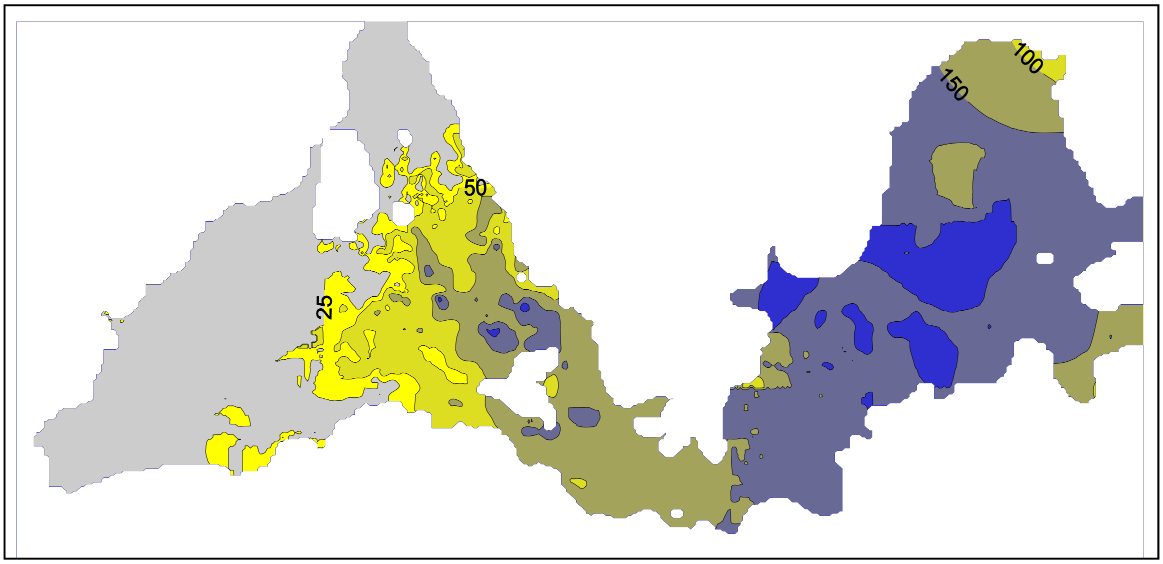

Figure 7. Available potentiometric head above the top of Illinois portion of the Mahomet-Teays aquifer (in feet). Greatest head exceeds 200 feet (dark blue) on the east. The aquifer is unconfined (light gray) on the west.

Long-term hydrographs, such as at Snicarte (Figure 8) and Petro North (Figure 9), identify ambient (unstressed) and targeted (stressed) aquifer regions. Other hydrographs portray, for example, the effects of seasonal irrigation withdrawals and groundwater/stream interaction. Maintaining wells and the capacity for long-term data collection (and archival) is important for determining aquifer yield, documenting groundwater/stream interaction, identifying new areas of stress, and assessing aquifer system responses to climate change. All such activities are ongoing in Illinois and Indiana.

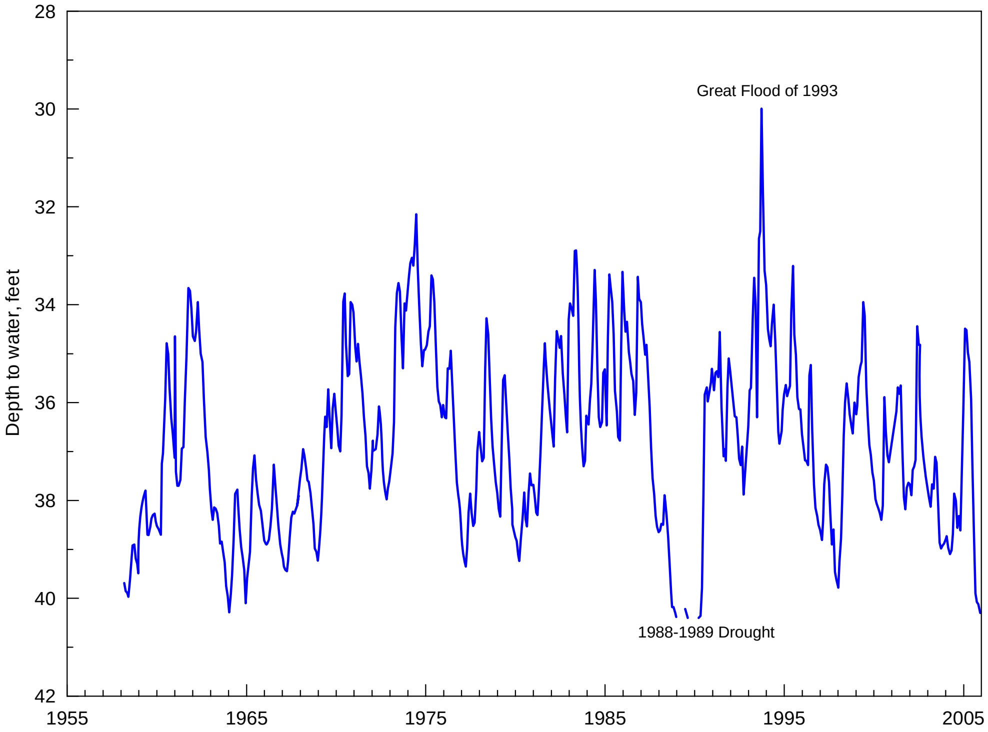

Figure 8 Long-term hydrograph near Snicarte, IL in the western unconfined portion of the Mahomet-Teays aquifer, showing a response to climatic conditions even though >2000 irrigation wells have been drilled in the region over this period.

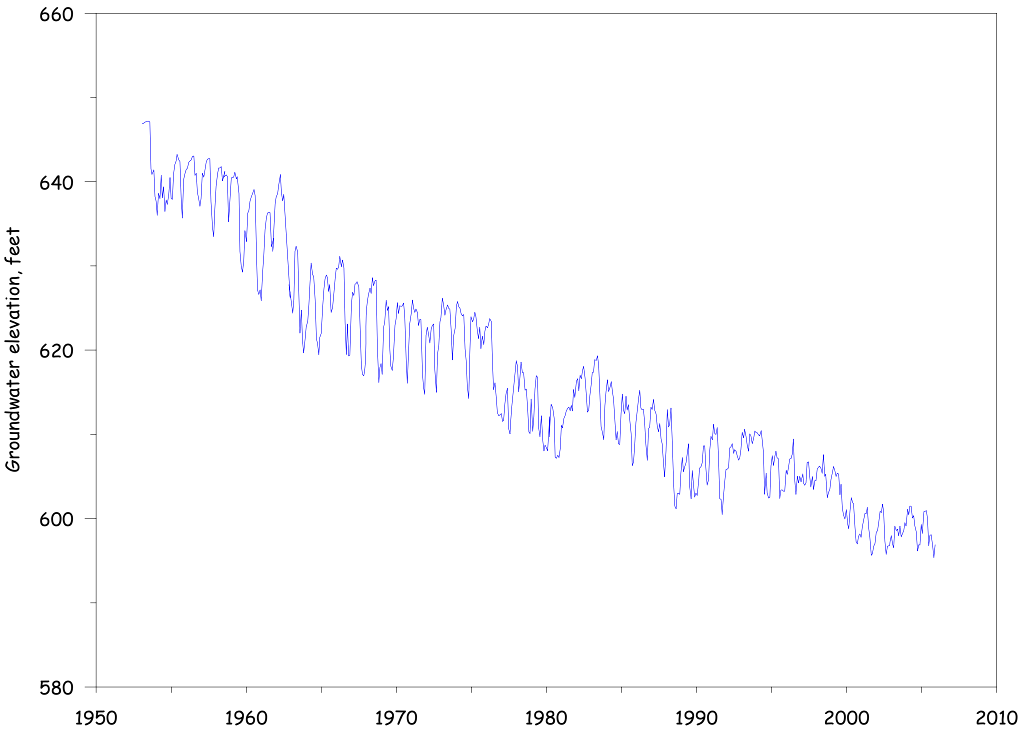

Figure 9. Long-term hydrograph at Petro North ob-well near Champaign, IL in the eastern confined portion of Mahomet-Teays aquifer, showing long-term response to ever-increasing withdrawals.

## Digital modeling of the Mahomet-Teays in Illinois

A three-dimensional digital groundwater flow model of the aquifer system in Illinois has been created. The model continues to be updated as our understanding is revised from interpretations of new hydrogeologic data. However, the model provides a very solid framework for putting water level observations into context of the flow system, identifying target areas for monitoring stressed and unstressed regions of the aquifer, and locating data gaps. The model also is especially useful for assessing the impacts on groundwater levels from scenarios of pumping, based for example, on projections of future regional water supply demand (WHPA Inc., 2008). An example of model output of drawdown between 2005 and 2050 is presented in Figure 10.

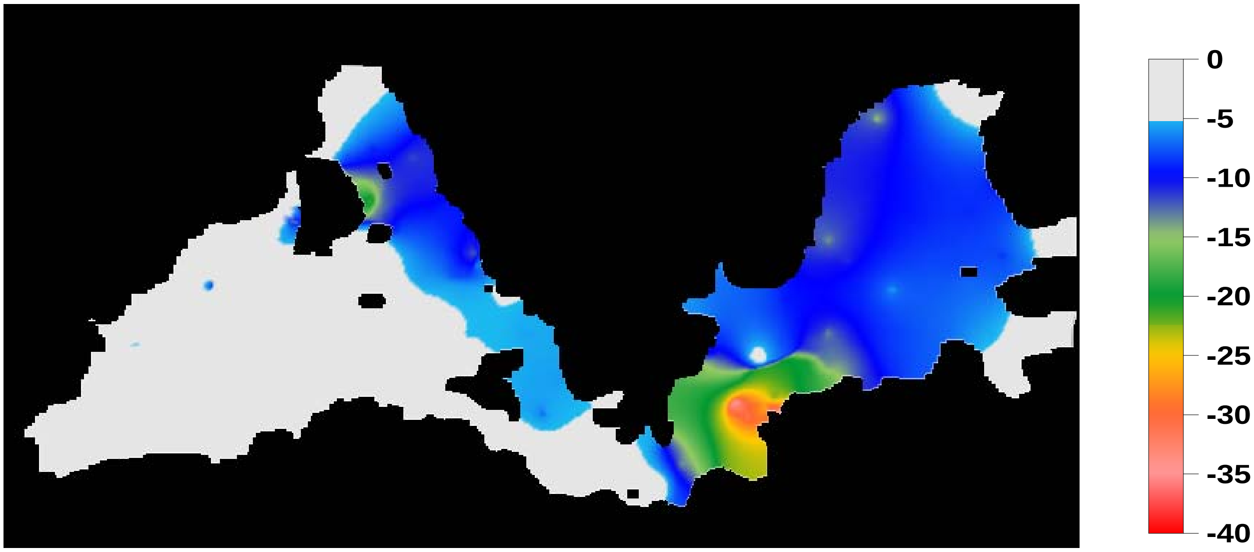

Figure 10. Simulated drawdown from 2005 to 2050 based on one possible scenario of future water demand (WHPA Inc., 2008). Greatest drawdown occurs in the eastern confined portion of the aquifer near Champaign, IL despite significant irrigation demand over the unconfined western portion.

Modeling, therefore, provides great insight on determination/assessment of locales that a) are, or will be, affected (i.e., stressed) or not affected (i.e., unstressed) by pumping, and b) behave hydrologically similarly, thereby reducing the need for redundant observation wells.

## Ongoing and Historical Groundwater Data Collection

The ISWS collects data from an observation well "network" composed of over 180 wells at over 140 sites (Figure 11), largely comprised of wells especially built for monitoring aquifer conditions (i.e., water levels and quality). Numerous sites contain "nested" observation wells to monitor the Mahomet Aquifer, overlying confined units, and the water table. Water level observations generally are collected on a monthly or quarterly basis with selected wells containing digital dataloggers polling water levels as often as hourly. Numerous local and state entities have funded a cooperative ISWS/ISGS drilling and monitoring effort. On the west, the Imperial Valley Water Authority has outfitted and funded the ISWS to maintain 11 wells (blue asterisks) with dataloggers for long-term water level monitoring. Also in this region are wells constructed for the Illinois Department of Agriculture (green crosses) for agrichemical sampling and ISWS wells (brown circles) for local resource development monitoring. Just east of this area are observation well sites (orange triangles) maintained by the ISWS via funding from the Long Range Water Plan Steering Committee, a coalition of local water authorities, counties, and communities, to assess the viability of the aquifer for a potential major development of 15 Mgd to serve the City of Bloomington (IL) and surrounding communities. The City of Decatur maintains a set of observation wells (blue stars) around a well field intermittently operated in times of drought to supplement their surface reservoir supply. The eastern half of the aquifer contains a host of observation wells (red circles and magenta x's) drilled and maintained by ISWS/ISGS through state and private funds (e.g., Illinois American Water Co.). Two ISWS observation wells have 50+ year historical records (Snicarte and Petro North), having been started in the 1950s during or after the major drought of that era.

Far fewer observation wells are available for consideration in Indiana. Only five observation wells are routinely monitoring groundwater levels in the Mahomet-Teays system: Benton 4, nested Tippecanoe 17 and Tippecanoe 18, Wabash 4, and Grant 10 (Figure 11). These five wells were part of the USGS-Indiana Department of Natural Resources (InDNR) cooperative network; two of the wells recently (2010) assumed ownership by other entities (Tippecanoe 17 by Purdue University and Wabash 4 by a private farmer). Data for Benton 4, Tippecanoe 18, and Grant 10 are available on-line through the USGS.

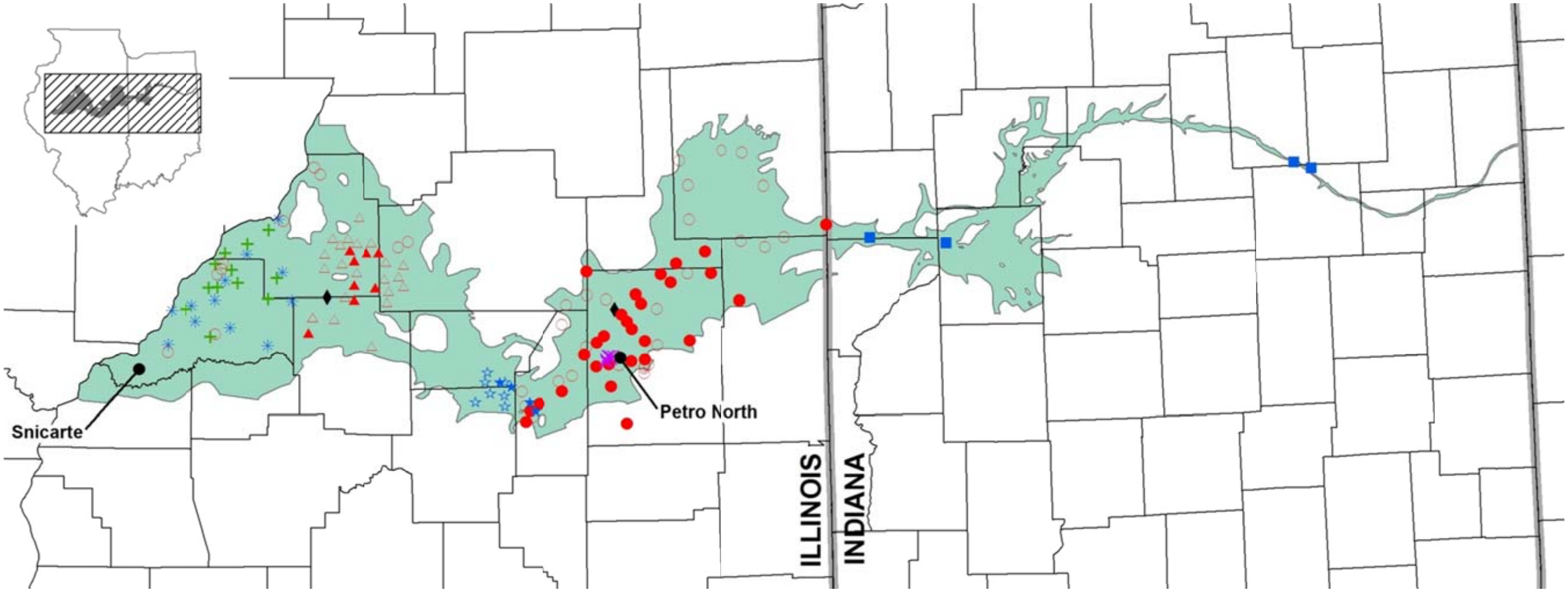

Figure 11. Mahomet-Teays aquifer system ob-wells in Illinois and Indiana (closed symbols are nested sites).

In addition, the USGS-IL in cooperation with the ISWS will be initiating real-time groundwater level monitoring at two selected ob-well sites within the Mahomet-Teays Aquifer system (marked by black diamonds in Figure 11). Data for these two sites can be accessed through USGS' National Water Information System Web Interface. This will complement two additional sites in western Indiana maintained by the USGS-IN.

The numerous observation well sites located within the Mahomet-Teays aquifer boundary contain "nested" well configurations, constructed to monitor not only water levels (and quality) in the Mahomet-Teays, but also aquifers overlying the Mahomet-Teays. The Mahomet-Teays is composed of sediments deposited during the Pre-Illinois Episode (Figure 12). Nested wells completed in units overlying the Mahomet-Teays typically monitor confined and unconfined shallower aquifers that occur in sediments deposited during the Illinois and Wisconsin Episodes. Determination of glacial episodes of monitored units in Indiana has not been conducted, so rather than trying to classify the observation wells completed in these various units separately, we have elected to place wells completed in Illinois and Wisconsin Episode aquifers together into a lumped Illinois/Wisconsin Episodes Aquifers classification. All the aquifers are classified as sand and gravel aquifers (glaciated regions) "N100GLCIAL" nationally and as Quaternary system local aquifers "110QRNR"by the USGS (Table 1).

**Table 1. Illinois-Indiana Pilot Aquifers**

| Local (IL) Name | Glacial Episode | National Aquifer Code | Local Aquifer Code | IL-IN Pilot Aquifer |
|---|---|---|---|---|
| Mahomet-Teays | Pre-Illinois | N100GLCIAL | 110QRNR | Aquifer 1 |
| Glasford | Illinois | N100GLCIAL | 110QRNR | Aquifer 2 |
| Mason | Wisconsin | N100GLCIAL | 110QRNR | Aquifer 2 |

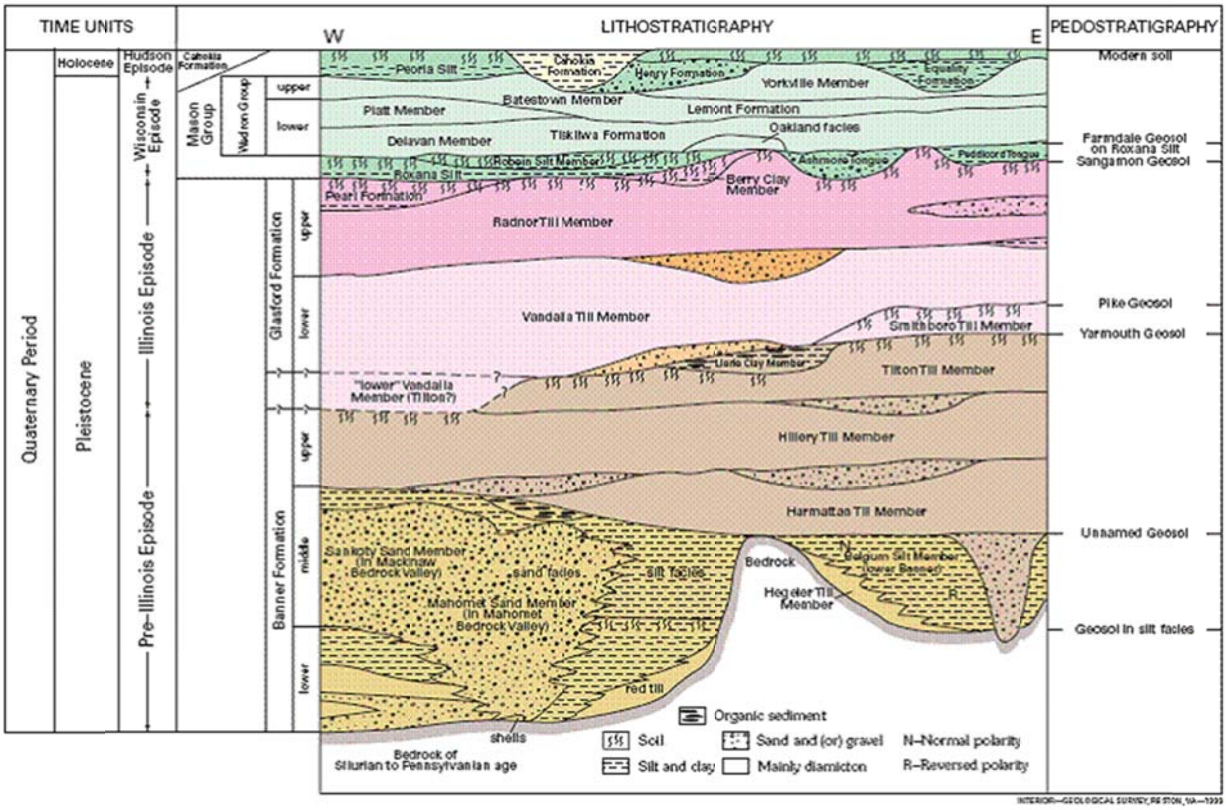

Figure 12. Diagrammatic stratigraphic column of glaciogenic sediments in east-central Illinois (Soller et al., 1999).

## Collaboration and Cooperation

### Pilot Study

Initially, the Indiana Department of Natural Resources (InDNR) Division of Water (Jerry Unterreiner, Mark Basch, and Robert Schmidt), Indiana Department of Environmental Management (InDEM) Office of Water Quality (James Sullivan and Rebecca Travis), and the U.S. Geological Survey Indiana Water Science Center (USGS-IN) (David Lampe) met to discuss possibilities for the study of a portion of the regional Silurian and Devonian carbonate-rock aquifer in northwestern Indiana. On behalf of the Indiana contingent, Dr. Unterreiner contacted Steve Wilson at the Illinois State Water Survey (ISWS) to discuss potential interest in collaboration. At the same time, ISWS personnel (Allen Wehrmann, George Roadcap, and Steve Wilson) had been discussing the idea of submitting a proposal for either the deep bedrock (Cambrian-Ordovician) aquifers of northeastern Illinois in cooperation with Wisconsin agencies or the Mahomet-Teays aquifer with Indiana agencies. Contact of Steve Wilson (also an SOGW member) by Indiana on the Silurian/Devonian aquifer led to further discussions between Illinois and Indiana and the subsequent joint Illinois-Indiana proposal for the Mahomet-Teays Aquifer System.

Once agreed, additional contacts were made within Illinois to include other federal, state, and local agencies that are involved with groundwater data collections within the Mahomet-Teays. This included Rick Cobb with the Illinois Environmental Protection Agency (IEPA), Dennis McKenna and Susan Barron with the Illinois Department of Agriculture (IDA), Doug Yeskis and Pat Mills with the U.S. Geological Survey-Illinois Water Science Center (USGS-IL), Dave Larson with the Illinois State Geological Survey (ISGS), Dorland Smith with the Imperial Valley Water Authority (IVWA), and Mel Pleines with the Mahomet Aquifer Consortium (MAC, a grass-roots organization dedicated to studying and educating the public about the Mahomet Aquifer). Numerous presentations were made to the public and agency personnel to promote the activities of the various Illinois/Indiana agencies involved in this Pilot and update them on progress. All those contacted were very supportive of the Pilot effort, were interested in the long-term viability of a NGWMN, and especially the presence of a Mahomet-Teays Aquifer well network within the NGWMN.

### Future Opportunities

On the Illinois side in particular, advantage has not been taken of data available from the Illinois Department of Agriculture (IDA). The IDA operates a statewide network of monitoring wells dedicated to assessing groundwater quality with regard to potential contamination by agricultural chemicals. The monitoring network was created by the ISGS and ISWS and emphasis was placed on monitoring aquifer materials felt to be most susceptible to contamination based on maps of aquifer sensitivity to pesticide leaching. The sandy soils of the unconfined western portion of the Mahomet-Teays aquifer contain several monitoring wells that could provide valuable, interesting additional water quality data to this NGWMN Pilot. Time constraints on the part of the ISWS lead personnel were the principal reason for not including the IDA wells.

## Water-Level Network Well Selection

From the start of the selection process, and due to the sheer number of observation wells in the Illinois portion of the Mahomet-Teays, our premise was that we did not necessarily want or need to include ALL available observation wells in the network. This agrees with the approach described in the Framework document (SOGW, 2009) in terms of NOT creating a "network-of-networks".

