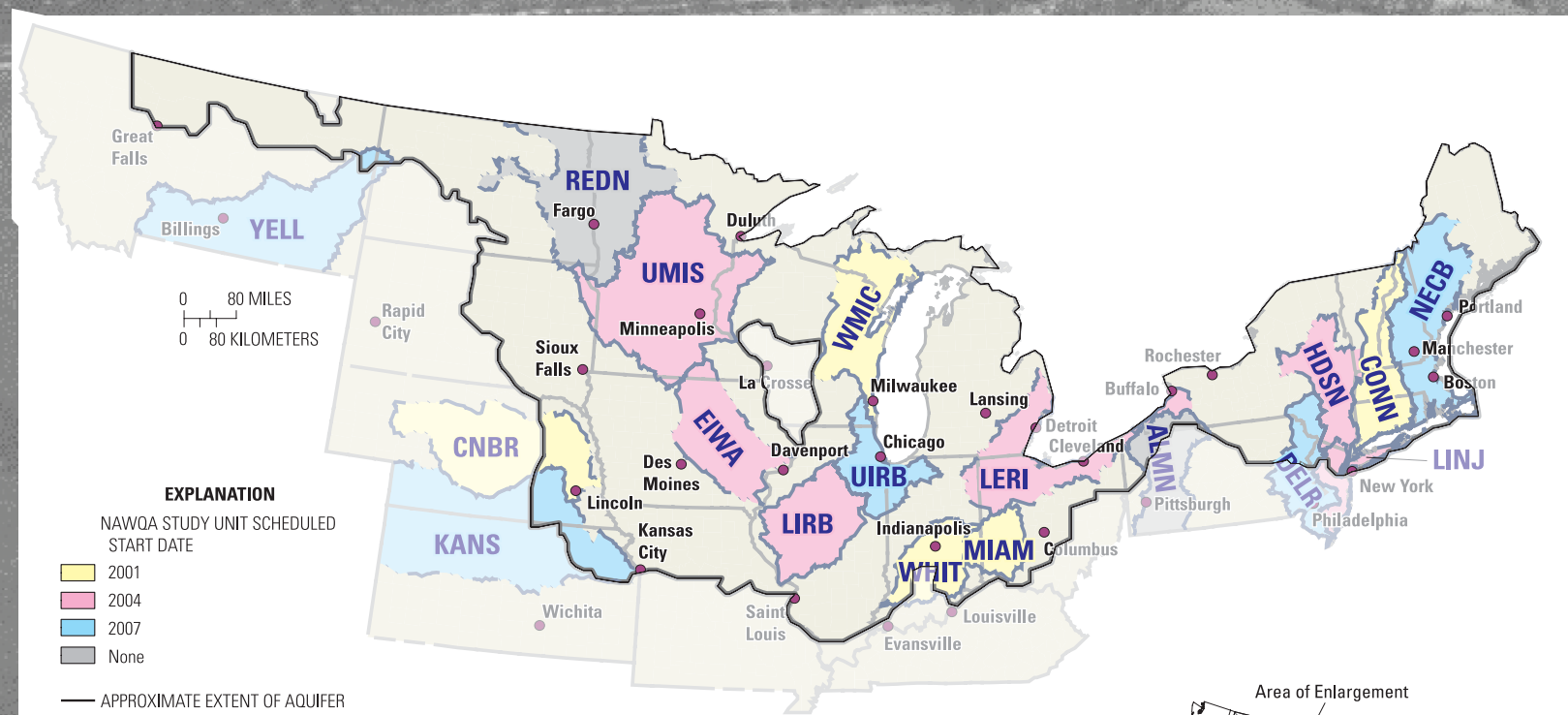


GLACIAL AND ALLUVIAL AQUIFER SYSTEM



Regional Aquifer Workplan July 2003

Workplan for Cycle II NAWQA Activities in the Glacial and alluvial Aquifer System

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CONTENTS

Introduction

Objectives and approach.....	
Pertinent major USGS programs in the study area.....	
Regional frameworks.....	
Water Use.....	
Land Use.....	
Geology and hydrogeology.....	
Aquifer nomenclature.....	
Hydraulic characterization.....	
East.....	
Central.....	
West.....	

Regional framework.....

Water quality issues.....	
Arsenic.....	
Pesticides.....	
Induced infiltration.....	
Nitrate.....	
Radon and radium.....	
Volatile organic compounds.....	

Cycle I studies.....

Major aquifer studies.....	
Land-use studies.....	

Cycle II plans.....

Status and trends.....	
Process and understanding.....	

Reports.....

Reference.....