That said, the selection process for Indiana was such that we were forced to include all five of the observation wells available. For Illinois, the situation was quite different. As discussed previously, there are over 180 observation wells completed at over 140 locations in the Mahomet-Teays aquifer system located across Illinois (Figure 11). Most of the wells, including all wells in Illinois, are constructed of 2-inch diameter PVC and are dedicated to the purpose of water level observation. This quickly eliminated the need to distinguish between wells due to variations in construction. When sufficient data were available (all but the newest wells have a period of record greater than 15 years), hydrographs were prepared for each well. Examination of these plots, coupled with what is known about current and likely future aquifer conditions based on historical data and modeled scenarios of the future, provided an initial framework for deciding what wells to include in the NGWMN. A generally even spatial distribution across the aquifer also was sought – a statistical approach to our network design was not used principally because of well limitations in Indiana (only five wells), extreme variations in recharge conditions in Illinois (at least two orders of magnitude), and a decided preference to include two wells with with water-level records longer than 50 years.

The selection process for wells in Illinois generally followed the steps outlined below:

1. Plot well hydrographs
2. Assess hydrographs for a) length of period of record (longer record is preferred) and quality (less missing data is better), b) similarities/differences among wells within an area (for example, selecting one well out of several whose hydrographs all appear the same), c) exclusion of wells exhibiting odd behavior (such as being nonresponsive to hydrologic events to which nearby wells were responding – suggesting a clogged well), d) prefer wells with hydrographs that exhibit long-term trends (such as response to pumping) or long-term natural fluctuation not influenced by pumping, and e) include wells representative of surface water/groundwater interaction
3. Prefer wells with good well construction information and geologic log
4. Assess spatial distribution of wells, recognizing a need to also collect water level data in reasonably close proximity to wells being monitored for water quality (see section on water-quality subnetwork well selection)
5. Assignment of "unstressed" or "targeted" labels to wells was completed after the wells were selected for inclusion in the Network

Wells were excluded if the information provided from them was felt to be redundant of other wells selected. In one instance, a well was excluded because the well had a history of clogging and recent water level data suggested the well was clogged again. Appendix A contains hydrographs of the wells finally selected for inclusion in the Illinois-Indiana Pilot.

The ISWS maintains a unique 6-digit number for each well in its database. Historically, this number was preceded with a "P", hence the ISWS identification number is often called the P-number. P-numbers are assigned sequentially as well records are entered into the ISWS Wells Database. P-numbers, therefore, do not contain a geographic reference. In contrast, the ISGS well records database numbers wells according to American Petroleum Institute (API) convention: a 12-digit number with first two digits corresponding to the state (e.g., Illinois = 12), next three digits corresponding to the county FIPS (Federal Information Processing Standard) code, followed by a 7-digit number assigned sequentially to wells in that county. ISWS P-numbers are cross-referenced to the ISGS API number. If the well is a community well, it will also be assigned a unique Safe Drinking Water Information System well number (SDWIS Well Number) by the IEPA. The ISWS also cross-references their P-number to the IEPA SDWIS Well Number. For purposes of the NGWMN, the ISWS P-number will be the reference number for all Illinois well data, especially for the NGWMN Data Portal. Similar to the ISWS, a sequential numbering system is used for the Indiana Water Well Record Database. For purposes of the NGWMN and this report, the unique InDNR water well record reference number and the name of the well will be used (e.g., the ob-well in Benton County is identified as 121640-Benton 4). In the following sections of this report, the local Illinois or Indiana well name will be most commonly used.

### Unstressed Subnetwork

The unstressed subnetwork includes monitoring wells that provide data from unstressed (or minimally stressed) aquifers or parts of aquifers. This unstressed subnetwork ensures that a consistent group of wells is regularly monitored to generate water-level data from areas not affected by pumping and unaffected by anthropogenic contamination. A good example of such a well appears in Figure 13. However, in places it is likely that total network-wide isolation from land use and developmental pressures is not possible. So in practice, unstressed areas are those that either have limited pumping stress (e.g., seasonal irrigation effects with no carryover impacts to the following irrigation season, see Figure 8) or have been minimally affected by human activities. In terms of groundwater quality, this means at a minimum, anthropogenic impacts do not affect the primary use of the water – this also suggests that anthropogenic impacts cannot be separated from natural variations.

The “goals and objectives” of the unstressed subnetwork principally are to provide long-term historical groundwater level and groundwater quality data for background reference. To the extent possible, this also includes an ability to assess natural variations in groundwater levels and quality due to seasonal and climatic conditions. Such data may also be useful for examining long-term, possibly subtle, effects due to climate change.

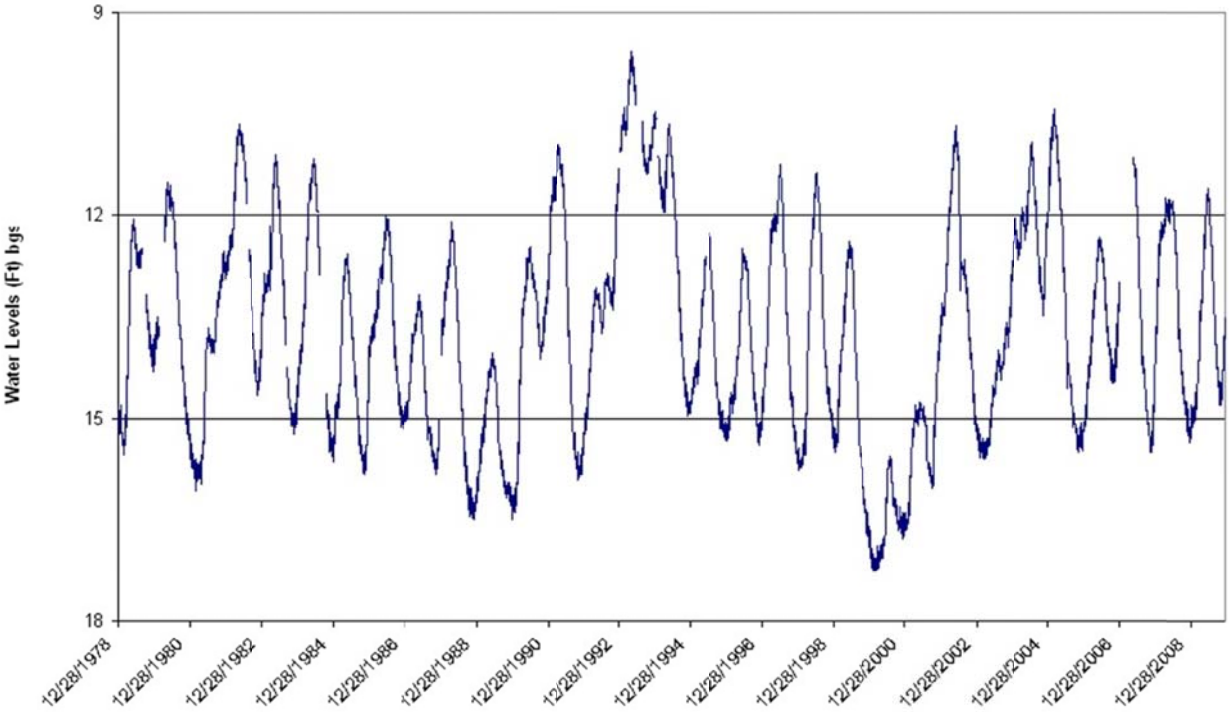

Figure 13. Long-term hydrograph at Indiana ob-well Benton 4 (Aquifer 1 unstressed water level subnetwork).

### Aquifer 1: Mahomet-Teays Aquifer (Unstressed)

Table 2 contains general details of the wells selected to be in the unstressed water level subnetwork monitoring conditions in the Mahomet-Teays Aquifer (Aquifer 1). This includes two wells in Indiana and 11 wells in Illinois. Tippecanoe 17 in Indiana is included here as being completed in the Mahomet-Teays; however, it is speculated that it may not be deep enough to actually be monitoring conditions in this aquifer and another deeper well is proposed at this location as part of the data gap analysis. Of the 11 Illinois wells, three (MTH-17d, CHAM-08-09A, and FRD-94A) are nested with shallower wells monitoring water levels in overlying Illinois and Wisconsin Episodes Aquifers (Aquifer 2). Three of the Illinois wells (MTOW-2 at Easton, MTOW-9 at Havana, and IRO-98B near Crescent City) also are co-located near wells selected for inclusion in the water quality subnetwork. High-quality water level data is not generally available from community wells due to the need to seal such wells from surface entry and the use of inaccurate airline gages for water level measurement. Therefore, where appropriate, observation wells dedicated to water level monitoring that can describe local aquifer hydrologic conditions in proximity to community wells being used for water quality sampling were added to the water level subnetwork. A map of the wells selected to be in this subnetwork appears as Figure 14.

**Table 2. Wells in the unstressed water-level subnetwork of Aquifer 1: the Mahomet-Teays Aquifer**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Level Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| Benton 4 | Indiana | Surveillance | Daily | 1978-2008 | 295-300 |
| Tippecanoe 17† | Indiana | Surveillance | Daily | 1989-2003 | 207-212 |
| MTH-5 | Illinois | Surveillance | Quarterly | 1993-2010 | 237-242 |
| MTH-17d | Illinois | Surveillance | Quarterly* | 1993-2010 | 147-152 |
| MTOW-2 | Illinois | Trend | Hourly | 1995-2010 | ??-82 |
| MTOW-6 | Illinois | Trend | Hourly | 1995-2010 | 38.5-43.5 |
| MTOW-9 | Illinois | Surveillance | Monthly | 1995-2010 | 46-48 |
| FRD-94A | Illinois | Surveillance | Monthly | 1994-2010 | 367.5-372.5 |
| VER-94D | Illinois | Surveillance | Monthly | 1994-2010 | 292.5-297.5 |
| IRO-98B | Illinois | Surveillance | Monthly | 1998-2010 | 158.7-163.7 |
| PIA-2000A | Illinois | Surveillance | Monthly | 2000-2010 | 291-296 |
| Snicarte #2 | Illinois | Trend | Hourly | 1958-2010** | 52.5-62.5 |
| CHAM-08-09A | Illinois | Trend | Hourly | 2008-2010 | 259.5-264.5 |

† Tippecanoe 17 is included here in Aquifer 1, but may not be deep enough to be completed in the Mahomet-Teays.

*MTH-17d has historically been measured quarterly but recently has been upgraded to real-time (hourly) in cooperation with the USGS-IL.

**Snicarte #2 was constructed in 2006 to replace Snicarte #1. Due to physical proximity and highly correlated water levels in the two wells, Snicarte #1 was abandoned and the historical record from Snicarte #1 was converted to extend the record at Snicarte #2.

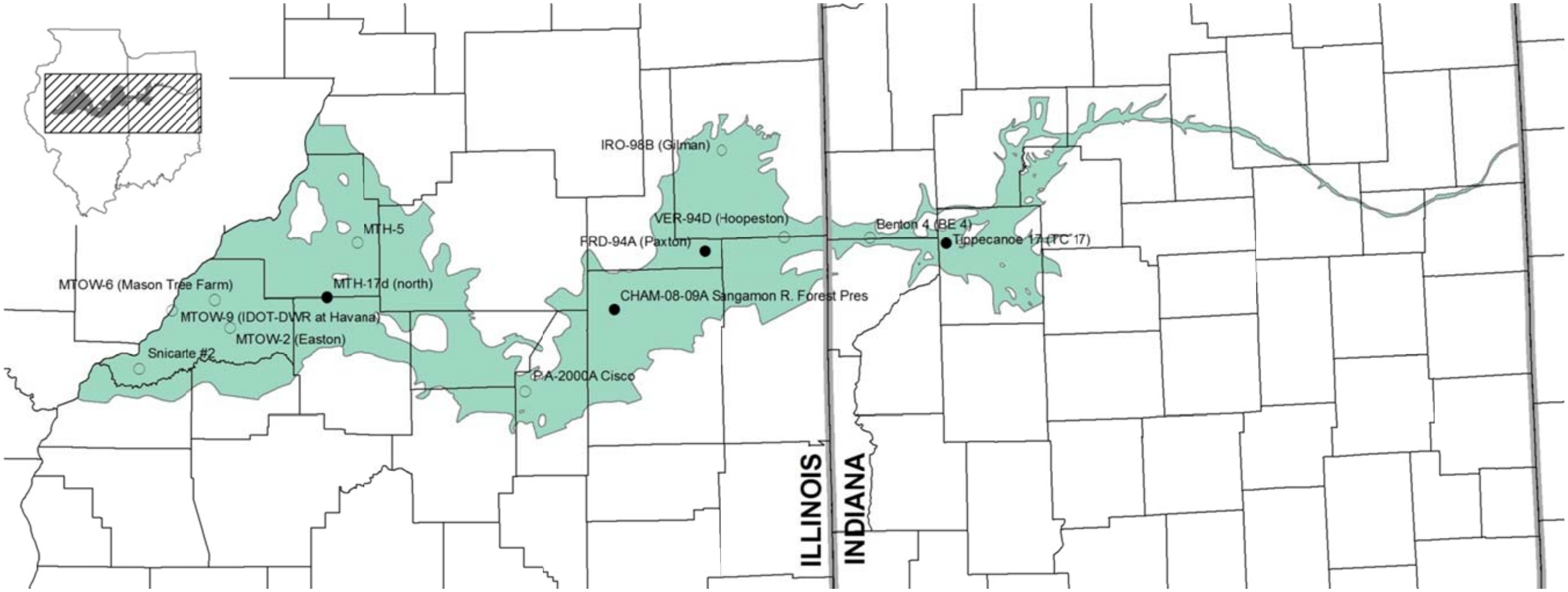

Figure 14 Wells in the unstressed water-level subnetwork of Aquifer 1: the Mahomet-Teays Aquifer

### Aquifer 2: Illinois and Wisconsin Episodes Aquifers (Unstressed)

These wells were selected principally on the basis that they are nested with deeper wells monitoring water levels in the underlying Mahomet-Teays Aquifer (Aquifer 1). Important information can be provided by such wells, as shallower wells may be more responsive to climatological conditions, especially if the shallower aquifers are unconfined. Shallower aquifers also may serve as source beds for the underlying, more heavily pumped, principal aquifer. An examination of water level response is such aquifers can provide valuable information on the long-term sustainability of the deeper, underlying aquifer. Table 3 lists the wells included in the subnetwork and a map of these wells is presented as Figure 15.

**Table 3. Wells in the unstressed water level subnetwork of Aquifer 2: Illinois/Wisconsin Episodes Aquifers**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Level Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| Tippecanoe 18 | Indiana | Surveillance | Daily | 1989-2009 | 59-64 |
| MTH-17s | Illinois | Trend | Hourly* | 1993-2010 | 67-72 |
| MTH-17WT | Illinois | Trend | Hourly* | 2010 | 10-20 |
| FRD-94B | Illinois | Surveillance | Monthly | 1994-2010 | 192.5-197.5 |
| CHAM-08-09B | Illinois | Trend | Hourly | 2008-2010 | 166-171 |
| CHAM-08-09C | Illinois | Trend | Hourly | 2008-2010 | 64-69 |

*MTH-17s has historically been measured quarterly but is being upgraded to real-time (hourly) in cooperation with the USGS-IL. MTH-17WT is a new well constructed in 2010 by USGS to complement MTH-17d and MTH-17s.

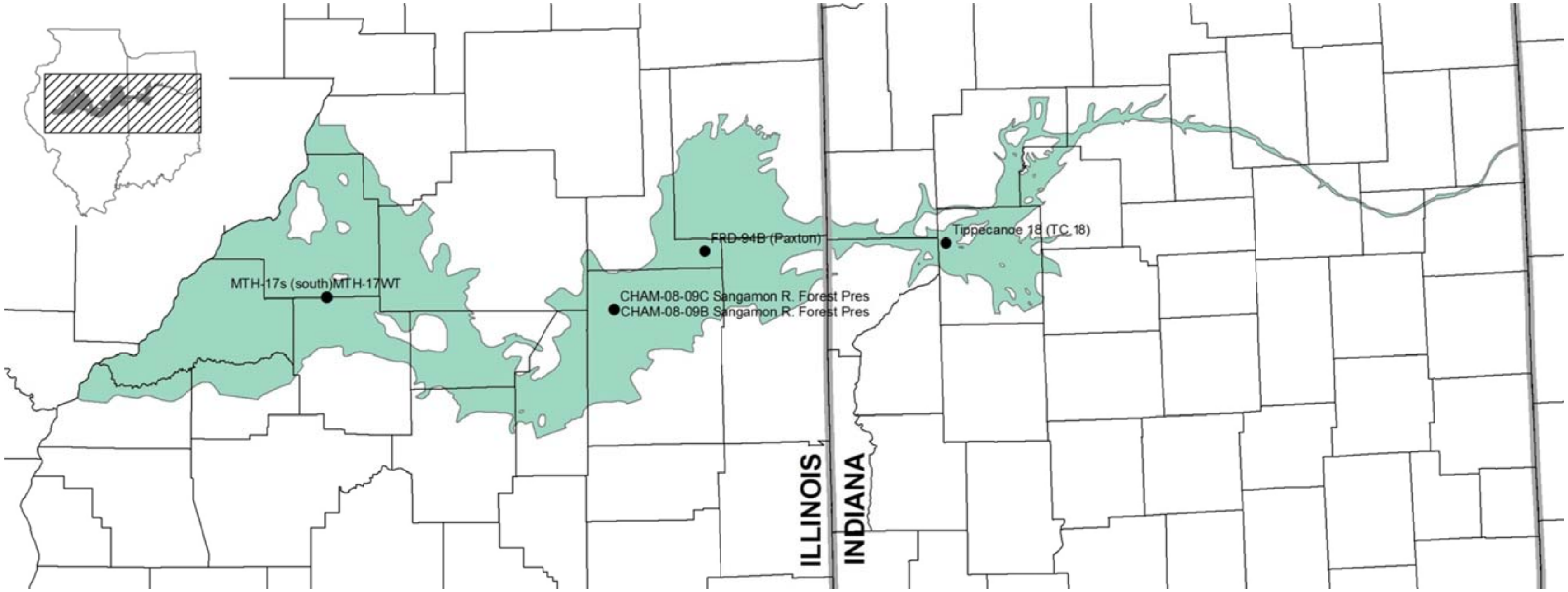

Figure 15. Wells in the unstressed water-level subnetwork of Aquifer 2: the Illinois/Wisconsin Episodes Aquifers

### Targeted Subnetwork

Targeted wells exhibit a long-term response to a changed or changing environment. Such wells typically may show a declining water level due to continued and/or increasing groundwater withdrawals or a land use change that might, for example, affect recharge. Good examples of such well hydrographs appear in Figure 8 and Figure 16. A response to seasonal withdrawals, such as irrigation, with complete water-level recovery during the non-irrigating months is not included in our targeted subnetwork. Such well exclusion from the targeted subnetwork could change should the aquifer become overpumped and it becomes apparent the aquifer is not recovering during the off-season (such as might occur due to climate change affecting recharge or causing a significant and recurring increase in the total irrigation water requirement).

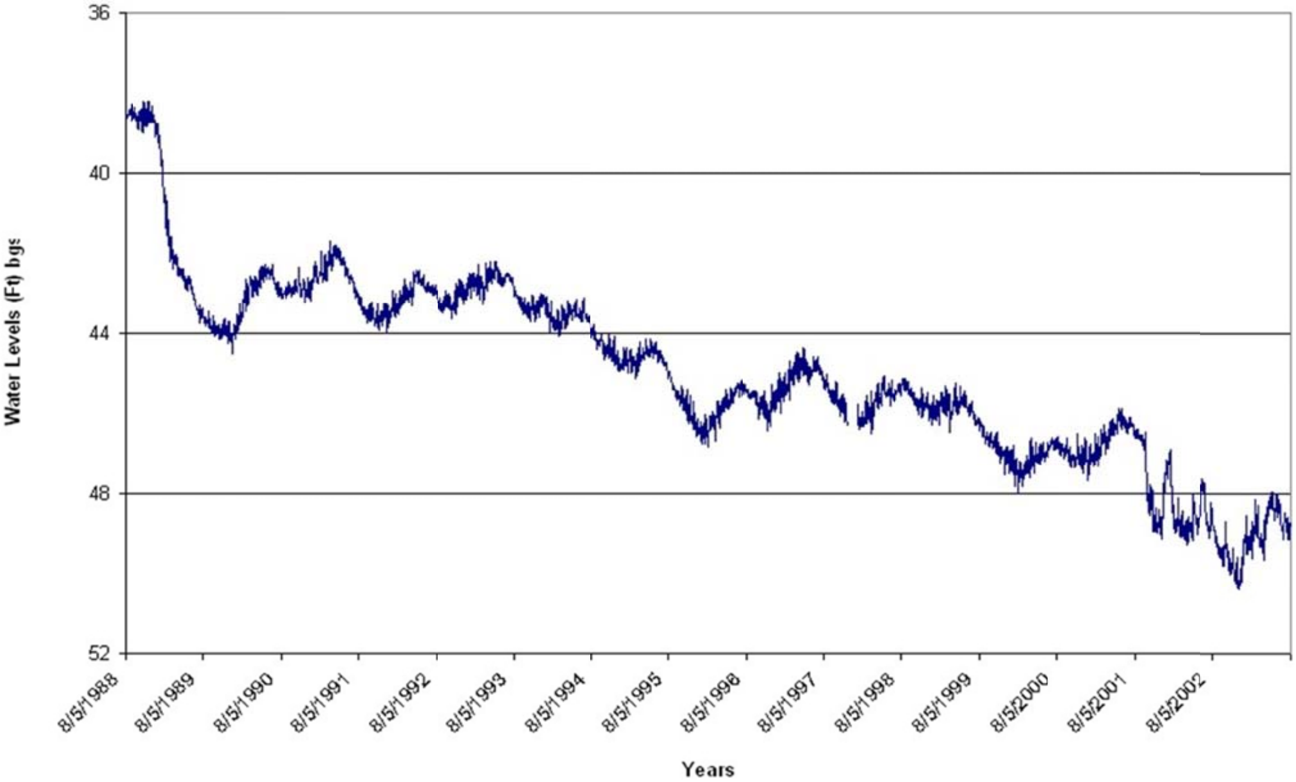

Figure 16. Water level decline in Indiana observation well Wabash 4 (Aquifer 1, targeted water level subnetwork).

### Aquifer 1: Mahomet-Teays Aquifer (Targeted)

Table 4 contains general details of the wells selected to be in the targeted water level subnetwork monitoring conditions in the Mahomet-Teays Aquifer (Aquifer 1). A map of these well locations is provided in Figure 19. The six wells selected occur within two areas of pumping influence – near Champaign-Urbana, Illinois and Marion, Indiana. The wells selected occur at different radial distances from the pumping centers and thus provide information on the area of influence and potential recharge area serving the well fields.

Included in the Aquifer 1 targeted subnetwork is Indiana's Grant 10 observation well (see Figure 17). Note that the water level in this well has apparently reached a new equilibrium in response to withdrawals around it (Figure 18). This suggests that 1) a history or record of withdrawals in the vicinity of observation wells may be important to well selection and also to NGWMN users, and 2) without the water level record prior to the 1988/89 timeframe at Grant 10, one might conclude this well is unstressed. Hence, it is important to have a) a minimum baseline length (in some instances, 5 years may not be enough), b) local knowledge, and c) flexibility to change the unstressed/targeted "flag" as knowledge is gained about the aquifer system or as aquifer conditions change (and as recognized in the Framework document, SOGW, 2009).

**Table 4. Wells in the targeted water-level subnetwork of Aquifer 1: Mahomet-Teays Aquifer.**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Level Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| Wabash 4 | Indiana | Surveillance | Daily to 2003 | 1988-2002 | 116-121 |
| Grant 10 | Indiana | Trend | Daily to 2003 | 1987-2009 | 209-214 |
| CHM-95D | Illinois | Surveillance | Monthly | 1994-2010 | 277.5-282.5 |
| CHM-96C | Illinois | Trend | Hourly | 1996-2010 | 287.6-292.6 |
| Petro North | Illinois | Trend | Hourly | 1953-2010 | 232-235 |
| CHAM-07-01A | Illinois | Trend | Hourly | 2007-2010 | 310-315 |

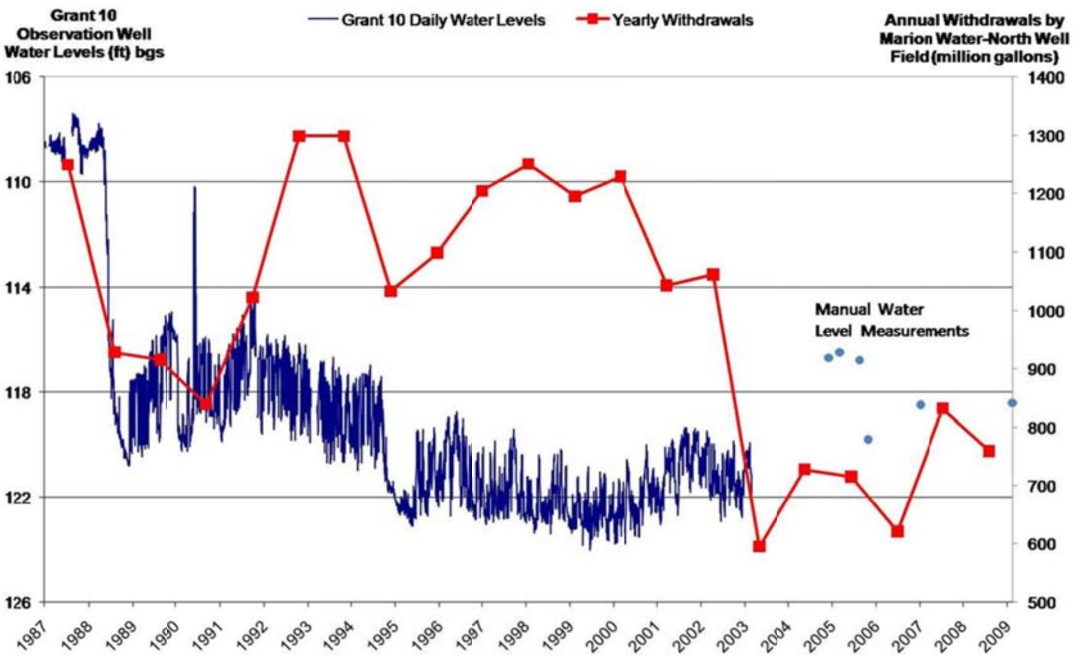

Figure 17. Water level response in Grant 10 (Aquifer 1 targeted water level subnetwork) relative to Marion Water-North Well Field withdrawals. Note this timeline is different than in Figure 16.

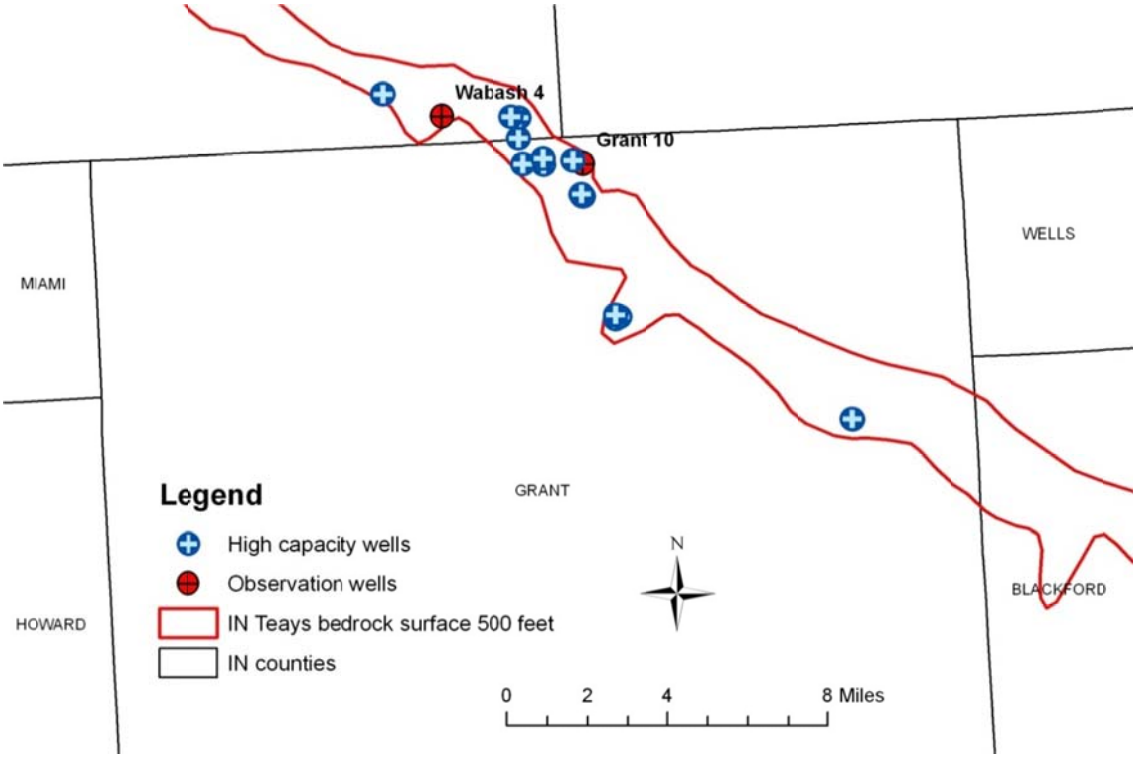

Figure 18. Location of Wabash 4 (Figure 16) and Grant 10 (Figure 17) observation wells relative to high-capacity pumping wells in the area.

Figure 19. Wells in the targeted water-level subnetwork of Aquifer 1: the Mahomet-Teays Aquifer. Closed black circles represent well nested with targeted Aquifer 2: the Illinois/Wisconsin Episodes Aquifer.

### Aquifer 2: Illinois and Wisconsin Episodes Aquifers (Targeted)

Table 5 contains details of the wells selected to be in the targeted water level subnetwork for monitoring conditions in the Illinois and Wisconsin Episodes Aquifers (Aquifer 2). A map of these well locations is provided in Figure 20. Only three wells are included in this subnetwork and are nested with deeper wells monitoring water levels in the Mahomet-Teays Aquifer (Aquifer 1). These three wells are located within the cone of depression created by the well field serving Champaign-Urbana, Illinois area.

**Table 5. Wells in the targeted water-level subnetwork of Aquifer 2: Illinois/Wisconsin Episodes Aquifers**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Level Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| CHAM-07-07 | Illinois | Surveillance | Monthly | 2007-2010 | 100-105 |
| CHAM-07-01B | Illinois | Trend | Hourly | 2007-2010 | 245-250 |
| CHAM-07-01C | Illinois | Trend | Hourly | 2007-2010 | 145-150 |

Figure 20. Wells in the targeted water-level subnetwork of Aquifer 2: the Illinois/Wisconsin Episodes Aquifers. Closed black circles represent wells nested with targeted Aquifer 1: the Mahomet-Teays Aquifer.

### Water-Level Subnetwork Gap Analysis

Within the water-level subnetwork, data gaps exist in three forms. Spatial data gaps occur where additional wells are needed to better describe or monitor aquifer conditions areally and/or vertically. Temporal data gaps occur when data are not collected routinely or at a high enough frequency to describe the variability in water levels, especially in response to short-lived events, such as variable pumping, stream stage, or recharge events (typically in unconfined aquifers that respond quickly to rainfall or snowmelt). An assortment of other “miscellaneous” data gaps occur such as when supporting information about well construction, measuring point (or land surface) elevation, or borehole geologic data are missing. A map of the final selected well locations for the water level subnetwork for Aquifers 1 and 2 is presented in Figure 21**.**

Spatial data gaps obviously exist where observation wells are lacking (refer to the numbered red ovals in Figure 22). Spatial data gaps for the targeted water level subnetwork of Aquifer 1 exist in Indiana in Adams County (far east-central Indiana, #1) and in Tippecanoe County (west-central Indiana near Lafayette, #3). Water rights issues in Adams County have been associated with high-capacity pumpage within the Teays system suggesting the aquifer is being stressed in this area. In Tippecanoe County, there is considerable pumpage by high-capacity facilities, but observation well Tippecanoe 18 (64’ deep) is clearly too shallow and Tippecanoe 17 (212’ deep) may not be deep enough to assess water levels in the Mahomet-Teays aquifer. A third, deeper well is proposed for this location. No additional wells are proposed for the targeted water level subnetwork in Illinois.

Additional wells can improve understanding of aquifer conditions in unstressed areas in both states. This would include the large area across central Indiana between the existing observations wells at Grant 10/Wabash 4 and Tippecanoe 17/18 (#2). InDNR prefers single-aquifer monitoring, rather than nesting wells into overlying units; therefore, only two wells drilled into the Mahomet-Teays (Aquifer 1) are proposed for this region. Three areas (#4, #5, and #6) in Illinois highlight locations where added wells (well nests) could improve aquifer understanding. Area #4 is located in an area where it is believed, but has not been confirmed, that groundwater flow is toward the southeast into the North Fork Vermilion River (which then empties into the Wabash River) – a two-well nest is proposed for this area. Area #5 is actually bisected into two smaller bedrock valleys by a bedrock high. The Salt Fork River has apparently incised into the Mahomet-Teays within this area and serves as an outlet for groundwater moving down-valley. A two-well nest along the thalweg of each valley is suggested. Finally, another two-well nest is recommended in the northwest corner of the aquifer (#6) where the Mahomet-Teays joins the Illinois River valley above Peoria.

Altogether, this accounts for two wells in Indiana and four well nests (two wells in each nest) in Illinois, for a total of 10 wells in unstressed regions of the Mahomet-Teays system. Two wells are proposed in targeted regions of Indiana, bringing the total number of additional wells proposed for the Illinois-Indiana water-level subnetwork to 12.

Temporal data gaps are not a matter of well construction, but of site visitation frequency or equipment installation. Dataloggers outfitted with pressure transducers that measure water level height over the sensor have become nearly standard practice for water level observation, especially at distant locations. Telemetry via phone line or satellite can provide real-time or near real-time data. To capture the effects of pumping, precipitation (recharge), and stream stage events, a minimum of daily measurement is recommended with a preference for either ⅓-day (every 8 hours) or ¼-day (every six hours) if not hourly measurements. Dataloggers are proposed for all new locations in Illinois; satellite telemetry is proposed for Indiana (in cooperation with USGS).

In addition, the observation well MTOW-9 is measured currently only on a monthly schedule. MTOW-9 is known to respond to Illinois River stage (see hydrograph in Appendix A). Upgrade of measurement frequency with a datalogger at this site is proposed.

For Illinois, data gaps exist with respect to completing some minimum data elements. This includes description of a lithologic log for observation wells MTOW-2 (Easton) and Petro North. Geologic samples exist in ISGS archives for Petro North and need to be pulled and described, entered into the ISGS Geologic Records database, and transmitted to the Data Portal. For MTOW-2 (Easton), it is proposed that downhole geophysical logging (multiple probes including gamma, and possibly ultrasonic imaging, caliper, neutron, and temperature/conductivity – personal communication, Tim Young, ISGS geophysicist, 1/24/2011) be performed.

Several wells have not been accurately surveyed for elevation. Land surface elevations for many have been estimated from USGS topographic maps or orthophoto quads. The use of global positioning system (GPS) equipment to determine horizontal (x,y – latitude/longitude) coordinates is usually quite acceptable. However, unless a very high-quality GPS is used (typically along with some post-processing), vertical precision is not likely to be within 0.1 feet. For most mapping applications, 0.1 feet may be acceptable, but vertical gradients (such as in well nests) will require precision to 0.01 feet (i.e., within the precision of the water level measurements). Optically surveyed or high-accuracy GPS elevations for several wells is needed to bring the network to acceptable standard.

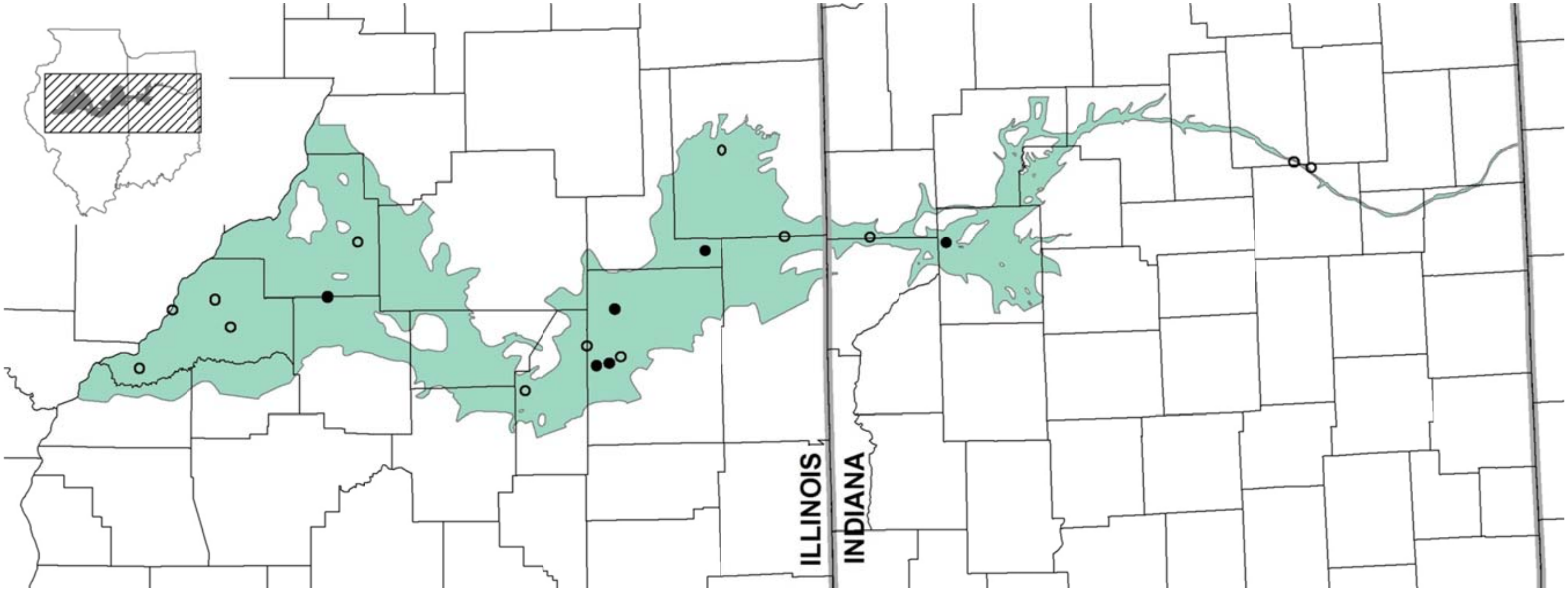

Figure 21. Locations of wells selected for the Illinois/Indiana Pilot water level subnetwork. Closed black circles represent nested well locations.

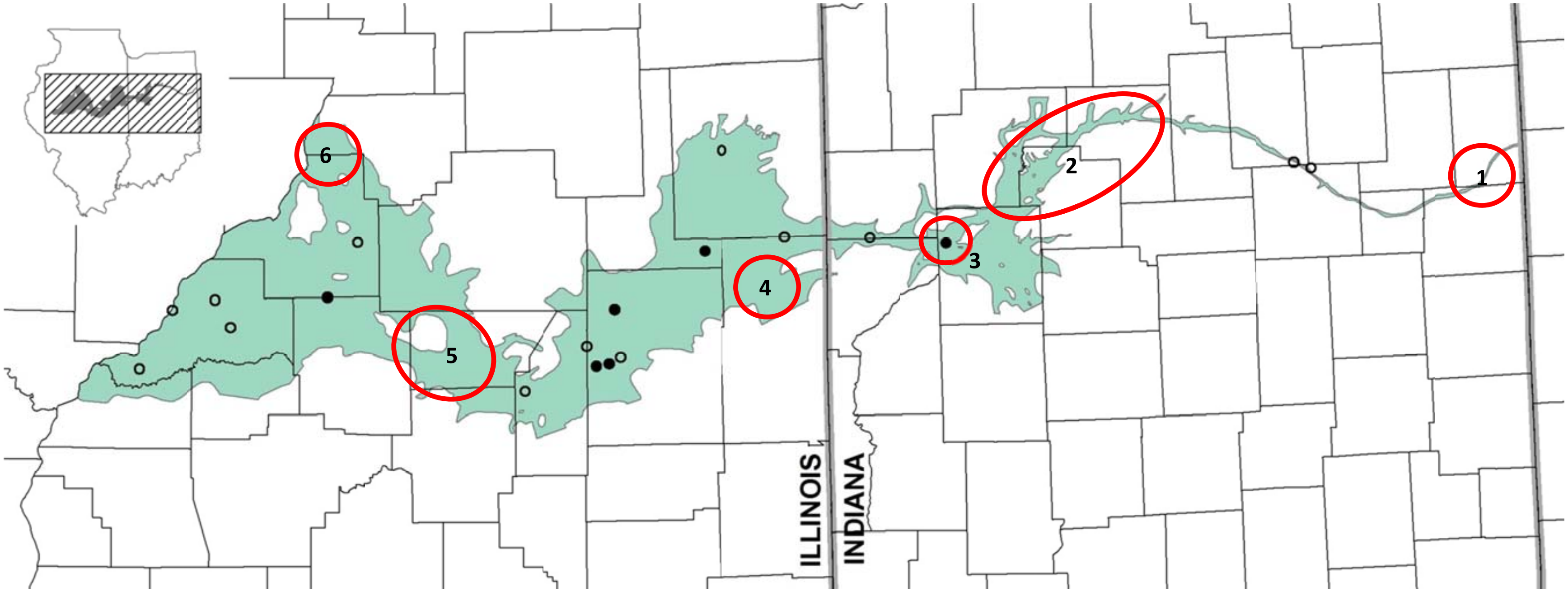

Figure 22. Spatial data gaps (numbered red ovals) in the Illinois/Indiana Pilot water level subnetwork.

## Water-Quality Network Well Selection

Most of Illinois' observation wells have been sampled for a variety of water quality parameters for purposes of documenting general groundwater chemistry (Wilson et al., 1998), and in some cases, geochemistry (Panno et al., 1994). Naturally-occurring arsenic also has been a subject of characterization (Holm, 1995; Kelly, 2005; Holm and Wilson, 2009) as has a microbiological examination of selected wells (Kirk et al., 2004). However, while these wells have been sampled at least once during their life, they are not sampled on a routine, recurring basis.

Public water supply wells within the Mahomet-Teays system also have been sampled, by the IEPA, ISWS, and USGS-IL for a variety of regulatory, public service, and research purposes. Most historical IEPA records of raw water quality have been incorporated into the ISWS' groundwater quality database. The IEPA currently operates a statewide Community Water Supply (CWS) "Ambient Network", sampling selected community supply well raw water (i.e., not treated) for a variety of analytes, most recently focusing on volatile organic compounds. Additionally, the USGS-IL has collected samples from dozens of private, community, and dedicated observation wells for analyses of a wide range of naturally-occurring and anthropogenic constituents, including trace metals, herbicides, and wastewater compounds (e.g., Mills and McMillan, 2004; Warner, 2000).

The IEPA CWS Ambient Network was initiated in 1984 (IEPA, 2010). The CWS Network was designed to: provide an overview of groundwater quality being produced by Illinois' CWS wells, provide an overview of, and establish baseline and trends in, groundwater quality in Illinois' major aquifers, and evaluate effectiveness of Clean Water and Safe Drinking Water Act program activities in protecting Illinois groundwater (McMillan and Dulka, 2001). CWS Network wells were selected using a random stratified probability-based approach at a 95 percent confidence level. The random selection of CWS wells was stratified by well depth, aquifer type, and the presence of aquifer material within 50 feet of land surface. The random stratified selection process resulted in 354 fixed monitoring locations from a population of nearly 3,000 active CWS wells statewide.

CWS Network sampling frequency was initially quite variable, with some wells being sampled only once every few years or a gap in sampling of 5 or more years. Current sampling frequency is much more regular and since about 1996 has been biannual. Major dissolved anions and cations form the basis for analysis; however, many additional recent sampling events (since about 2000) have included a host of organic parameters (e.g., volatile organic compounds, agricultural chemicals including degradates, and gasoline components and the additive MTBE). A complete list of analytes appears in Table 6.

The situation in Indiana is quite different. In Indiana, there is no active routine monitoring of the Mahomet-Teays. Therefore, a decision was made to initiate a monitoring program using the available observation wells in the water level network.

#### Unstressed Subnetwork

A network of wells that provides water quality data indicative of natural groundwater quality meets the Illinois/Indiana definition for "unstressed." Such a network should also provide information on natural water quality variability, both spatially and temporally. Water quality should not contain detectable contaminants associated with anthropogenic activities (e.g., volatile organic compounds, herbicides, pesticides). Presence of such compounds would move the well into the Targeted Water Quality Subnetwork.

In some instances, it may require comparison to other wells within the aquifer to assess whether a well sample contains water quality that is not considered "natural." A good example of this is nitrate. The presence of nitrate in groundwater often occurs naturally from the breakdown of organic matter; elevated concentrations of nitrate often are associated with excess application of fertilizer or contamination by human/animal wastes. The decision as to when a nitrate concentration is considered elevated or not is subject to some judgment. Therefore, the mere presence of nitrate in a groundwater sample does not automatically move a well from the unstressed to targeted subnetwork.

In the Mahomet-Teays, arsenic is a naturally occurring element in groundwater. Dissolved arsenic concentrations are spatially quite variable and are known to exceed the 10 µg/L drinking water standard in places. Like nitrate, the presence of arsenic in the water will not cause a well to fall into the targeted subnetwork. If, however, an external agent (such as pumping to cause aeration of the aquifer material and dissolution of arsenic from the aquifer matrix) can be determined to be the reason for the arsenic in the groundwater, then the well will be in the targeted subnetwork.

### Aquifer 1: Mahomet-Teays Aquifer (Unstressed)

Twleve wells in the IEPA CWS Ambient Network are within the Mahomet-Teays aquifer system. The IEPA CWS Ambient Network represents the only active, routine monitoring of water quality in the Mahomet-Teays in Illinois. While water quality data exist for each of the selected Illinois water level observation wells (excepting the very new wells), we have elected to select only wells within the IEPA CWS Ambient Network for inclusion in the Illinois portion of the NGWMN. We acknowledge some of the shortfalls in using community supply wells for monitoring aquifer quality and water quality changes (e.g., long well screens and high pumping rates that integrate water quality), these wells also provide some advantages that our dedicated wells cannot. First, these community wells have a fairly long sampling history, all going back to 1982-83. Second, the sampling history often contains a minimum of six sampling periods with one well having been sampled 18 times since 1982. Third, the sampling includes a broad range of analytes, including a host of organic compounds (see Table 6 for a complete list of analytes). Finally, because the aquifer is confined for most of its extent in Illinois, there is only a small chance of entry of surface contaminants from land use practices or quality changes due to land cover. Dedicated monitoring wells would likely do no better at detecting potential anthropogenic influences. "Integrated" aquifer sampling from community supply wells, then, provides a good view of overall aquifer health and drinking water quality.

Of the 12 wells actively being sampled within the Mahomet-Teays in Illinois, two wells are being sampled in each of two communities (Delavan #1 and #3, and Illinois American-Champaign #53 and #59). Illinois American-Champaign #59 was found to be "double-screened" across two depth intervals and because there is another well being sampled nearby, this well was dropped from the water quality subnetwork. Good geologic information could not be found for Delavan #1 (it was drilled in 1899) and because nearby Delavan #3 was also being sampled, Delavan #1 was also dropped from NGWMN consideration.

All of the IEPA CWS Ambient Network wells are completed in the Mahomet-Teays (Aquifer 1). No wells sample shallower aquifers (Aquifer 2). Examination of the analytical data shows no readily apparent anthropogenic influence (including no detectable presence of organic compounds). Therefore, all wells are considered to be within the unstressed water quality subnetwork and no wells could be considered as candidates for a targeted subnetwork.

Four of the water level observation wells (Benton 4, Tippecanoe 17, Tippecanoe 18, and Grant 10) chosen for the Indiana portion of the NGWMN water-quality subnetwork are also part of the water-level network, although they have not yet achieved the baseline criteria. Benton 4 was only recently sampled by the Indiana Department of Environmental Management (InDEM). The results for Benton 4 and InDEM sampling protocol are available. Previous sampling and testing of the Indiana observation wells were conducted by the USGS. Results for Benton 4 will be posted on its respective USGS site. An example of previous results for Grant 10 is shown in Figure 23.