Appendix A - Additional maps.....

Appendix B - Cycle II study descriptions.....

CONNSUS2
WMICMAS2
WMICLUSAG2
LIRBSUS1
UIRBLUSRC1
UIRBLUSCR1
LERILUSRC1
LERISUS1

Appendix C - Cycle I study descriptions.....

LERISPCG1
LERILUSCR1

FIGURES

1. Location of glacial and alluvial aquifer system and NAWQA study units.
2. Withdrawals for water use by category for the glacial and alluvial aquifer system in 1990 (adapted from Marilee Horn, USGS, personal communication, 2001).
3. Water Use for public and domestic withdrawals by State from the glacial and alluvial aquifer system based on 1990 data (adapted from personal communication, Marilee Horn, USGS)
4. Population served from the glacial and alluvial aquifer system (adapted from personal communication, Marilee Horn, USGS).
5. Comparison of population served for public or domestic supply and withdrawals from the glacial and alluvial aquifer system by East, Central or West areas (adapted from personal communication, Marilee Horn, USGS).
6. Land use over the glacial and alluvial aquifer system.
7. Major land-use over the glacial and alluvial aquifer system compared to percent of land-use represented by the combined land use within all study units overlying the glacial and alluvial aquifer system.
8. Division of the glacial and alluvial aquifer system into East, Central, and West areas based upon physiography and source of glacial material.
9. Uppermost bedrock underlying the glacial and alluvial aquifer system (based on King and Biekman, 1974).
10. Sand and gravel aquifers of alluvial and glacial origin
11. Division of the glacial and alluvial aquifer system into East, Central, and West areas based upon physiography and source of glacial material.
12. Location of coarse- and fine-grained material in the uppermost glacial deposits used to describe the relative intrinsic susceptibility.
13. Example geologic cross-sections in the glaciated area.
14. Location of valleys in connection with the land surface and presence of buried bedrock valleys.
15. Organization chart of the NAWQA studies within the glacial and alluvial aquifer system.
16. Range of concentrations of selected constituents (arsenic, atrazine, chloroform, deethylatrazine, MTBE, and nitrate) from NAWQA Cycle I data (data obtained from NAWQA data warehouse in November 2002).
17. Ground-water age dating information collected by December 2001 (obtained from personal communication, Jan. 2001).
18. Water-quality issues within the glacial and alluvial aquifer system.
19. Location of major aquifer study (MAS) wells in the eastern area of the glacial and alluvial aquifer system.
20. Location of major aquifer study (MAS) wells in the central area of the glacial and alluvial aquifer system.
21. Location of major aquifer study (MAS) wells in the western area of the glacial and alluvial aquifer system.
22. Location of land-use study (LUS) wells in the eastern area of the glacial and alluvial aquifer system.
23. Location of land-use study (LUS) wells in the central area of the glacial and alluvial aquifer system.

24. Location of land-use study (LUS) wells in the western area of the glacial and alluvial aquifer system.
25. Distribution of land-use studies in NAWQA Cycle II by major land-use category.
26. Location of trend sites in Cycle II as proposed in the NIT plan and shown in the NAWQA ground-water planning database (January 2003).
27. Reports written in Cycle I and planned reports for the 2001 study units for Cycle II based on FY03 workplans

TABLES

1. Hydraulic characteristics of the glacial and alluvial aquifer system from published reports.
2. Estimated hydraulic conductivities of typical glacial material in Illinois (modified from Berg and others, 1984)
3. Ancillary information on major aquifer studies in the glacial and alluvial aquifer system (June 2002)
4. Number of wells in MAS by State (October 2002).
5. Land-use studies in the glacial deposit aquifer (June 2002).
6. The NAWQA cycle I accomplishments, cycle II plans, and GAPT planning team recommendations.
7. Trend samples by network type (adapted from gw planning data base in January 2003).
8. Cities in the glacial and alluvial aquifer system considered for NAWQA source-water assessment study.
9. Potential process and understanding work planned in the 2001 study units within the glacial and alluvial aquifer system.
10. Number of ground-water reports by study unit related to chemical-quality topic (based on FY03 workplans).

Introduction

Large continental glaciers covered parts of Canada and the northern United States between approximately 1.6 million and 10,000 years ago. These glaciers left behind a blanket of sand, gravel, and clay deposits ranging in thickness from less than 1 foot (ft) to over 1,000 ft. These deposits often are the major drinking-water supply in this part of the United States and Canada. This sequence of materials deposited by continental glaciers or glacial meltwater, and including reworked glacial deposits as recent alluvium, which overlie the bedrock, are hereafter referred to as the "glacial and alluvial aquifer system".