## Table 6. IEPA Community Water Supply Ambient Network Analyte List

**FIELD PARAMETERS**

CONDUCTANCE
FLOW (PUMPING) RATE (GAL/M)
OXIDATION-REDUCTION POTENTIAL (EH)
TEMPERATURE (CENTIGRADE)
STATIC WATER LEVEL (FEET)
PUMPING LEVEL (FEET)
RUN TIME PRIOR TO SAMPLING (MIN)

**INORGANIC ANALYTES**

ALKALINITY, TOTAL
ALUMINUM
NITROGEN-AMMONIA AS (N)
ARSENIC
BARIUM
CADMIUM
CALCIUM
CHLORIDE
CALCIUM
CHROMIUM
COPPER, FREE
CYANIDE
FLUORIDE
HARDNESS (CALCULATED)
HARDNESS, TOTAL (AS CAC03)
IRON
LEAD
MAGNESIUM
MANGANESE
MERCURY
NICKEL
NITRATE-NITRITE
NITRATE
POTASSIUM
PHOSPHATE, TOTAL
SELENIUM
SILICA
SILVER
STRONTIUM
SODIUM
SULFATE
RESIDUE, TOTAL, FILTERABLE
CONDUCTIVITY @ 25 C UMHOS/CM

**INORGANIC ANALYTES (concluded)**

TDS
TURBIDITY
ANTIMONY, TOTAL
BERYLLIUM, TOTAL
BORON, TOTAL
COBALT, TOTAL
MOLYBDENUM, TOTAL
THALLIUM, TOTAL
VANADIUM, TOTAL
PHOSPHORUS, TOTAL
ZINC

**ORGANIC ANALYTES**

1,1,1,2-TETRACHLOROETHANE
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHYLENE
1,1-DICHLOROPROPENE
1,2,3-TRICHLOROPROPANE
1,2,4-TRICHLOROBENZENE
1,2-DICHLOROETHANE
1,2-DICHLOROPROPANE
1,3-DICHLOROPROPANE
2,2-DICHLOROPROPANE
2,4,5-TP
2,4-D
ACETOCHLOR
ALDRIN
ATRAZINE
BENZENE
BENZO(A)PYRENE
BHC-GAMMA
BROMACIL
BROMOBENZENE
BROMOFORM
BROMOMETHANE
CARBON TETRACHLORIDE
CHLORDANE
CHLOROBENZENE
CHLOROETHANE

## ORGANIC ANALYTES (continued)

CHLOROFORM

CHLOROMETHANE

CHLOROPYRIFOS

CHLOROTOLUENES

CIS-1,2-DICHLOROETHYLENE

CIS-1,3-DICHLOROPROPENE

CYANAZINE

DALAPON

DCPA

DCPA MONO/DI-ACID DEGRADATES

DI(2-ETHYLHEXYL) ADIPATE

DI(2-ETHYLHEXYL) PHTHALATE

DIBROMOCHLOROMETHANE

DICAMBA

DICHLOROBENZENES, TOTAL

DICHLOROMETHANE

DIELDRIN

DINOSEB

ENDRIN

ETHION

ETHYLBENZENE

ETHYLENE DIBROMIDE

FONOFOS

HEPTACHLOR

HEPTACHLOR EPOXIDE

HEXACHLOROBENZENE

HEXACHLOROCYCLOPENTADIENE

LASSO

MALATHION

METHOXYCHLOR

METHYL TERT-BUTYL ETHER

METHYL PARATHION

METOLACHLOR

METRIBUZIN

O-DICHLOROBENZENE

ORTHO-PARA DDD

ORTHO-PARA DDE

ORTHO-PARA DDT

PARA-PARA DDD

PARA-PARA DDE

PARA-PARA DDT

## ORGANIC ANALYTES (concluded)

P-DICHLOROBENZENE

PENTACHLOROPHENOL

PHENOLS

PICLORAM

PROMETON

PROPACHLOR

SIMAZINE

SPECTRACIDE

STYRENE

TERBUFOS

TETRACHLOROETHYLENE

THIMET

TOLUENE

TOTAL DDT

TOTAL POLYCHLORINATED BIPHENYLS (PCB)

TOXAPHENE

TRANS-1,2-DICHLOROETHYLENE

TRANS-1,3-DICHLOROPROPENE

TRICHLOROETHYLENE

TRIFLURALIN

VINYL CHLORIDE

XYLENES, TOTAL

## BIOLOGIC PARAMETERS

E. COLI

COLIFORM (TCR)

| Sample Date / Time | Time Datum | Time Datum Reliability Code | Sample Medium Code | Agency Collecting Sample Code | Temperature, water (00010) deg C | Agency analyzing sample (00028) code | Specific conductance, water, unfiltered (00095) µS/cm @ 25 deg C | Hydrogen ion, water, unfiltered calcd (00191) mg/L | pH, water, unfiltered, field (000400) standard units | pH, water, unfiltered, lab (000403) standard units | Carbon dioxide, water, unfiltered (00405) mg/L | ANC, water unfiltered, end point, field (00410) mg/L as $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8-14-1988 / 1243 | EST | T | WG | USGS-WRD | 14.8 | 80020 | 795 | 0.00003 | 7.6 | 7.8 | 18 | 351 |

| Total solids dried at 105 deg C, water, unfiltered (00500) mg/L | Nitrate + nitrite, water, filtered (00631) mg/L as N | Phosphate, water, unfiltered (00650) mg/L | Hardness, water (00900) mg/L as $CaCO_3$ | Calcium, water, filtered (00915) mg/L | Magnesium, water, filtered (00925) mg/L | Sodium, water, filtered (00930) mg/L | Sodium adsorption (00931) ratio | Sodium fraction of cations (00932) percent | Potasium, water, filtered (00935) mg/L | Chloride, water, filtered (00940) mg/L | Sulfate, water, filtered (00945) mg/L | Iron, water, filtered (00945) µg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 532 | 0.150 | 0.061 | 340 | 72.0 | 40.0 | 41.0 | 1.0 | 20 | 2.50 | 6.1 | 91.0 | 570 |

| Depth to water level below LSD (30210) meters | Dissolved solids, sum of constituents (70301) mg/L | Dissolved solids, water (70303) tons/acre-ft | Othophosphate, water, unfiltered (70507) mg/L as P | Depth to water level below LSD (72019) feet | Specific conductance, water, unfiltered (90095) µS/cm @ 25 deg C | ANC, water, unfiltered, end point, lab (90410) mg/L as $CaCO_3$ |
|---|---|---|---|---|---|---|
| 32.9 | 464 | 0.63 | 0.02 | 108.00 | 811 | 357 |

Figure 23. Water sample analysis for Grant 10 (Aquifer 1 Mahomet-Teays unstressed).

Table 7 contains general details of the wells selected for the Illinois-Indiana water-quality subnetwork. A map of these well locations is provided in Figure 24. InDEM will have the resources to sample the Indiana wells over the next two years. IEPA has plans to sample the Illinois subnetwork wells perhaps as many as six times during 2011 to establish a statistical water quality reference.

**Table 7. Wells in the unstressed water-quality subnetwork of Aquifer 1: Mahomet-Teays Aquifer**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Quality Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| Benton 4 | Indiana | Baseline not achieved | Once | 10/06/2010 | 295-300 |
| Tippecanoe 17 | Indiana | Baseline not achieved | Once | 08/17/1989 | 207-212 |
| Grant 10 | Indiana | Baseline not achieved | Once | 08/14/1987 | 209-214 |
| Paxton #7 | Illinois | Surveillance | ~Biannual | 1983- | 240-340 |
| Crescent City #2 | Illinois | Surveillance | ~Biannual | 1984- | 125-132 |
| IL-American Champaign #53 | Illinois | Surveillance | ~Biannual | 1983- | 234-289 |
| Danvers #4 | Illinois | Surveillance | ~Biannual | 1982- | 418-438 |
| Easton #1 | Illinois | Surveillance | ~Biannual | 1982- | ??-135 |
| Havana #5 | Illinois | Surveillance | ~Biannual | 1982- | 46-96 |
| Sangamon Valley PWD #1 | Illinois | Surveillance | ~Biannual | 1984- | 253-283 |
| Delavan #3 | Illinois | Surveillance | ~Biannual | 1984- | 156-185 |
| Hopedale #5 | Illinois | Surveillance | ~Biannual | 1986 | 185-205 |
| Clinton #11 | Illinois | Surveillance | ~Biannual | 1991- | 300-360 |

### Aquifer 2: Illinois and Wisconsin Episodes Aquifers (Unstressed)

Because no wells within the IEPA CWS Ambient Network are completed in shallower aquifers, only Tippecanoe 18 in Indiana is part of the unstressed water-quality subnetwork of Aquifer 2.

**Table 8. Wells in the unstressed water-quality subnetwork of Aquifer 2: Illinois/Wisconsin Episodes Aquifers**

| Site Name | State | Surveillance or Trend Site | Frequency of Measurement | Period of Water-Quality Record | Screened Interval (ft) |
|---|---|---|---|---|---|
| Tippecanoe 18 | Indiana | Baseline not achieved | Once | 08/18/1989 | 59-64 |

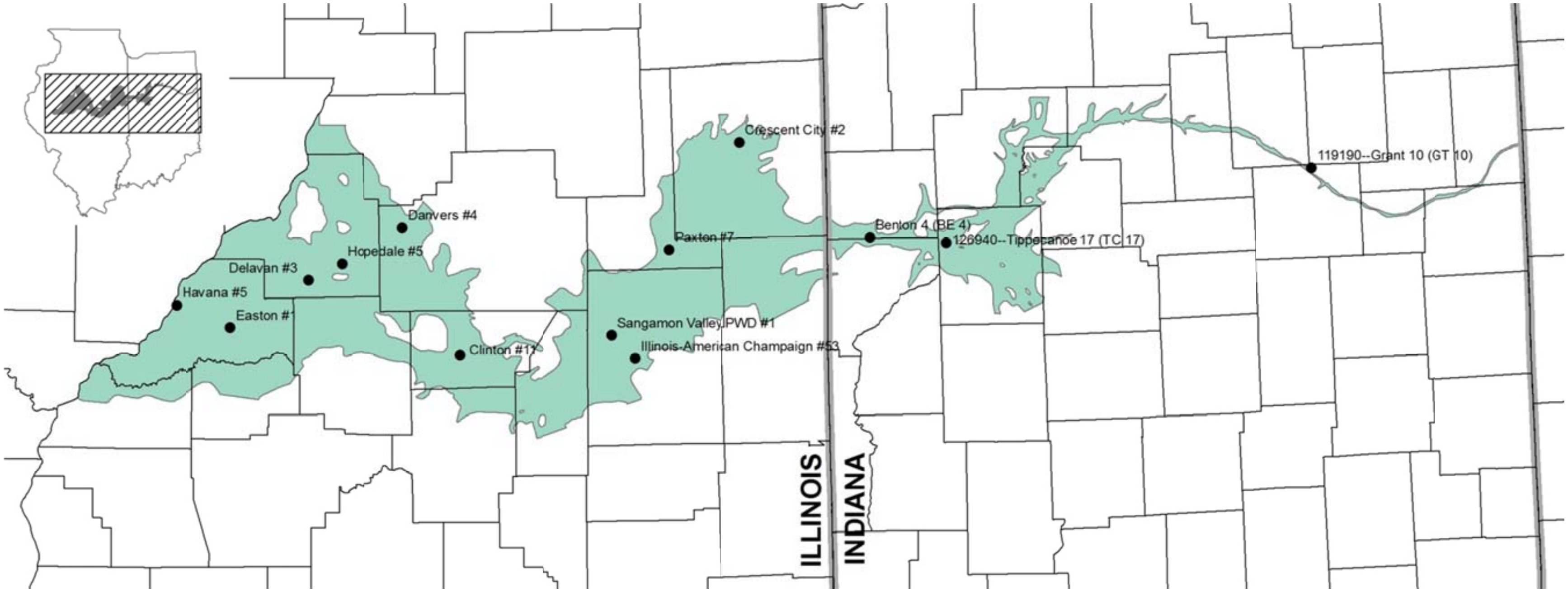

Figure 24. Wells in the unstressed water-quality subnetwork of Aquifer 1: the Mahomet-Teays Aquifer.

### Targeted Subnetwork

Classification of a well as “targeted” due to a water quality parameter created some discussion within the Illinois-Indiana Pilot participants. For example, should a well remain in the unstressed subnetwork if chemicals of concern increase in concentration within an aquifer over time, but still remain below drinking water standards? Could the unstressed network include “watch” or “warning” modifiers where a “watch” stage leads to increased monitoring and a “warning” stage triggers best management practices to avoid being classed as targeted?

For the purpose of this Pilot, however, it was agreed that “targeted” water-quality subnetwork wells show an impact from anthropogenic activities on water quality. As mentioned in the discussion regarding unstressed water quality, this is not always easily defined because many water quality parameters (e.g., nitrate, arsenic) occur naturally and some effort is needed to establish what concentrations would be considered “background” or natural versus impacted or contaminated. Temporal variability in water quality makes distinguishing between natural and humanly- influenced natural even more difficult. However, the presence of synthetic compounds in groundwater (e.g., volatile organic compounds, pesticides, herbicides and degradates) is an indication of human impact and lead directly to a well being classified in the targeted water-quality subnetwork. For these compounds and many like them, the mere detection of them in the water will place the well in the targeted subnetwork, even though detected concentrations may be far below drinking water standards.

No wells in Illinois or Indiana currently selected for water quality monitoring fall into our definition of “targeted”. This also means wells whose water levels are affected by pumpage (i.e., classified as “targeted” in the water-level subnetwork) will not be classified in the targeted water-quality subnetwork until such time as the water quality is affected.

#### Aquifer 1: Mahomet-Teays Aquifer (Targeted)

No selected wells currently fall into the targeted subnetwork for Aquifer 1.

#### Aquifer 2: Illinois and Wisconsin Episodes Aquifers (Targeted)

No selected wells currently fall into the targeted subnetwork for Aquifer 2.

### Water-Quality Subnetwork Gap Analysis

The Illinois-Indiana Pilot water-quality network is clearly not as strong as the water-level network. This is largely a factor of historical needs and costs. Most of the available observation wells have been sampled once to document groundwater quality when the well was constructed; resampling was not deemed necessary to meet the needs of a water-level network. Several wells have been sampled more than once as part of limited special studies (such as for assessing the occurrence of arsenic in the Mahomet-Teays system, e.g., Holm, 1995; Holm and Wilson, 2000), but none of the current population of observation wells routinely used for water-level measurement is part of a routine water-quality sampling effort. For Indiana, we have chosen to initiate sampling of the water-level subnetwork. For Illinois, we selected CWS wells that have been part of a long and on-going program of routine sampling by IEPA.

This sampling strategy contains several data gaps. For the most part, such gaps are spatial in nature as the list of analytes for the Indiana and Illinois wells appear to cover the minimum desired set of constituents at an adequate sampling frequency (i.e., annual). A greater density of sampling points, especially in Indiana, is needed. Adding the wells proposed to address spatial gaps in the water-level subnetwork will help address this problem. The same approach is proposed for Illinois (i.e., routine sampling of new wells proposed to close spatial data gaps in the water-level subnetwork in Illinois). The addition of such wells to the water-quality subnetwork will also help address spatial gaps in the vertical dimension, as the shallower aquifers (Aquifer 2: Illinois and Wisconsin Episodes Aquifers) are largely unmonitored by this subnetwork. It is proposed to also add the three-well ob-well nest (CHAM-07-01A, B, C) located within the area affected by the Illinois-American Water Co. wellfield west of Champaign to address the vertical dimension within the only Illinois area classified as targeted in the water-level subnetwork. This does bring up a potential issue of using different kinds of wells within the water-quality subnetwork (public supply wells and dedicated monitoring wells) – an issue that must be left unresolved in this report.

An additional option is available in Illinois. Several monitoring wells in the unconfined western region of the Mahomet-Teays are being routinely sampled by the Illinois Department of Agriculture (IDA). The wells have a history of sampling results dating back to about 2000 (Mehnert et al., 2005) and includes results of pesticide and pesticide degradate analysis. With the cooperation of the IDA, several of these wells could be incorporated into this subnetwork. The principal reasons they have not been selected at this point has been a matter of time and effort by the Pilot team, and not the fault of the IDA.

A lithologic description apparently does not exist for one well within the active IEPA CWS Ambient Network and this proposed water-quality subnetwork (Crescent City #2). Downhole geophysical logging similar to that recommended for a well in the water-level subnetwork is proposed (see discussion on page 35).

Finally, no wells within the current water-quality network fall into the targeted subnetwork. This is not by design, but rather, a fortuitous circumstance in that the Mahomet-Teays aquifer is largely well-protected from anthropogenic influences by relatively thick confining beds. The addition of shallower wells (such as wells in the IDA network) in the unconfined western portion of the Mahomet-Teays, as opposed to the deeper CWS wells currently in the network, could change this classification if pesticides or pesticide degradates are found in such wells.

## Field Practices

This section describes the Illinois-Indiana Pilot field practices (by reference), includes a comparison to Appendix 5 in the Framework Document, and an analysis of the differences between the Pilot practices and those in the Framework Document.

### Groundwater Level Monitoring Field Practices

The USGS currently maintains the observation wells Benton 4, Tippecanoe 18, and Grant 10 in cooperation with the InDNR conforming to USGS standards for water-level monitoring practices. The InDNR measures water levels manually for Wabash 4 and Grant 10. In Indiana, water-level measurements are recorded in feet with reference to land-surface datum (Morlock and others, 2003). If known, the elevation of the land-surface datum above sea level is given in the well description. The height of the measuring point above or below land-surface datum is given in each well description. The field practice conducted by InDNR in the past differs from the SOGW framework document in that typically only one measurement is made with an electric-tape versus the three measurements recommended in the Framework document (SOGW, 2009).

Field measurement of groundwater levels follows protocols prescribed by ISWS Standard Operating Procedure for Groundwater Level Measurement (1999). Minor differences were found between the recommended NGWMN standards and standard field practices in Illinois. Triple measurement of depth-to-water is not typical; however, repeated measurement is desired and reference to previous measurements in field notes is helpful for comparison to assess whether or not a current measurement is “in-the-ballpark.”

Neither Illinois nor Indiana decontaminates measuring devices (electric dropline or steel tape) between wells, principally because a) the water-level observation wells are not part of a water-quality sampling network, b) the "active" screened interval of the well is tens of feet below the top of the water and only the top few inches to feet of water would come into contact with the measuring device, and c) proper purging of the well is expected to alleviate cross-contamination concerns. Decontamination of equipment between wells is a relatively easy fix to incorporate into a standard field practice by using a disinfecting wipe on those portions of the tape/dropline that enter the well. Weather conditions are noted by some field staff, but not all, and such information is not transferred to digital records. We do not contemplate requiring a change in this practice, except to note unusual weather conditions that might affect data or data collection.

In Illinois, depth-to-water is recorded as depth below the measuring point and the elevation of the measuring point (typically the top of the well casing) is given in each well description. This protocol will need to be revised for all water level data provided to the Portal.

More major differences were noted with practices related to minimum data elements, and consistency in recording and archiving such information. In the case of Illinois observation wells, some minimum data elements are missing or are not well-documented for some wells. For example, to convert depth-to-water below measuring point to depth-to-water below land surface, well casing stick-up is needed. While casing stick-up has been measured for many wells, it has not been recorded for all. If missing, this is a minimum data element that is easily determined. Similarly, a few wells remote from survey benchmarks have not been surveyed for elevation. Ideally, we like to have well elevations surveyed to within 0.1 feet and to within 0.01 feet for nested wells where vertical gradients can be evaluated.

Instrumentation used to take the water-level measurement (instrument type and model, serial number, etc.) is not recorded in field notes or in a database. At the very least, such information will be noted in the field. For dataloggers, a formal recording of which instrument is placed in which well, and for what period will be done. For wells with dataloggers, the frequency of an actual site visit for data download is not routine. This must become routine, on the order of every two months or quarterly, to minimize potential loss of data and to provide a manual field-check (and possible correction) of the automated water level. Further, ISWS has not created a formal procedure for archiving the automated water-level measurements – currently stored as separate spreadsheets and not in the database table with the manual measurements. Steps will be taken in discussion with the ISWS database manager to formalize procedures and create a Standard Operating Procedure for storing these data.

In addition, field notebooks have not been routinely copied/scanned upon return from the field. This exposes field notes to damage or loss upon return to the field. A formal process of scanning field notebooks upon return to the office and uploading the scanned images to the ISWS document server will be created.

### Groundwater Quality Monitoring Field Practices

The USGS water quality samples for Grant 10, Tippecanoe 17, and Tippecanoe 18 were analyzed onsite for sulfide and measurement of alkalinity, pH, water temperature, specific conductance, and dissolved oxygen. More detailed field practices are given in Morlock and others (2003). All other sample analyses were performed at a USGS laboratory. Laboratory methods used by the USGS laboratory are given in Techniques of Water-Resources Investigations (TWRI), Book 1, Chapter D2; and Book 5, Chapters A1, A3, and A4.

The InDEM water-quality field practices and laboratory procedures for their Indiana Ground Water Monitoring Network (InGWMN) are currently not publicly available. However, the InDEM field practices and laboratory procedures follow standard approved methods (James Sullivan, Indiana Department of Environmental Management, oral commun., 2010). Differences in the InDEM InGWMN field practices guide, quality assurance project plan, and laboratory methods manual and the SOGW framework document are cited in the next section.

Benton 4 was sampled under the IGWMN program in October 2010, with the USGS providing pumping and purging assistance. In brief, the InDEM procedures are similar to the USGS with water quality samples for Benton 4 analyzed onsite for sulfide and measurement of alkalinity, pH, water temperature, specific conductance, and dissolved oxygen. All other sample analyses were performed at a certified laboratory utilizing U.S. Environmental Protection Agency (USEPA) laboratory methods or USEPA approved methods. Indiana field practices and laboratory procedures follow standard approved methods by the USGS, USEPA, and InDEM (James Sullivan, Indiana Department of Environmental Management, oral commun., 2010). Unapproved new technologies were not utilized.

Quality assurance and field sampling methodologies within the IEPA CWS Ambient Network follow procedures set forth in their Quality Assurance and Field Methods Manual (McMillan and Dulka, 2001). A brief overview of the methods creation and procedures review by USGS-IL are summarized in the Illinois Integrated Water Quality Report (2010):

> *The prototype monitoring efforts included development of quality assurance and field sampling methods. Illinois EPA's quality assurance and field sampling methods, originally developed in 1984 in cooperation with the USGS, were compiled into a field manual in 1985 (Cobb and Sinnott,1987 and Barcelona,[et al.,] 1985). This manual has since been revised many times to include quality improvements. Monitoring at all stations sampled by Illinois EPA is completed by using Hydrolab® samplers to insure that in-situ groundwater conditions are reached prior to sampling. Water quality parameters include: field temperature, field specific conductance, field pH, field pumping rate, inorganic chemical (IOC) analysis, synthetic organic compound (SOC), and VOC analysis. All laboratory analytical procedures are documented in the Illinois EPA Laboratories Manual.*
>
> *In the year 2000, the Illinois EPA tasked the USGS to conduct a yearlong independent evaluation of our groundwater quality sampling methodology. The USGS concluded that Illinois EPA sampling program (sampling methodology guidelines, water quality meter calibration, and sampling performance) is considered to provide samples representative of aquifer water quality. Only minor revisions to the sampling program were suggested (Mills and Terrio 2003). In addition, Illinois EPA also participates in the annual USGS National Field Quality-Assurance Program.*

A general review of IEPA water-quality sampling standard operating procedures (SOPs) suggests the minimum standards recommended in the Framework document (SOGW, 2009) are being followed. Some of these standards were, in fact, adopted from procedures recommended by ISWS investigators (e.g., Barcelona et al., 1985). IEPA standard procedures also include oxidation-reducton potential (ORP) as a purging parameter in addition to those recommended in the Framework document. Also not included in the Framework document, pre- and post-sample-collection instrument calibration and log are also included in the IEPA SOP. Three-volume well purging is not a prerequisite; rather, parameter stabilization for a period up to a maximum of 30 minutes is required (if stabilization is not met within 30 minutes of purging, a final set of parameter readings is recorded and then sampling is initiated). IEPA SOP also calls for chain-of-custody, which is not mentioned in the Framework document.

Finally, review of the historical data provided by IEPA for the wells selected to be within the water-quality subnetwork revealed a few inconsistencies, believed by IEPA personnel to be inconsistencies with legacy data collected in years before data QA/QC became the widely recognized issue that it is today. Database inconsistencies included some analyte code discrepancies (e.g., use of 1016 and 1019 codes for calcium), inconsistent use of concentration units (mg/l vs. µg/l) for the same analyte, and either no (null or blank) detection limit or a "zero" detection limit for some analytes. We see no ready solution in dealing with legacy data; an effort will be made to correct data unit and analyte code discrepancies.

### Gap Analysis

Discussion of differences between desired NGWMN standards and Illinois/Indiana field practices is provided in the previous sections. The field and laboratory practices of the USGS-IN, InDNR, and IEPA compare very favorably with the Framework document (SOGW, 2009). No major differences were identified.

## Data Management System

### Description of Pilot Study System(s)

For Indiana, the data management system for water-level monitoring is maintained by the USGS and the InDNR. The USGS follows their standard protocol, with automatic water levels recorded electronically and either accessible from the Internet in real-time or periodically uploaded to the system. Manual water levels also are routinely collected, used to field-check and calibrate digital dataloggers, and uploaded to the system. The InDNR records periodic water-level data to a field notebook and transfers that data to the specific observation well binder that is kept for each well within the InDNR network at the state office. The data are then transferred electronically to an Excel database. Water-quality data also is accessible from the USGS web site.

The ISWS records manually-collected field data in field logbooks and transfers those data to a computer database upon return to the office. Water level and water quality data are stored in a SQL Server 2008 database running on a 64-bit Windows Server 2008 computer. Observation well water level data are correlated to information regarding measurement technique, measuring point elevation, aquifer name, and timestamp. The water quality data includes a laboratory analysis number, analyte storet or SDWIS code, concentration, concentration unit, detection limit, and date information. The mapping of multiple storet and analyte coding systems employed by various laboratories and agencies (e.g., ISWS and IEPA) needs to be addressed. In addition to the periodic tracking and sampling of water level and water quality data, various metadata about individual wells is also recorded including depth, location, type, usage, construction details, owner and driller name. High-capacity (>70 gpm capacity) and community wells also have annual pumping data. Finally, numerous scanned documents related to wells such as driller logs, permits, sealing forms, chemical forms and pump installation reports have been digitally archived. All data and related well information are cross-referenced by a unique ISWS point (well) identification number (P-number). All of this information is available internally to ISWS staff; however, most information is not publicly accessible, including groundwater-level or groundwater-quality data.

Well lithologic data (driller's logs) are maintained as hard copies by ISWS and ISGS. The ISGS also maintains the lithologic information digitally in their Well Records (Oracle) database. On-line, public access to the Well Records database is provided via their ILWATER Internet Map Server application (*http://www.isgs.illinois.edu/maps-data-pub/wwdb/launchims.shtml*). Cross-reference is available for many wells (unfortunately, not all) between the ISWS Wells database using the ISWS P-number and the ISGS Well Records database using the ISGS API number.

### Comparison to Framework Document

Discussion of data systems, data standards, and data management within the Framework document (Appendix 6) is somewhat ambiguous and seems more open to the Pilots to assess comparability against the Framework. Because of the protocols used in preparing data for the USGS NWIS web-site, and because all the proposed Indiana well data are available via NWIS, the data management practices of the USGS-IN, InDNR, and InDEM are believed to compare very favorably with the Framework document (SOGW, 2009). Data management practices for Illinois also are generally believed to meet minimum data requirements. No major differences were identified.

### Gap Analysis

To expose ISWS' NGWMN water-level and water-quality data dynamically over the Internet, the ISWS will provide a set of XML Web services over HTTP as SOAP (Simple Object Access Protocol) - a computer communication protocol used to exchange web service data requests with the NGWMN Data Portal. Web service methods, input parameters, and result sets will be password-protected (that is, for security between the Data Portal server and the ISWS server, as opposed to a user password) and made available through a WSDL (Web Services Description Language) document. The ISWS will work with the NGWMN Data Portal staff to define the structure and content of these web services.

## Summary of Gap Analyses

This section summarizes the contents of each of the gap analysis sections above. An analysis of the adequacy of well coverage, frequency of measurement, analyte lists, field practices, database storage, management, and availability to the public with respect to the Framework Document, *and their associated costs* is one of the primary objectives of the Pilot phase of the NGWMN. Cost estimates are provided in the following Cost Estimates section.

### Water-Level Subnetwork

Data gaps for the Indiana water-level network exist in Tippecanoe County and Adams County (red ovals numbered 1 and 3 in Figure 22). Water rights issues in Adams County have been associated with high-capacity pumpage within the Teays system (#1). In Tippecanoe County (#3), there is considerable pumpage by high-capacity facilities and observation well Tippecanoe 17 may not be deep enough to properly assess water levels in the Mahomet-Teays aquifer. Two additional wells are proposed for the intervening region of Indiana (#2). Two-well nests are proposed for three areas (#4, #5, and #6) in Illinois where added wells (well nests) will improve aquifer understanding.

To address temporal data gaps, dataloggers are proposed for all new locations in Illinois; satellite telemetry is proposed for Indiana (in cooperation with USGS). In addition, the observation well MTOW-9 currently is measured only on a monthly schedule. MTOW-9 is known to respond to Illinois River stage (see hydrograph in Appendix A). Upgrade of measurement frequency with a datalogger at this site is proposed.

Many of the wells have not been accurately or precisely surveyed for elevation. Optical surveying or high-accuracy GPS elevations for several wells is needed to bring the network to acceptable standard.

With regard to the water-quality subnetwork, data gaps are largely spatial in nature as the list of analytes for the Indiana and Illinois wells appear to cover the minimum desired set of constituents at an adequate sampling frequency (i.e., annual). A greater density of sampling points, especially in Indiana, is needed. Adding the wells proposed to address spatial gaps in the water-level subnetwork will help address this problem. The same approach is proposed for Illinois (i.e., routine sampling of new wells proposed to close spatial data gaps in the water-level subnetwork in Illinois). The addition of such wells to the water-quality subnetwork will also help address spatial gaps in the vertical dimension, as the shallower aquifers (Aquifer 2: Illinois and Wisconsin Episodes Aquifers) are largely unmonitored by this subnetwork. It is proposed to also add the three-well ob-well nest (CHAM-07-01A, B, C) located within the area affected by the Illinois-American Water Co. wellfield west of Champaign to address the vertical dimension within the only Illinois area classified as targeted in the water-level subnetwork.

Minor differences were found between the recommended NGWMN standards and standard field practices in Illinois. Triple measurement of depth-to-water is not typical; however, repeated measurement is done and reference to previous measurements contained in field notes is designed to quickly assess whether or not a current measurement is “in-the-ballpark.” Neither Illinois nor Indiana decontaminates measuring devices (electric dropline or steel tape) between wells, and easy/inexpensive measures will be taken to address this issue.

More major differences were noted with practices related to minimum data elements, and consistency in recording and archiving such information. In the case of Illinois observation wells, some minimum data elements are missing or are not well-documented for some wells, for example, recording of well casing stick-up which is important to determination of depth-to-water below land surface. Instrumentation used to take the water-level measurement is not recorded in field notes or in a database. At the very least, such information will be noted in the field. For dataloggers, a formal recording of which instrument is placed in which well, and for what period will be done. For wells with dataloggers, the frequency of an actual site visit must become routine, on the order of every two months or quarterly, to minimize potential loss of data and to provide a manual field-check (and possible calibration) of the automated water level. Further, ISWS has not created a formal procedure for archiving the automated water-level measurements – currently stored as separate spreadsheets and not in the database table with the manual measurements. Steps will be taken to formalize procedures and create an SOP for storing these data. In addition, field notebooks have not been routinely copied/scanned upon return from the field and such process will be initiated to prevent potential loss of raw data. Lithologic log descriptions are needed for observation wells MTOW-2 (Easton) and Petro North. Geologic samples exist in ISGS archives for Petro North and need to be pulled and described, entered into the ISGS Geologic Records database,and transmitted to the Data Portal. For MTOW-2 (Easton), it is proposed that downhole geophysical logging be performed.

To close water-level operational data gaps, Illinois needs to develop new SOPs for automated water-level data collection and archival of such data.

### Water-Quality Subnetwork

While the proposed Illinois-Indiana Pilot water-quality network may not be as strong as the water-level network spatially or temporally, field and lab procedures appear to be much stronger. This is likely a result of water sampling QA/QC protocols instituted many years ago during the heyday of RCRA/Superfund activities and the need to collect and prepare data for intense legal scrutiny.

That said, review of the historical data provided by IEPA for the wells selected to be within the water-quality subnetwork revealed a few inconsistencies, believed to be inconsistencies with legacy data. We see no ready solution in dealing with legacy data; an effort will be made to correct data unit and analyte code discrepancies. In addition, a lithologic log apparently does not exist for one well within the proposed water-quality subnetwork (Crescent City #2). Downhole geophysical logging similar to that recommended for a well in the water-level subnetwork is proposed.

To address spatial data gaps, a greater density of sampling points is needed. Adding the wells proposed to address spatial gaps in the water-level subnetwork will help address this problem. The addition of such wells to the water-quality subnetwork will also help address spatial gaps in the vertical dimension, as the shallower aquifers are largely unmonitored by this subnetwork. It is proposed to also add the three-well ob-well nest (CHAM-07-01A, B, C) located just west of Champaign to address the vertical dimension within the only Illinois area classified as targeted in the water-level subnetwork.

### Data Management

Principal data management needs relate to Data Portal access to water-level, water-quality, and associated geologic and well construction data originating from Illinois agencies. The ISWS is willing to host the data for the Data Portal. Procedures are needed to create a routine for IEPA to send new data to the ISWS and for ISWS to expose that data to Data Portal users.

## Proposed Changes to the Framework Document

No particular corrections to the Framework document (SOGW, 2009) are suggested; however, we have included some suggestions for additional discussion or guidance might be considered. The need for a wide variety of complementary information (e.g., aquifer withdrawals, land use, and meteorological data) was recognized as useful, even necessary, to explain water level and analytical results (Section 1.5 and Figure 1.4.5.1). The inclusion of such data was clearly spelled out as beyond the scope of this Network – we agree with the concept of “walking before running” as was used in our face-to-face discussions.

One area that might need additional clarification relates to monitoring/sampling frequency. Discussion is provided in Framework Sections 4.5.1 and 4.5.2. The Mahomet-Teays aquifer, over most of its areal extent, is a high-conductivity, low-recharge, confined aquifer system. It does not clearly fit into the suggested frequency categories shown in Framework Tables 4.5.1 and 4.5.2. A third row under the Confined category, with greater frequencies than the low K/low recharge and lower frquencies than the high K/high recharge, might be helpful to potential future users of the Framework document.

The only other element is the widely discussed use of “unstressed” and “targeted” nomenclature to describe well/aquifer water level and water quality conditions. The need for such general classification was meant to provide those with local well/aquifer knowledge a means to pass on general aquifer characteristics to Data Portal users, and vice versa, allow users of the Data Portal to quickly access well/aquifer data exhibiting the desired condition. Particular concern has been raised that this categorization, especially the targeted tag, may have negative connotations. Further, it was expressed that the data should speak for itself, rather than making potentially subjective categorizations as to whether a well is unstressed or targeted. This is especially troublesome with regard to water quality where distinguishing the difference between natural/background quality and affected quality can be quite problematic. Therefore, we agree with those that argue for NOT classifying wells into unstressed or targeted categories. Perhaps a more objective way of assessing the data, such as through the use of on-line statistical tools could assist a user in paring down well selection to particular water-level or water-quality data (again, an issue related to “walking before running”).

## Benefits of the Network

Two major benefits derived from the pilot project were the sharing of data and communication between states and agencies. This was the first time that Illinois and Indiana agencies actually talked to one another about a common resource, the Mahomet-Teays aquifer. This also provided an opportunity to share data, not only across state lines, but between agencies within each State. Interagency coordination of data collection and new data collection efforts (e.g., IEPA water-quality sampling) have already begun. For example, the IEPA is expected to initiate a bimonthly water-quality sampling effort of Mahomet-Teays CWS Ambient Network wells in 2011 to statistically assess natural variability in each well. In addition, the USGS-IL will be instrumenting two well nests within the water-level subnetwork with satellite telemetry in 2011 and has already placed the wells on Groundwater Watch. As part of this effort, the ISWS has provided approximately 15 years of historical water-level measurements to the USGS-IL that has been posted on-line on the Groundwater Watch web-site.

The Pilot "exercise" has provided impetus for a critical review of field and data management practices as well as identifying some missing minimum data elements. While we believe we are collecting good data, several standard operating procedures need to be updated and/or created. The belief is, if we cannot prove we are collecting good data, then the data may not be as good as we believe.

This Pilot effort has offered a public education opportunity for the Mahomet-Teays aquifer in particular and groundwater in general. Alerting various governmental and non-governmental agencies about the philosophy behind a national groundwater monitoring network has been met universally with positive reaction. Finally, the pilot-project face-to-face conference in Austin, TX also was a tremendous learning experience for the Illinois-Indiana participants. Hearing about how other states operate their monitoring networks was extremely informative, and provided a gauge against we can measure how well we operate our networks.

## Cost Estimates

### Cost to Participate in the Pilot Study

The labor costs (salary and fringe benefits ) associated with the pilot tasks for Indiana are estimated to total $7,000, based on approximately 5 man-weeks of staff time in meetings and preparing data and text for presentation and this report.

Costs for Illinois to participate in the Pilot effort to-date are estimated to be approximately $25,500. This covers salary and fringe for about 12 man-weeks of effort, including 6 man-weeks for the Team Leader (Wehrmann) in preparing for teleconferences, for the face-to-face meeting, for meeting/e-mailing other Pilot participants, and for final report preparation; 3 man-weeks for ISWS staff time assisting the Team Leader in data organization/preparation, final report map preparation, and attending the face-to-face meeting; and 1 man-week each for IEPA, ISGS, and USGS-IL Pilot participation, including IEPA assistance in preparation of water-quality data for the Portal.

**Total Illinois-Indiana Pilot participation cost is estimated to be about $32,500.**

### Cost to Operate and Manage NGWMN Wells

The annual cost for operation and maintenance of the Indiana portion of the water-level subnetwork is estimated to be $7,050. This cost is based on $1,350/well/year for the InDNR-USGS cooperative program for the three wells: Benton 4, Tippecanoe 18, and Grant 10 ($4,050) and $1,500/well/year to manually measure the water levels in the other two observation wells (Tippecanoe 17 and Wabash 4) on a quarterly basis. This is also approximately equivalent to 12%-time effort for a field individual (~31 man-hours).

The annual cost for operation and maintenance of the Illinois portion of the water-level subnetwork is estimated to be approximately $7,140. This cost was derived from contractual agreements between the ISWS and three different sponsors: the Imperial Valley Water Authority, the Long Range Water Plan Steering Committee (LRWPSC), and Illinois-American Water Company to operate local observation well networks across the Mahomet-Teays within Illinois. Average per well costs vary tremendously, from as little as $145/well/year to $800/well/year, and depend on measurement frequency, distance to sites, and measurement method (manual vs. automated). The lowest cost appears to be affected by economies-in-scale associated with the large number of wells/well sites located in close proximity to one another combined with a relatively low frequency (quarterly) of measurement in the LRWPSC network (47 wells at 37 sites, locations marked by triangles in Figure 11). Approximate time is 12-13% for a field staff, about 34 man-hours. An additional cost for Illinois to transmit the water-level data to the Data Portal is estimated to be 2.5 percent of the salary (plus fringe) for an ISWS programming engineer, approximately $2,200 (6.5 man-hours).

**Total cost for operation and maintenance of the selected wells in the IL-IN Pilot water level subnetwork is estimated to be ~$16,500/year (very approximately 72 man-hours).**

To operate the water-quality subnetwork, Indiana estimated the cost for sampling and analysis for one well to be $3,000, based on sampling costs (staff time, vehicle expenses, sampling supplies) of $1,000 and InDEM laboratory analysis costs of $2,000 for sampling Benton 4 in 2010. A semiannual sampling of the four wells in the Indiana portion of the water quality subnetwork, then, amounts to $24,000 (about 25%-time or 64 man-hours). Annual sampling would cost $12,000 (about 12%-time or 32 man-hours).

The IEPA estimates that the annual cost of their CWS Ambient Network is $350,000. Downscaling sampling/analysis costs from this statewide program to the CWS wells selected for the Mahomet-Teays subnetwork incurs substantial economies-of-scale, and is estimated to be only about

$8,500/year, or about $850/well, 6%-time or 15 man-hours/year. The cost for Illinois to transmit water quality data to the Data Portal is estimated to be an additional 2.5%-time for an ISWS programming engineer, approximately $2,200 (6.5 man-hours). This cost also should generally account for the cost for IEPA to transmit their data to the ISWS for uploading to the Data Portal. Semiannual sampling of the Illinois water-quality subnetwork would cost $21,400; annual sampling would cost $10,700.

**Total cost for the IL-IN Pilot water quality subnetwork is approximately $45,000 for semiannual sampling (~100 man-hours) or $22,500 for annual sampling (~50 man-hours).**

### Cost to Implement the Changes Identified in the Gap Analysis

There are three principal categories of the costs necessary to implement the changes identified in the "Gap Analysis": capital costs for new well construction and instrumentation, one-time costs for basic data collection to eliminate missing minimum data elements for a few wells selcted to be in the Pilot network, and operation/maintenance costs for field data collection, digital data entry, archival and transmission to the Data Portal.

Some basic differences exist between Indiana and Illinois monitoring well construction philosophies and we have elected not to change each state's preferences. Specifically, Indiana prefers 6-inch diameter wells while Illinois prefers 2-inch diameter wells. Indiana prefers single wells completed in the principal aquifer only, while Illinois prefers to nest wells, one in Aquifer 1 and one in the shallower Aquifer 2.

## Water-Level Subnetwork Data Gap Closure

(1) For Indiana, the capital cost to install two "gap" targeted observation wells is $16,820. The two 6-inch wells are estimated to be 170 and 210 feet deep, respectively. The casing would be SS screen. Two "gap" unstressed wells, estimated to be 210 feet deep, 6-inch diameter, with 5-foot SS screen to cost $17,780. Total capital costs for Indiana portion of the water level subnetwork is $34,600. Drilling costs estimated at $24/foot plus costs for mobilization ($2,000/site), grouting ($650/well), and well construction materials ($1,200/well).

(2) For Illinois, capital costs to close the spatial data gap are for 4 nests, 4 wells in the principal aquifer (Aquifer 1) and 4 wells in the overlying shallower aquifer (Aquifer

2). Estimated average depth for Aquifer 1 wells is 300 feet and 200 feet for Aquifer 2 wells. Drilling by ISGS is estimated at $50/foot and includes continuous coring, downhole geophysical logging, and 2-inch diameter PVC well construction materials. Illinois drilling costs total $100,000 (based on 4 wells to 300 feet and 4 wells to 200 feet equals 2,000 feet of hole at $50/foot).

(3) For Illinois, data gaps exist with respect to completing some minimum data elements. This includes description of a lithologic log for observation wells MTOW-2 (Easton) and Petro North. Geologic samples exist in ISGS archives for Petro North and need to be pulled and described, entered into the ISGS Geologic Records database,and transmitted to the Data Portal (estimated cost $1,500). For MTOW-2 (Easton), it is proposed that downhole geophysical logging (multiple probes including gamma, and possibly ultrasonic imaging, caliper, neutron, and temperature/conductivity – personal communication, Tim Young, ISGS geophysicist, 1/24/2011) be performed at a cost of $1,000. Improved elevation data is needed at several selected wells and all new wells. The estimated cost for surveying these wells (traditional optical and high-quality GPS) is $2,000 (2 weeks of surveying and data post-processing).

(4) Additional capital costs include costs for instrumentation to address temporal gaps. Indiana works through a cooperative agreement with the USGS-IN and real-time satellite telemetry costs $11,000/well. For four wells in Indiana, the cost comes to $44,000. For Illinois, rather than telemetry, wells are proposed to contain dataloggers at $2,000/well. Instrumenting eight wells will cost $16,000. Added datalogger instrumentation is proposed for MTOW-9 to assess surface water/groundwater interaction ($2,000). Total cost for Pilot instrumentation is $62,000.

(5) For Indiana, additional operation and maintenance costs if implemented through the InDNR-USGS cooperative program would be $5,400/year (4 new wells at $1,350/well/year). For Illinois, new well operation and maintenance is estimated to be $3,000/year (2 man-weeks or 80 hours plus $1,000 for field supplies and vehicle operation). Database management is estimated at $2,200 (approximately 2.5%-time of database manager). Total O&M for the water level subnetwork is approximately $10,715.

(6) To close operational data gaps, Illinois needs to develop new SOPs for automated data collection and archival of such data. This is anticipated to be a one-time cost and involve approximately 1 man-month of labor (160 man-hours), or about $6,200.

### Water-Quality Subnetwork Gap Closure

(1) Because we propose incorporating the new wells recommended for the water-level subnetwork into the water-quality subnetwork, no additional capital costs for drilling of wells to close spatial gaps are involved.

(2) Field and laboratory procedures appear to meet NGWMN recommended minimums, so no new procedures are proposed.

(3) Semiannual sampling of the four new wells in the Indiana portion of the water-level subnetwork is estimated to be $24,000 (about 25%-time or 64 man-hours). Annual sampling would cost $12,000 (about 12%-time or 32 man-hours).

(4) For Illinois, sampling of the eight new wells proposed for the water-level subnetwork, plus the 3-well nest near Champaign is estimated to be $11,000 per sampling event, or $22,000 if sampled semiannually. Annual sampling is estimated to require 2 man-weeks or 80 man-hours; semiannual sampling would require 160 man-hours.

(5) It is proposed that downhole geophysical logging be performed at one well within the IEPA CWS Ambient Network that has been selected for inclusion in this subnetwork. Cost for logging is estimated to be $1,000 (includes ~4 man-days or 16 man-hours of labor) to log the hole and perform post-analysis.

(6) With regard to water-quality data management, principal cost is on the Illinois side to create a routine process for IEPA to transmit new data to the ISWS and for ISWS to post new data to the Data Portal. A one-time cost for creating the process is estimated to be one man-week (40 hours), or approximately $1,700. An annual cost for making data available to the Data Portal is included as a cost in the water-level subnetwork, item (5) in the previous section.

(7) As mentioned in the Water-Quality Subnetwork Gap Analysis (page 48), several monitoring wells in the unconfined western region of the Mahomet-Teays are being

routinely sampled by the Illinois Department of Agriculture. A selection of these wells could be added to the Pilot subnetwork, potentially at relatively little cost to the Pilot. Similar to the data management issue with IEPA in item (6) above, a routine procedure for transmitting new data to the ISWS for posting to the Data Portal will be needed. Estimated one-time cost for creating the procedures is another $1,700 (one man-week, or 40 hours). The estimated annual cost for making data available to the Data Portal is included as a cost in the water-level subnetwork, item (5) in the previous section.

### Data Management Gap Closure

(1) Creation of an SOP for data archival was included as item (6) in the previous section on water-level gap closure.

(2) Additional fields for inlusion in databases were not identified, and cost of adding such fields is expected to be minimal.

(3) Making data available to the Portal will not incur a capital expense on the part of the ISWS as server capacity is already available. However, if such capacity was needed, the cost for a desktop server to handle such tasks is estimated to be approximately $2,000, given the low storage needs for Illinois' data and the relatively low volume of "traffic" expected on the Data Portal. We estimate the lifespan for such a computer to be about 5 years.

## Summary of Estimated Incremental Costs to Close Illinois/Indiana NGWMN Data Gaps

| NGWMN Pilot Program Element | Incremental changes needed to meet network guidelines | Estimated Capital Costs | Estimated O&M costs |
|---|---|---|---|
| Spatial Gaps: Identify 3-D spatial "gaps" in network(s) | Number of proposed additional "stressed" wells and "unstressed" wells in major or important aquifers meeting NGWMN Criteria.<br>***4 wells in IN and 8 wells (4 nests) in IL*** | Estimate capital cost of installing proposed wells based on hydrogeology setting and purpose of well<br>***$16,820 for targeted (IN)***<br>***$17,780 for unstressed (IN)***<br>***$100,000 for unstressed (IL)*** | Operating and maintenance cost for proposed wells:<br>*Water-Level:*<br>***$5,400 (IN)***<br>***$3,000 (IL)***<br>***Water-Quality:***<br>***$12,000-24,000 (IN)***<br>***$11,000-22,000 (IL)*** |
| Field Practice Gaps: Determine whether field practices meet NGWMN criteria and what changes may be required | Summarize field practices that will need to be added or changed to follow NGWMN Framework Field Practices. | Estimate ("one time") Cost of developing additional or modified Field Practices<br>***Geophysical logging of two wells: $2,000 (IL)***<br>***Lithology for 1 well: $1,500***<br>***Surveying: $2,000*** | Estimate (O&M) Cost to implement additional or modified Field Practices<br>***$0*** |
| Data Management Gaps: Determine whether data management standards meet the NGWMN criteria | List data management standards that will need to be added or change to follow NGWMN Framework. | (a) Estimate ("one time") cost of developing additional or modified data management standards ***$6,200 (IL)***<br>(b) Estimate capital cost of modifying database to respond to additional data management standards, including adding data fields, data storage & transmission to the Portal ***$0*** | Estimate (O&M) cost of implementing additional or modified data management standards for data fields, data storage and transmission of data to the Portal<br>***$2,200 (IL)*** |
| Temporal Gaps: Identify changes in monitoring frequency to respond to the NGWMN Framework | Summarize changes in monitoring frequencies by type/purpose to follow NGWMN Framework. | Instrumentation for increased data collection frequency<br>***$44,000 for telemetry (IN)***<br>***$18,000 for dataloggers (IL)*** | (O&M) cost of changes in monitoring frequencies<br>***$0*** |
| Analyte Gaps: Identify changes in sample analyte/constituent list and testing protocols used | Summarize changes in sample constituent list and testing protocols to be used to follow NGWMN Framework.<br>***None identified*** | Estimate ("one time") cost to incorporate additional test protocols in analytical procedures<br>***$0*** | Estimate O&M cost to conduct additional test protocols<br>***$0*** |

# Acknowledgments

The authors would like to thank the following individuals for their contributions and cooperation in the preparation of this report: Mark Basch (Indiana Department of Natural Resources), David Lampe (US Geological Survey – Indiana Water Science Center), Rebecca Travis (Indiana Department of Environmental Management), Patrick Mills (US Geological Survey – Illinois Water Science Center), Dorland Smith and Mel Pleines (Illinois Water Authority Association and Mahomet Aquifer Consortium), and Joe Konczyk (Illinois Environmental Protection Agency). There is little doubt these people will be called upon to continue with their assistance as the NGWMN goes forward for the states of Illinois and Indiana. Additional thanks to Scott Meyer (ISWS) for his assistance in preparing several maps for this report and to Kevin Rennels (ISWS) for assembling much of the water level data that appears in the hydrographs and which were so valuable for well selection.

Finally, thank you to all the members of the SOGW and in particular, Bill Cunningham and Daryll Pope for their assistance, counsel, and especially contribution of valuable time in preparing for and participation in our monthly teleconference calls. Thanks also to Janie Hopkins and the Texas Water Development Board for their Texas hospitality during our face-to-face meeting in Austin.