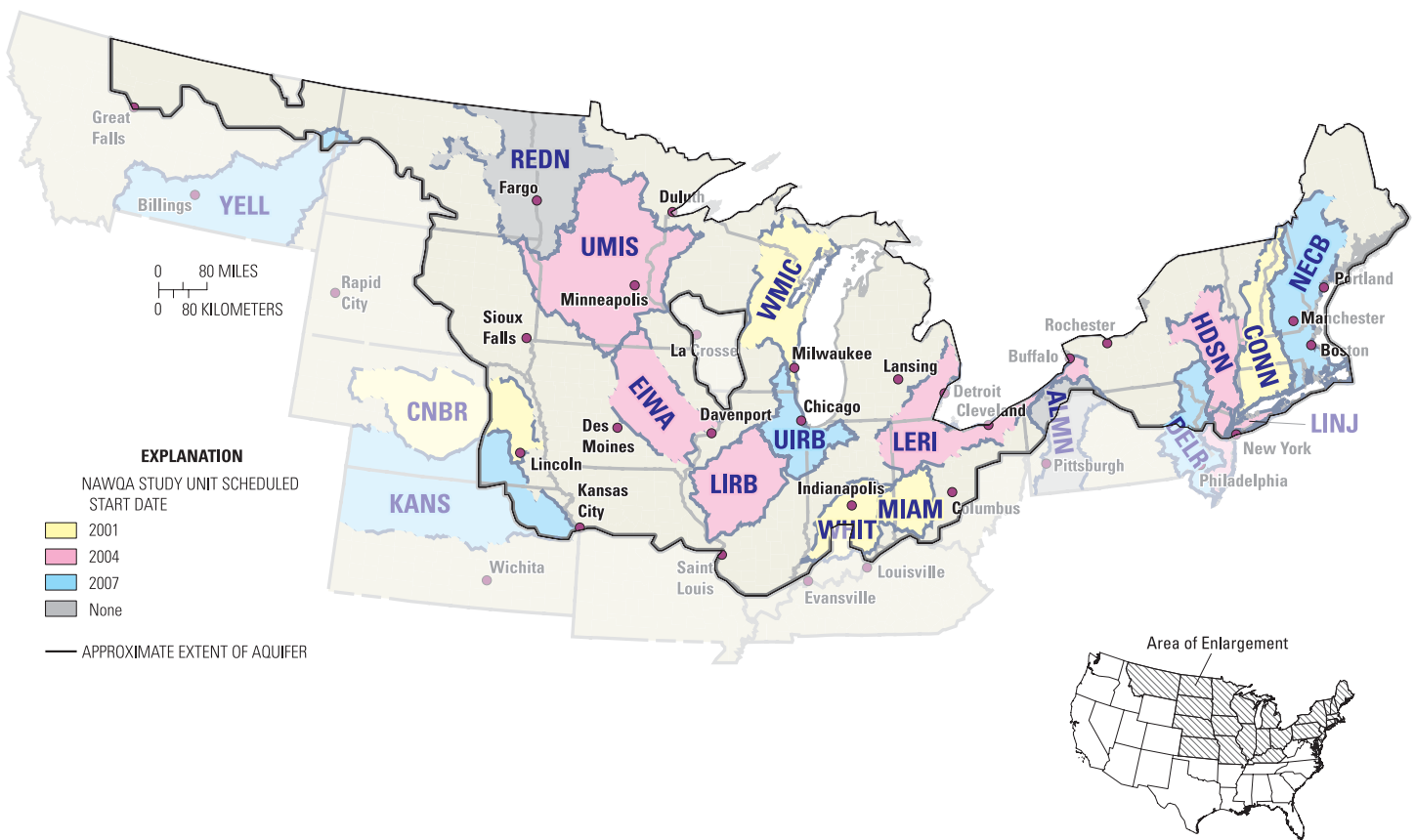


Figure 1 . Location of glacial and alluvial aquifer system and NAWQA study units.

The glacial and alluvial aquifer system is present in 21 States from Maine to Montana (fig. 1). The glacial deposits cover over 27 % (807,000 square miles (mi²)) of the continental United States. The glacial and alluvial aquifer system is of international importance because it also is a major drinking-water supply in Canada. The International Joint Commission has been interested in studies of the glacial and alluvial aquifer system and the interaction with the Great Lakes for many years (Swain, 1985). The glacial and alluvial aquifer system is ranked first in withdrawals for domestic and public drinking-water supply among the 16 principal aquifer systems in the United States selected for primary focus of ground-water studies in the second cycle of the National Water-Quality Assessment (NAWQA) program (Mallard and others, 1999).