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# Appendix A. Hydrographs from Wells Selected to be in the Illinois/Indiana Pilot NGWMN Water-Level Subnetwork

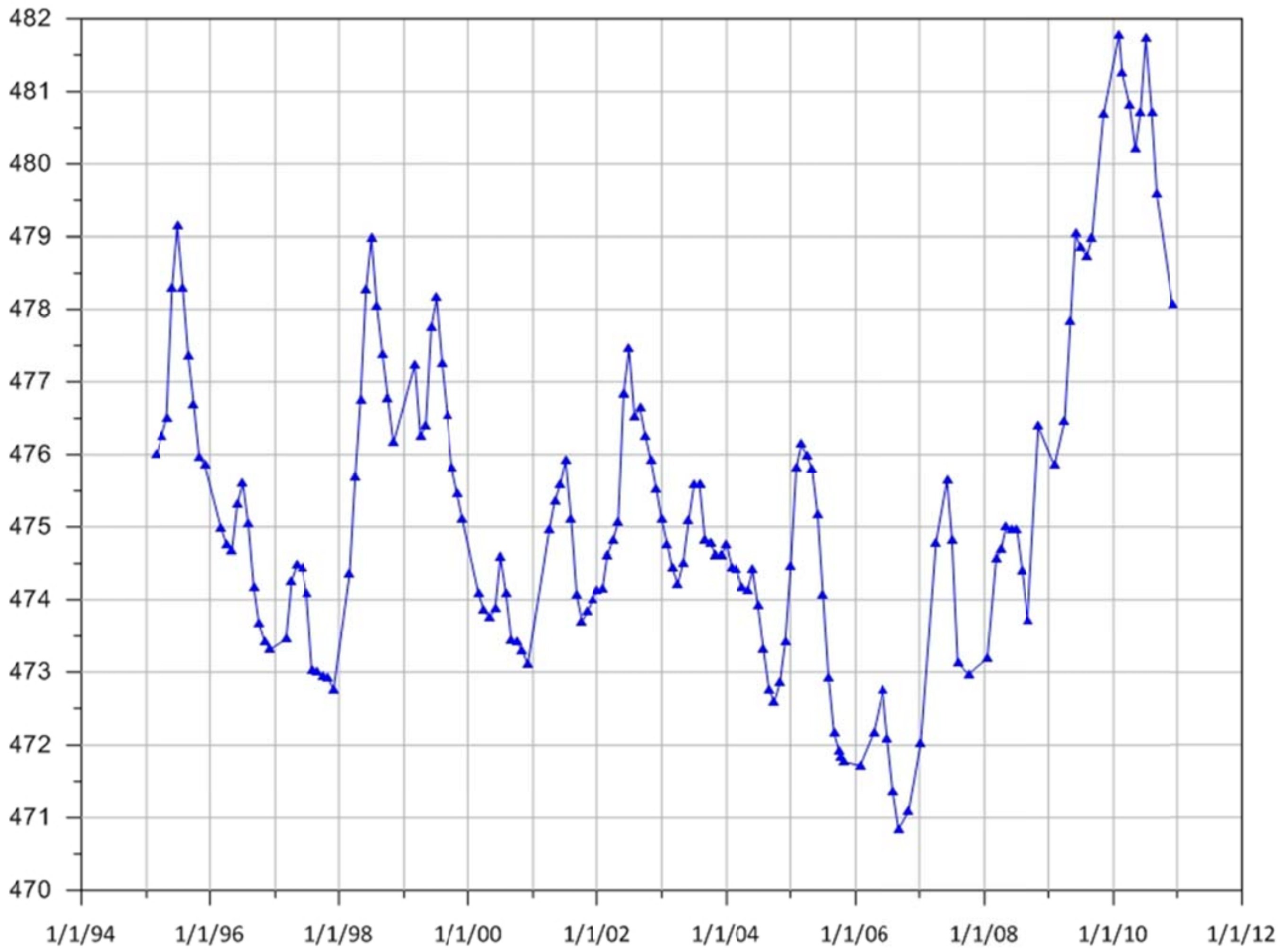

Figure A- 1. Hydrograph for MTOW-6 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

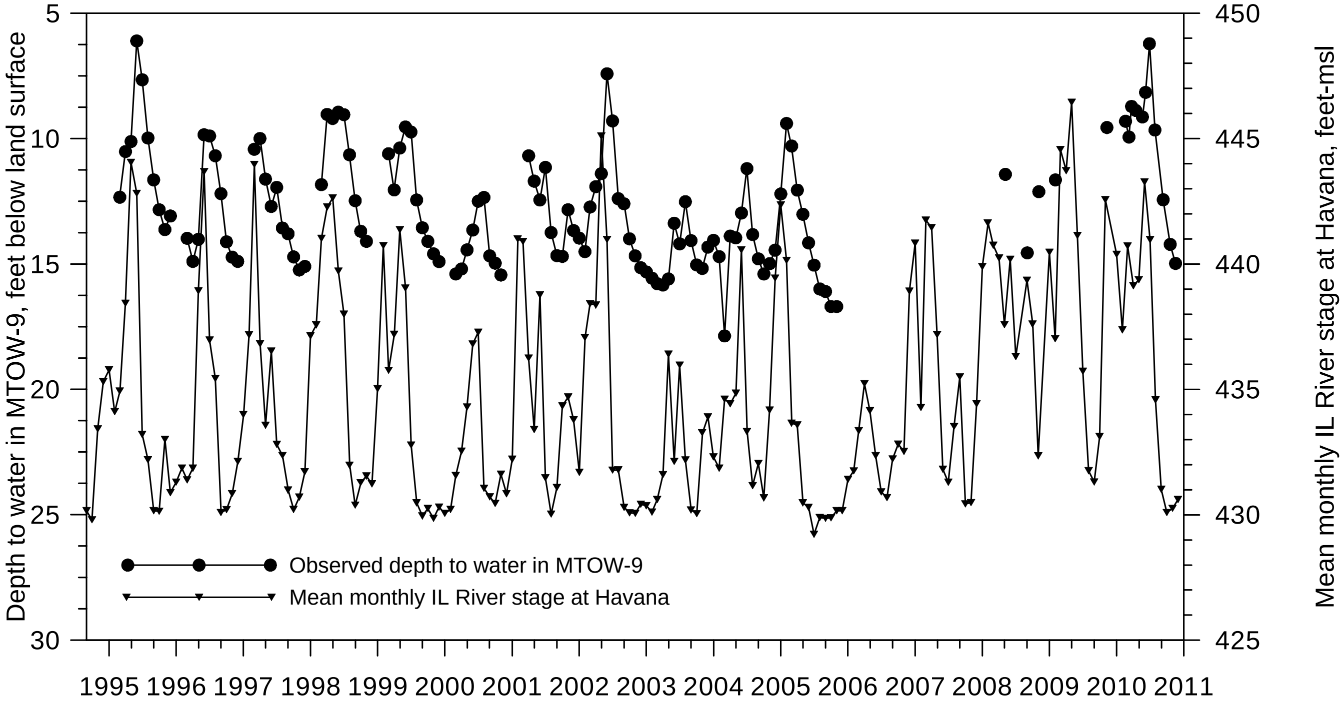

Figure A- 2. Hydrograph for MTOW-9 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1). Water levels are highly correlated to Illinois River stage.

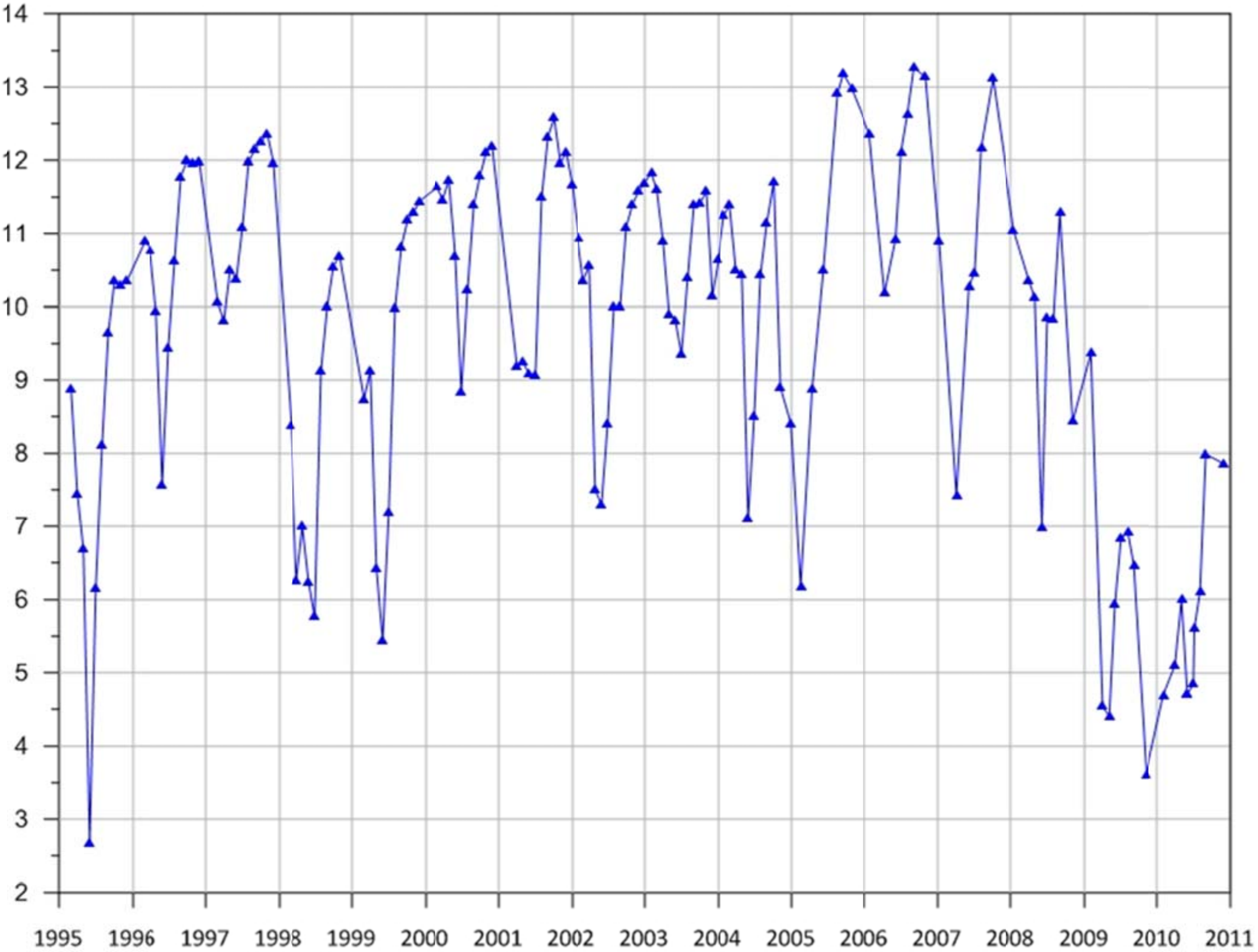

Figure A- 3. Hydrograph for MTOW-2 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

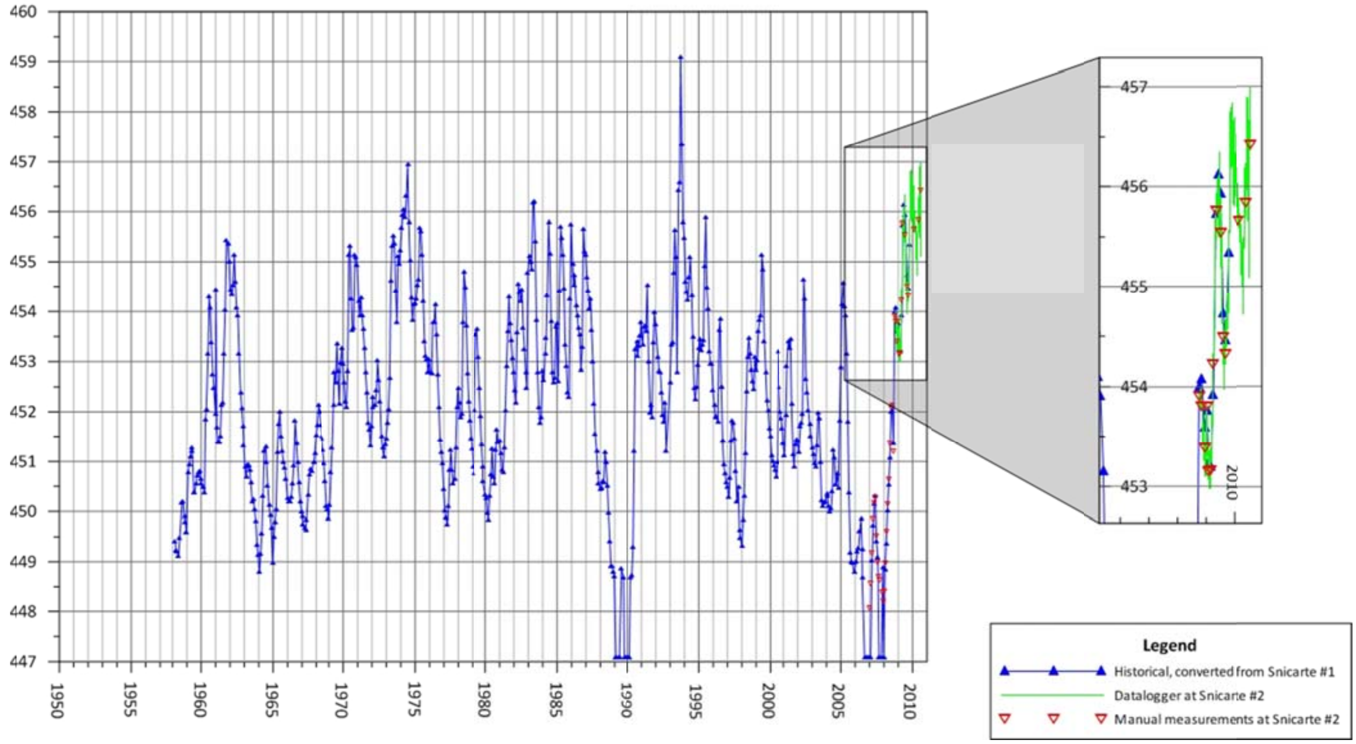

Figure A- 4. Hydrograph for Snicarte #2 monitoring water levels in the Mahomet-Teays aquifer (unstressed Aquifer 1).

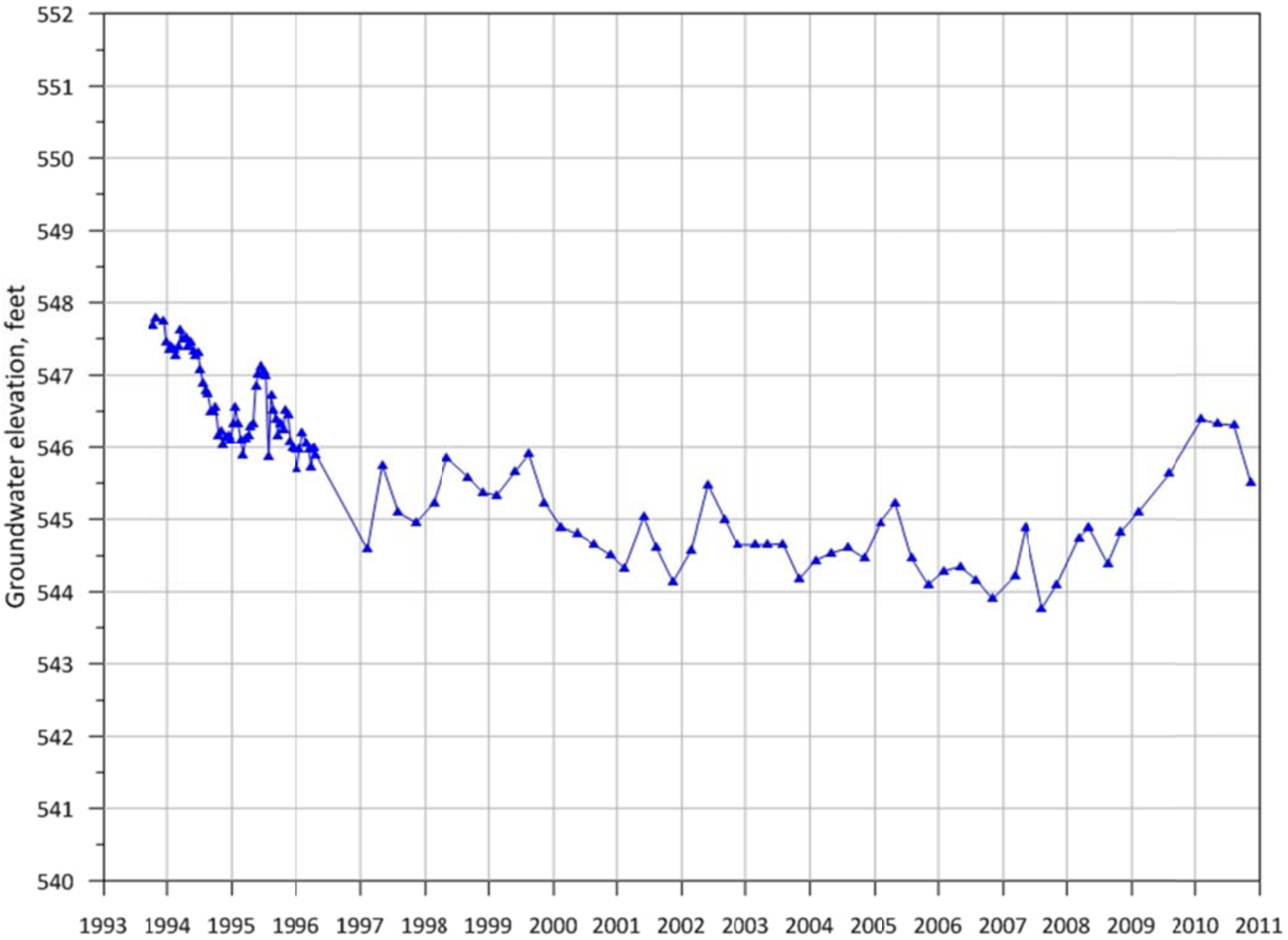

Figure A- 5. Hydrograph for MTH-5 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

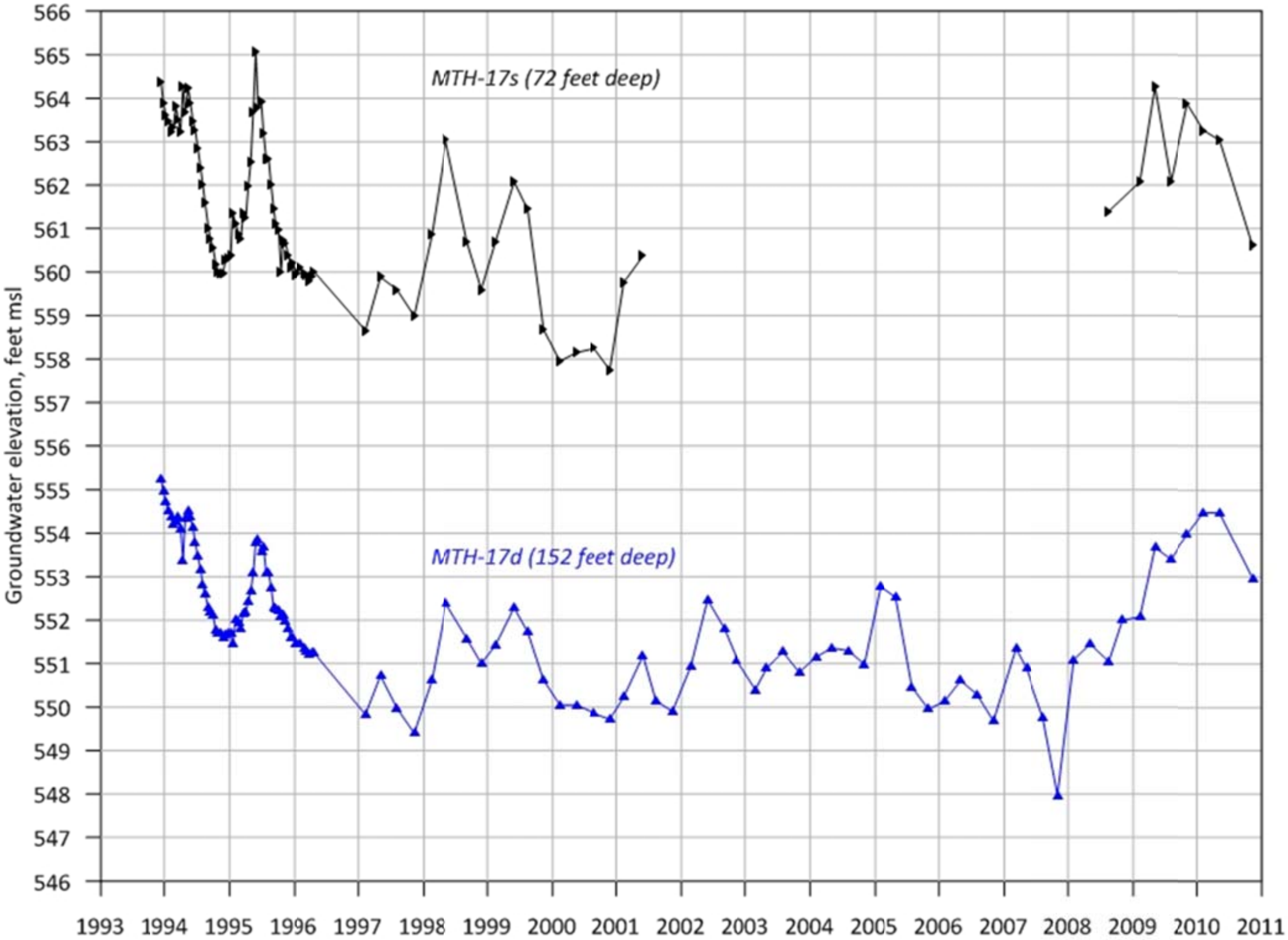

Figure A- 6. Hydrograph for Well Nest MTH-17 monitoring water levels in the Mahomet Teays and Illinois/Wisconsin Episodes Aquifers (unstressed Aquifers 1 and 2).

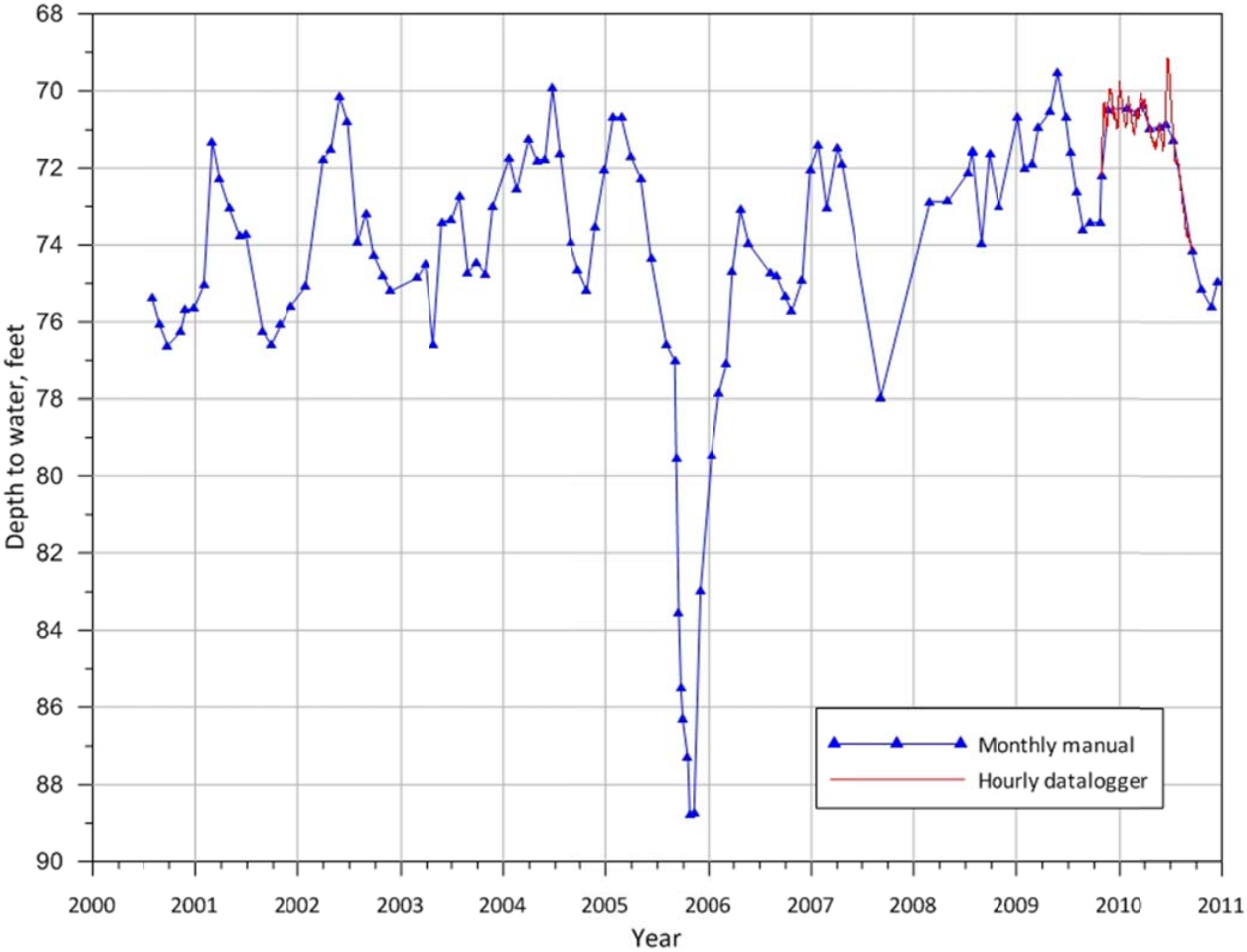

Figure A- 7. Hydrograph for PIA-2000A monitoring water levels in the Mahomet-Teays aquifer (unstressed Aquifer 1).

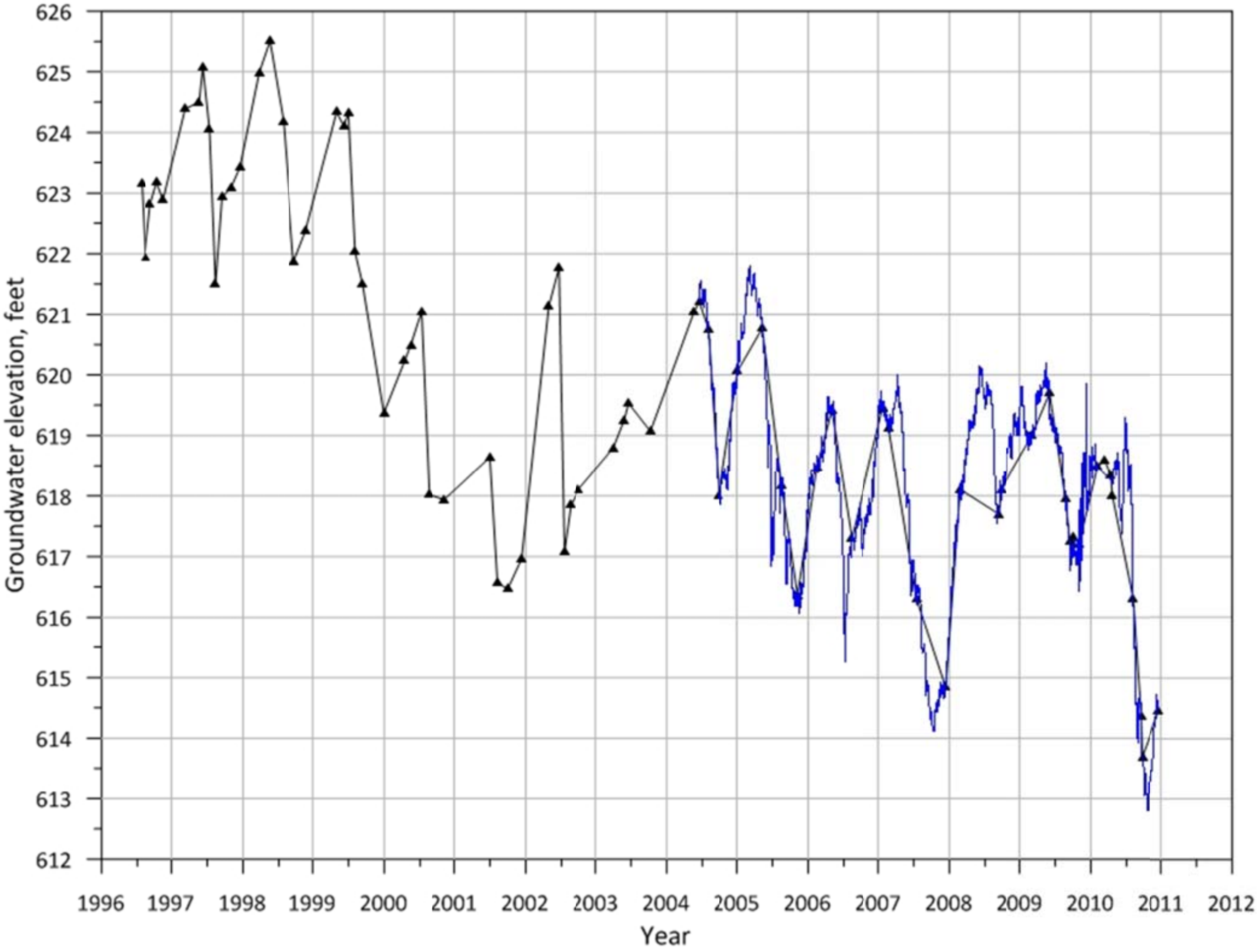

Figure A- 8. Hydrograph for CHM-96C monitoring water levels in the Mahomet-Teays Aquifer (targeted Aquifer 1).

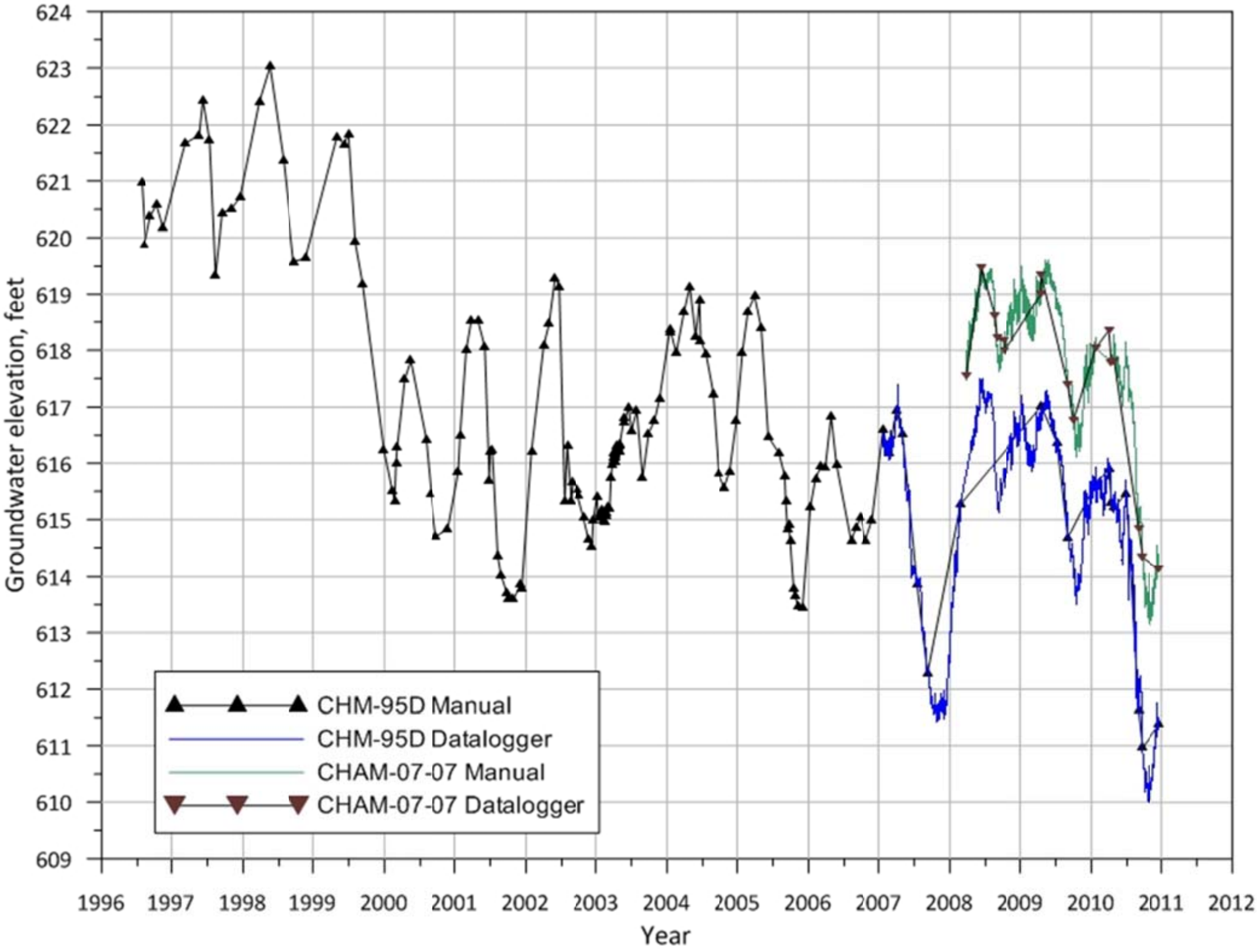

Figure A- 9. Hydrographs for CHM-95D and CHAM-07-07 monitoring water levels in the Mahomet-Teays and Illinois/Wisconsin Episodes Aquifers (targeted Aquifers 1 and 2).

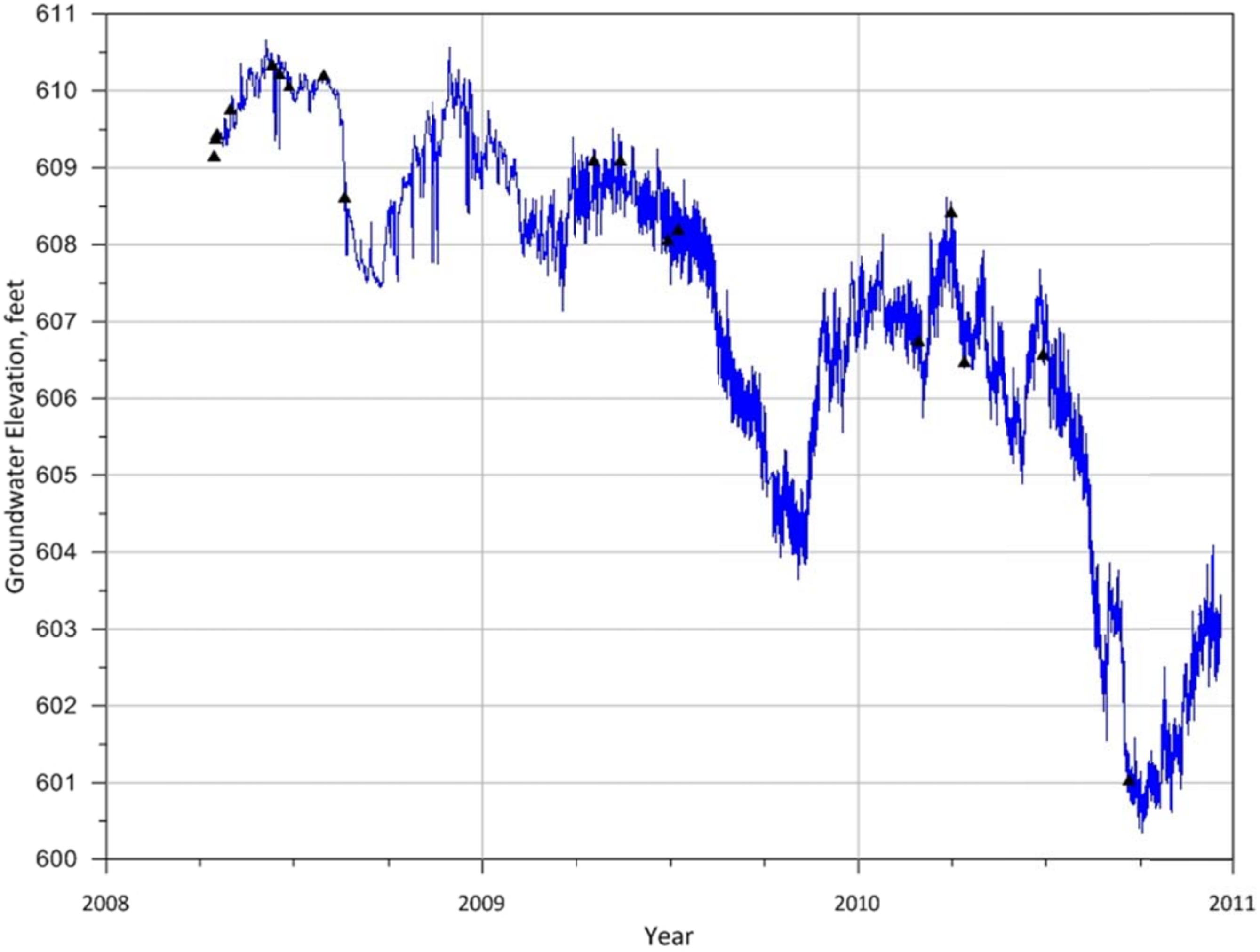

Figure A- 10. Hydrographs for CHAM-07-01 observation well nest monitoring water levels in the Mahomet-Teays & Illinois/Wisconsin Episodes Aquifers (targeted Aquifers 1 & 2).

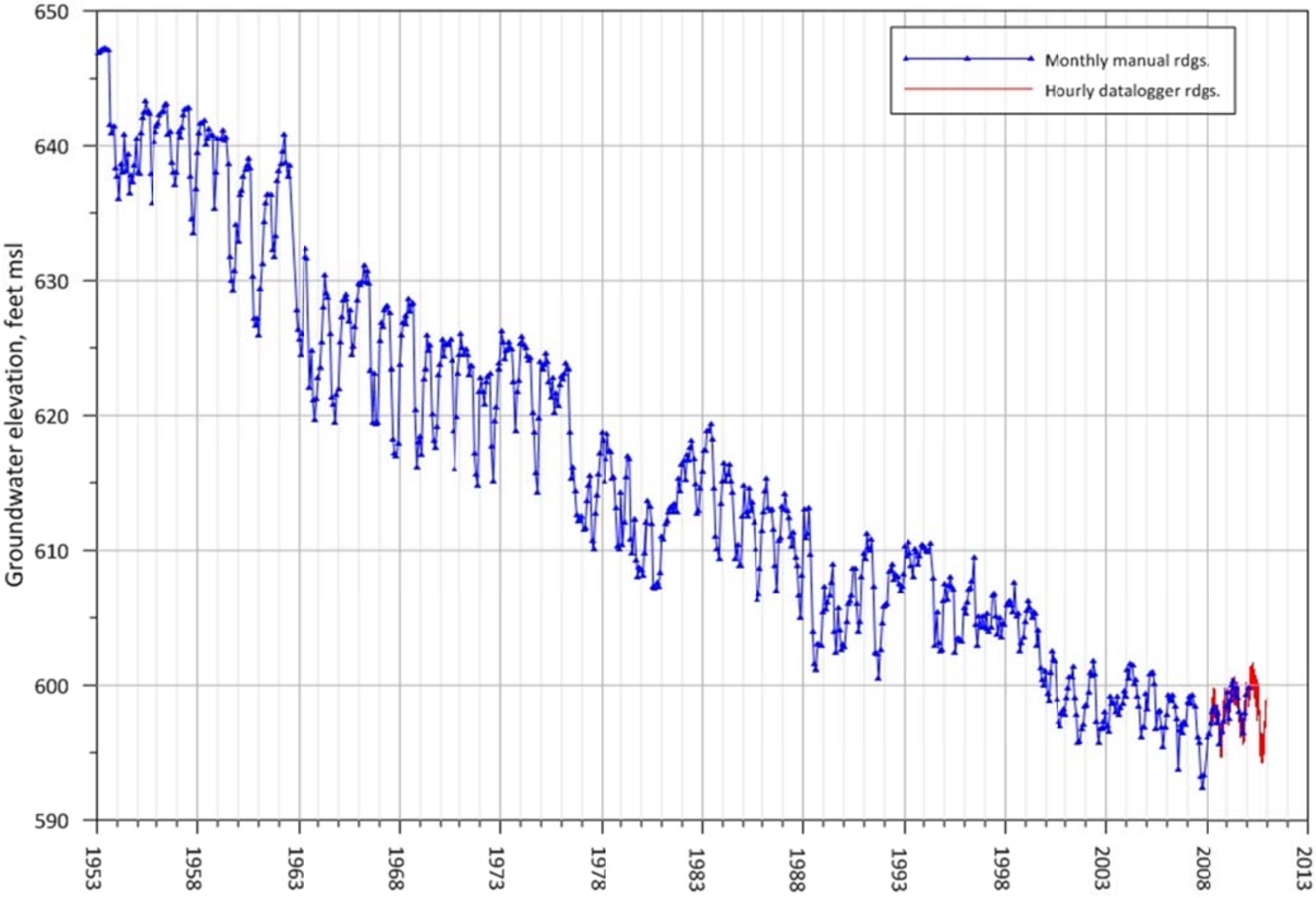

Figure A- 11. Hydrograph for Petro North observation well monitoring water levels in the Mahomet-Teays Aquifer (targeted Aquifer 1).

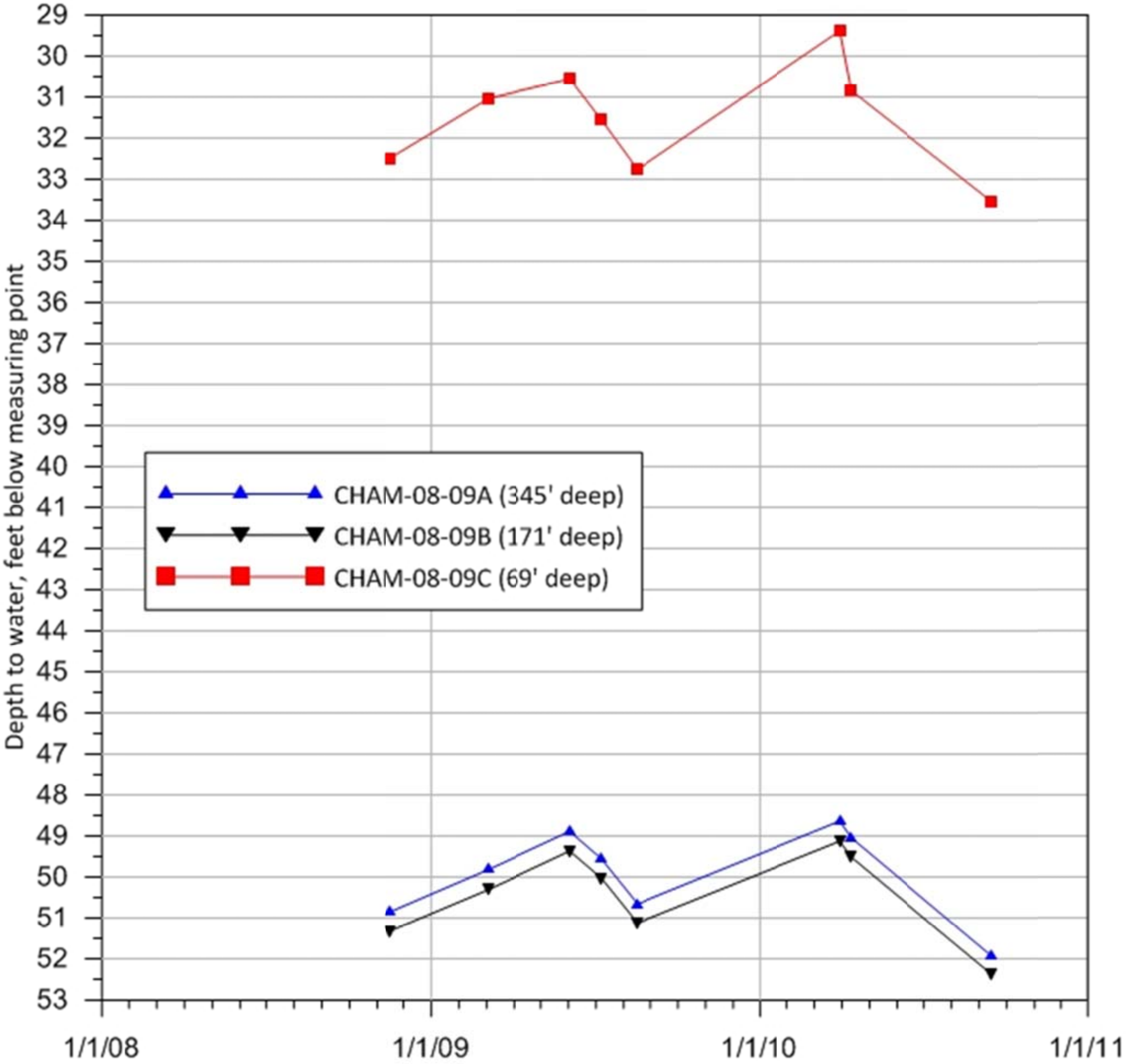

Figure A- 12. Hydrographs for CHAM-08-09 nest monitoring water levels in the Mahomet-Teays and Illinois/Wisconsin Episodes Aquifers (unstressed Aquifers 1 and 2).

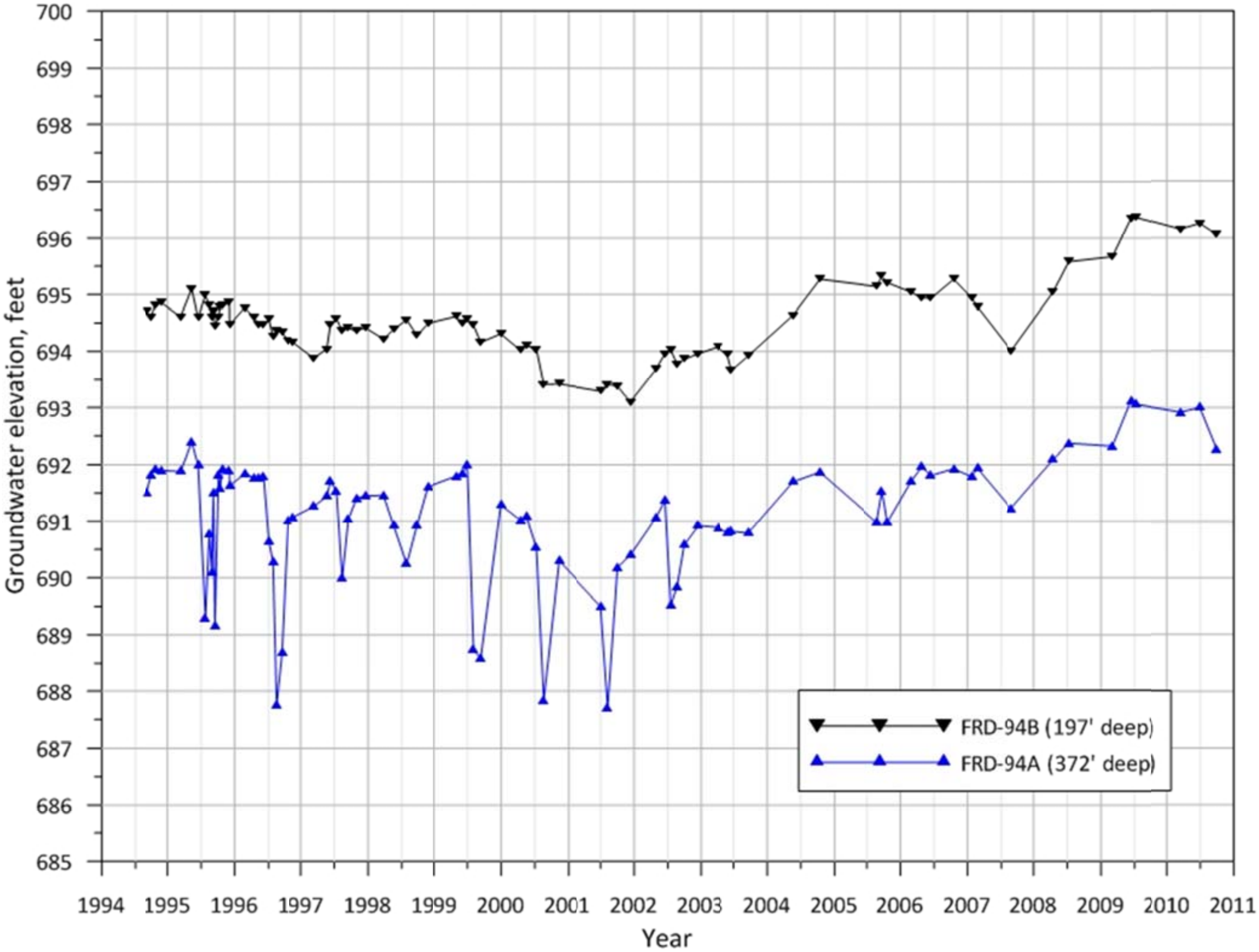

Figure A- 13. Hydrographs for FRD-94A and FRD-94B monitoring water levels in the Mahomet-Teays and Illinois/Wisconsin Episodes Aquifers (unstressed Aquifers 1 and 2).

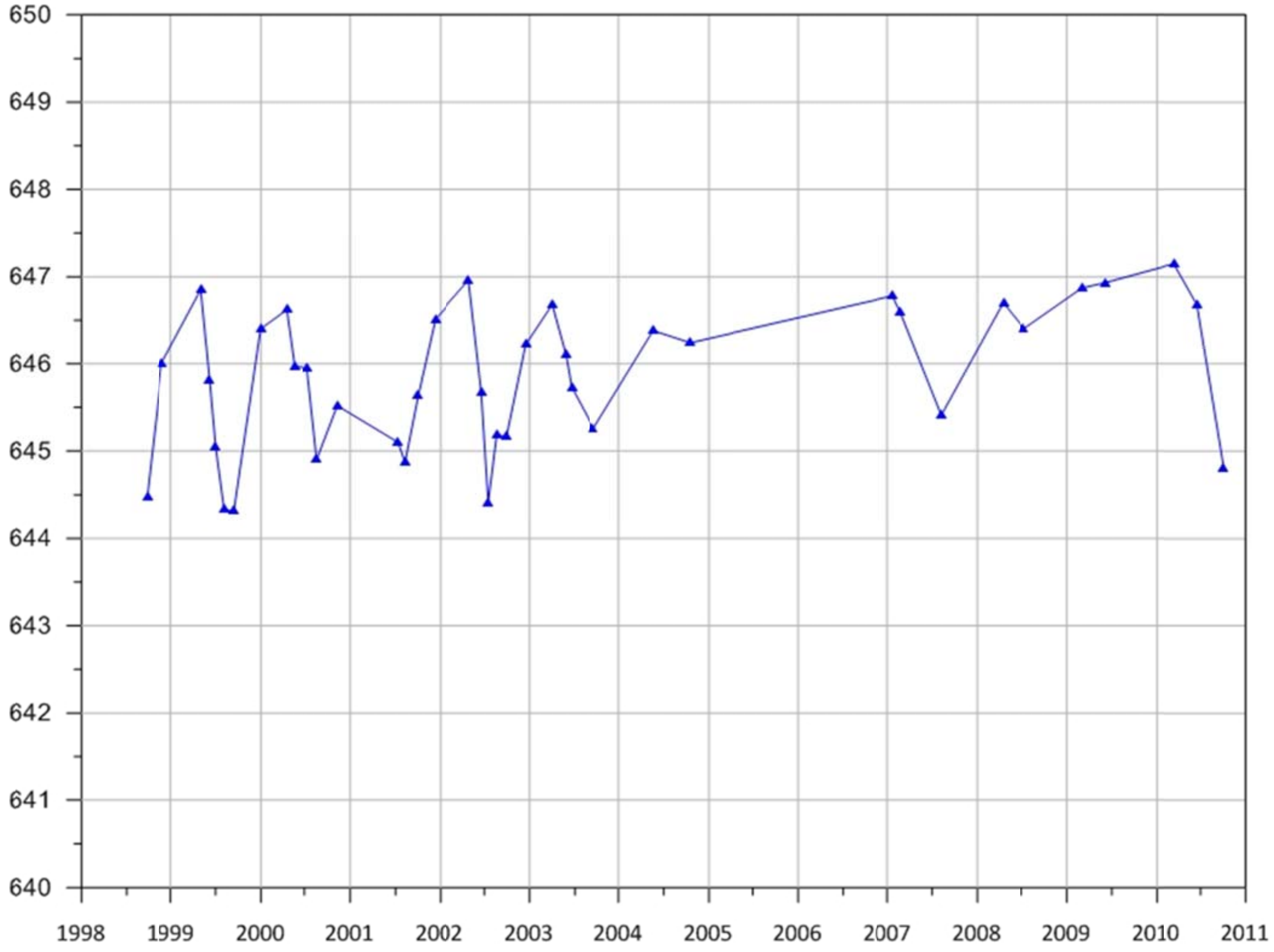

Figure A- 14. Hydrographs for IRO-98B monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

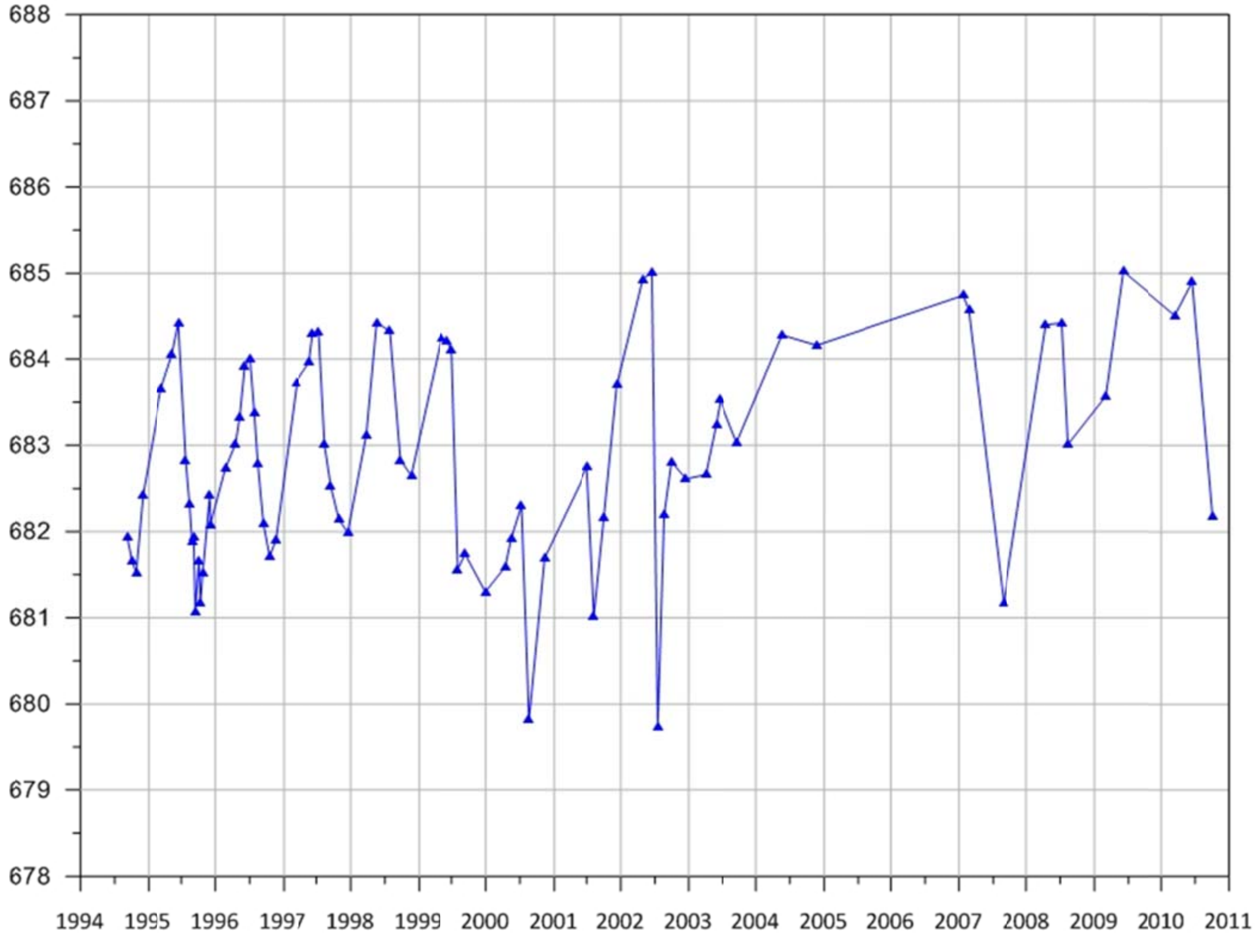

Figure A- 15. Hydrograph for VER-94D monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

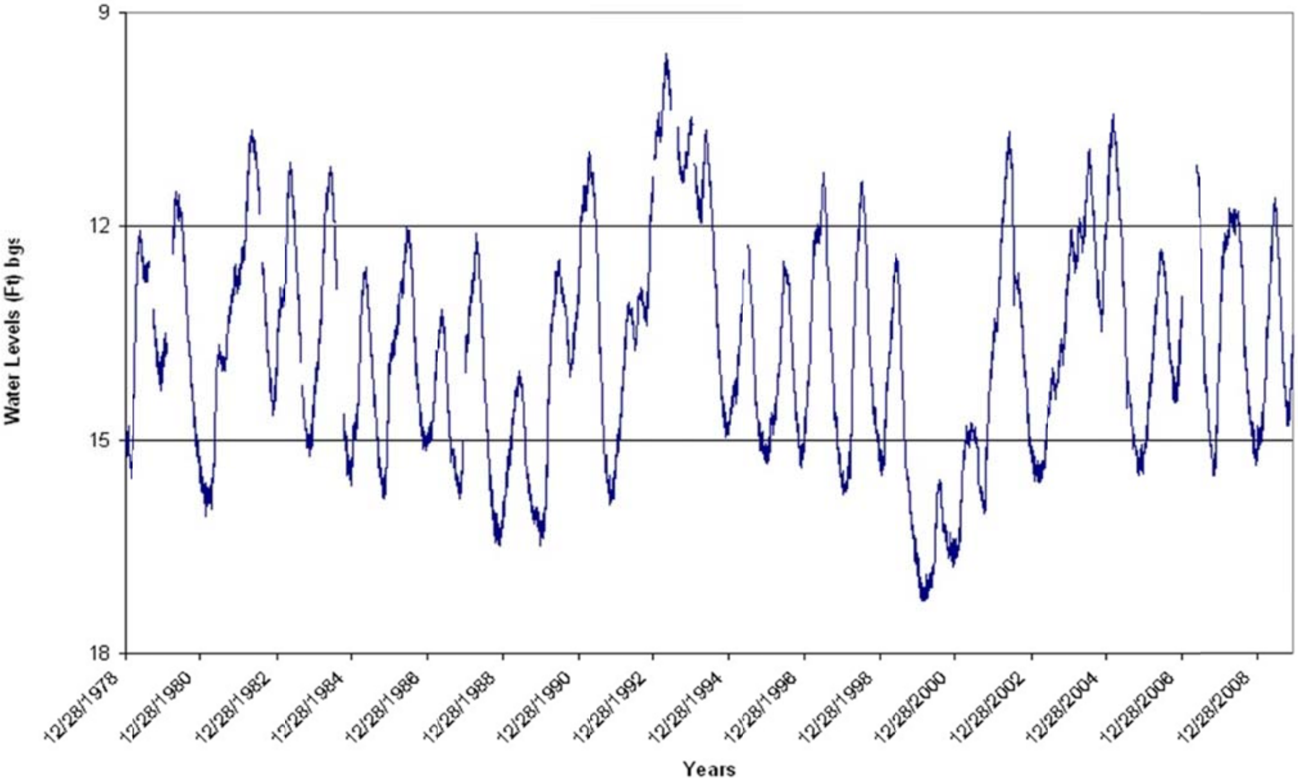

Figure A- 16. Hydrograph for Benton 4 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aquifer 1).

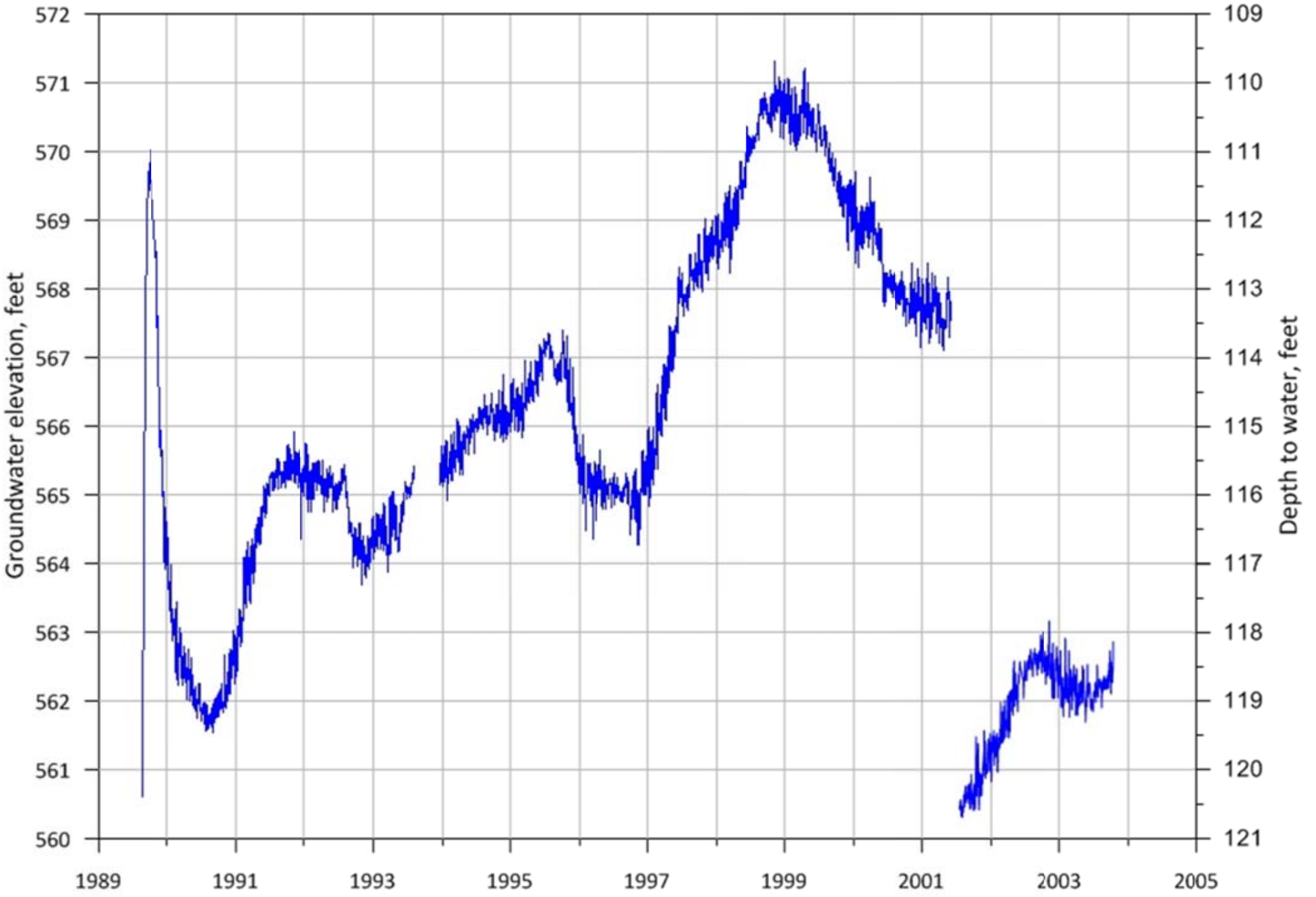

Figure A- 17. Hydrograph for Tippecanoe 17 monitoring water levels in the Mahomet-Teays Aquifer (unstressed Aq. 1).

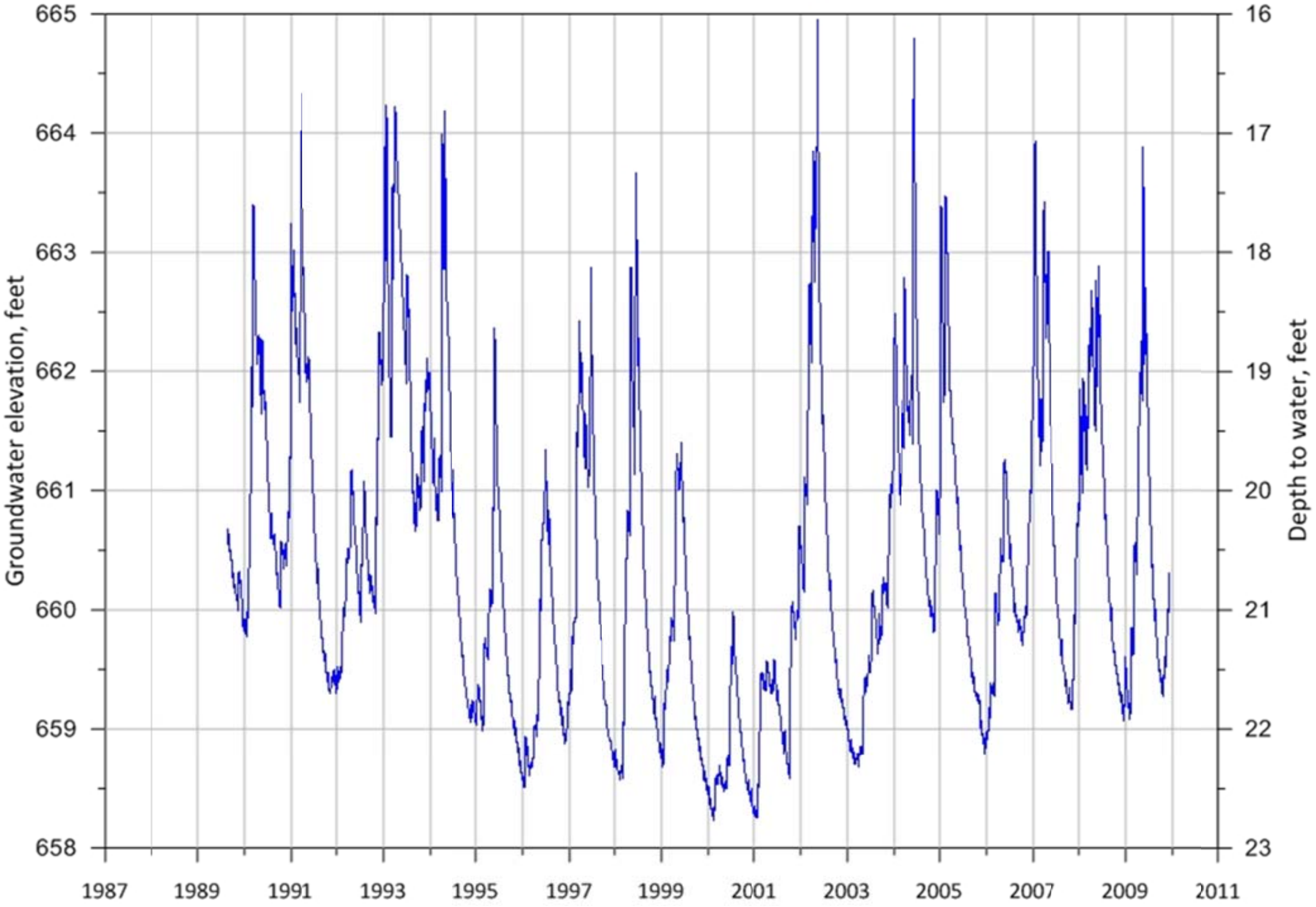

Figure A- 18. Hydrograph for Tippecanoe 18 monitoring water levels in the Illinois/Wisconsin Episodes Aquifers (unstressed Aquifer 2).

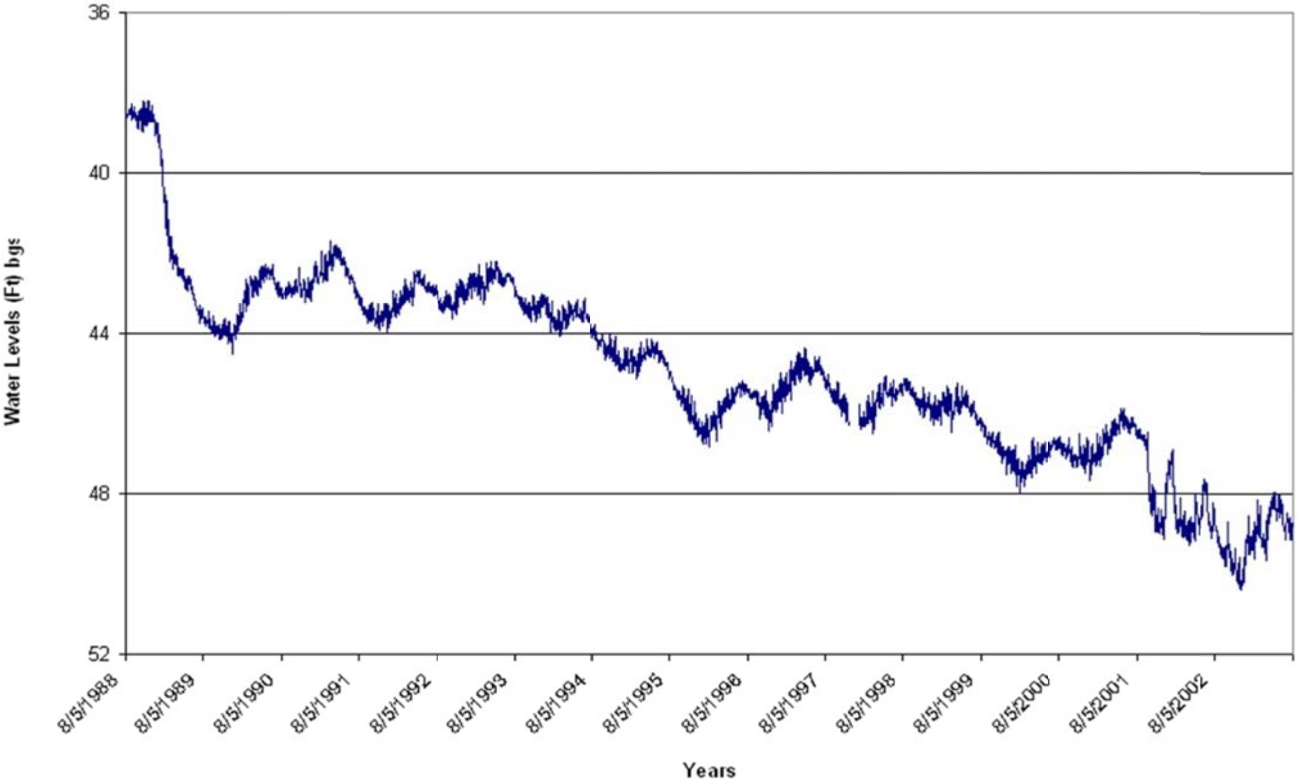

Figure A- 19. Hydrograph for Wabash 4 monitoring water levels in the Mahomet-Teays Aquifer (targeted Aquifer 1).

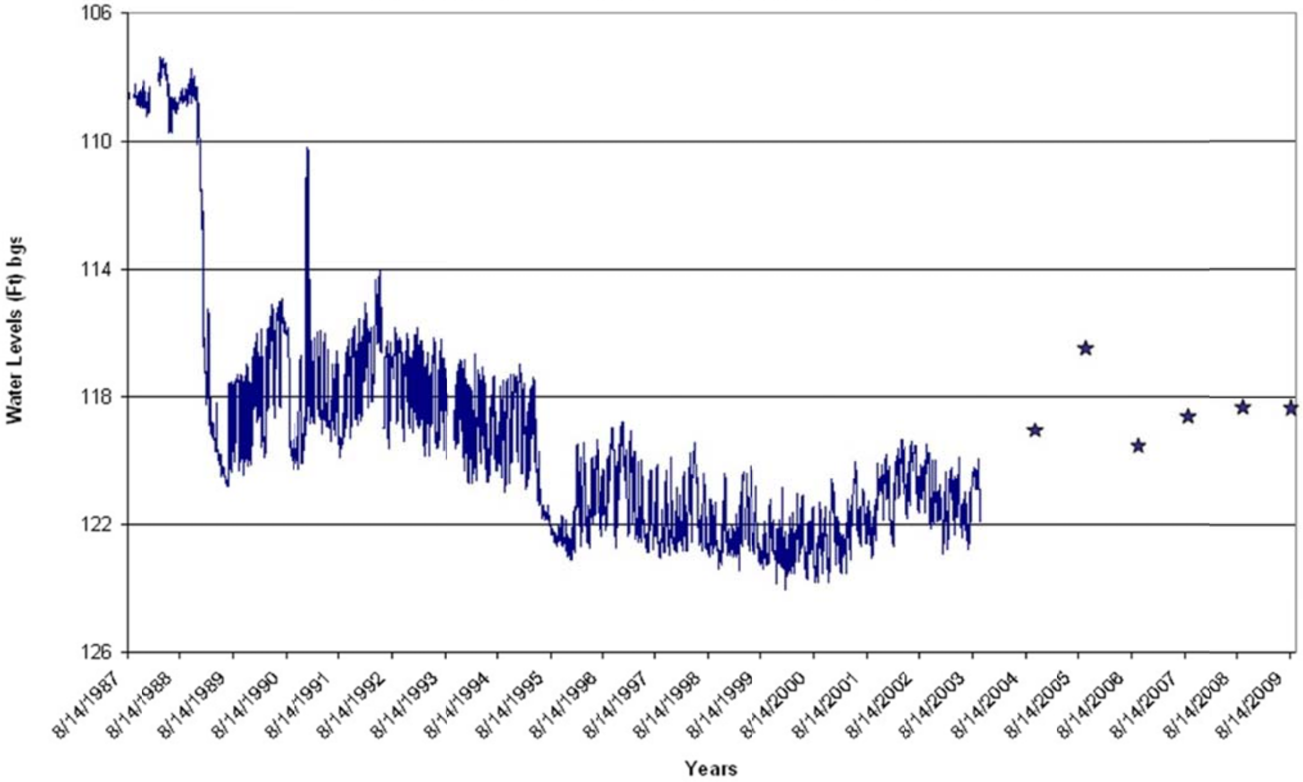

Figure A- 20. Hydrograph for Grant 10 monitoring water levels in the Mahomet-Teays Aquifer (targeted Aquifer 1). Stars represent intermittent manual measurements.