Objectives and approach

There are 19 NAWQA study units wholly or partially within the glaciated area of the conterminous United States. These study units are:

Allegheny and Monongahela River (ALMN),
Central Nebraska Basins (CNBR),
Connecticut, Housatonic, and Thames Rivers (CONN),
Delaware River (DELR),
Eastern Iowa Basins (EIWA),
Hudson River (HDSN),
High Plains Regional Ground water Area (HPGW),
Kansas River (KANS),
Lake Erie-lake Saint Clair (LERI),
Long Island-New Jersey (LINJ),
Lower Illinois River (LIRB),
Great and Little Miami River Basins (MIAM or WHMI),
New England Coastal Basins (NECB),
Red River of the North (REDN),
Upper Illinois River (UIRB),
Upper Mississippi (UMIS),
White River (WHIT or WHMI), and
Western Lake Michigan drainages (WMIC)
Yellowstone Basin (YELL).

Although the YELL study unit is partially within the glaciated area, there are no plans to study the glacial and alluvial aquifer system. Data from the rest of these studies can be synthesized for the glacial and alluvial aquifer system, but it is not known if the water-quality information is adequate to define the water quality of the glacial and alluvial aquifer system in the United States. In order to determine if the information is adequate, a team of ground-water hydrologists from the previously mentioned study units, geologists from the Geologic Discipline, and ground-water specialists developed a plan of study for the regional synthesis of major water-quality issues across the glaciated areas of the United States. Primary planning steps include:

1. Develop a regional stratification (environmental framework) of the ground-water system in the glaciated material to identify areas of similar hydrogeologic characteristics and settings.

2. Compile regional water-use information to identify important drinking water resources (defined by public and domestic water withdrawals) within the glacial and alluvial aquifer system.
3. Review NAWQA Cycle I accomplishments to identify areas within the glacial and alluvial aquifer system that have been addressed by NAWQA and those for which there is a lack of data.
4. Recommend and prioritize Cycle II activities to meet the objective of addressing the water quality in the glacial and alluvial aquifer system by assessing distribution of study components among study units within a regional context.
5. Identify principal ground-water issues that need to be addressed among NAWQA Cycle II study units.
6. Identify ancillary information and needs to accomplish a regional assessment.

Pertinent Major USGS Related Programs in the Study Area

Other programs in the USGS have studies within the area of the glacial and alluvial aquifer system. Some of these programs have objectives that would help in the delineation and characterization of the glacial and alluvial aquifer system. Communication between NAWQA and other programs are facilitated by many individuals, but those coordinating with GAPT are identified.

- Central Great Lakes Geologic Mapping Coalition (Jim McNeal, USGS, GD)
- ER Minerals Program
- ER Geologic Mapping Program (Jim McNeal, USGS, GD)
- BRASS Program
- Ground-Water Resources Program (Norm Granneman, USGS, WRD)
- Mapping Programs
- Urban Dynamics Program
- CENR (Committee on Environment and Natural Resources of the Science and Technology Council)
- Water Resources Research Institute
- State Geologists Program and many other Federal, State, and local programs done in cooperation with the USGS.

Regional frameworks

Several regional frameworks for the country were considered for use to synthesize water-quality data in the glacial and alluvial aquifer system. Each of these frameworks was designed for a specific purpose, and was too detailed, too coarse, or too different in purpose to be used solely for this regional

water-quality design. Key ideas from these frameworks were integrated in the design of a suitable water-quality framework for the glacial and alluvial aquifer system:

- Hydrologic landscapes (Wollock, 1996) is based on land-surface form, geologic texture, and climate.
- USEPA Landscapes
- Ecoregions (Omernick, 1987) is based on geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.
- Ground-water regions (Clawges and Price, 1999) is based on work by Heath (1984) on hydrology and water use.
- Land Resource Regions (U.S. Soil Conservation Service, 1970) is based on soils, climate, water resources and land uses.
- RASA (Sun and others, 1997) The Regional Aquifer-System Analysis (RASA) studies were based on geographic distribution of the aquifer of concern. The objective of the RASA Program is to define the regional geohydrology and establish a framework of background information--geologic, hydrologic, and geochemical--that can be used for regional assessment of ground-water resources and in support of detailed local studies. The program was completed in 1995. There are seven RASA studies in the area of the glacial and alluvial aquifer system. The only RASA with a focus on glacial deposits is the northeast glacial and alluvial aquifer system. The framework established by this study is integral to the water-quality assessment of the glacial-deposit aquifer system. Various other RASA studies include reports and data on the glacial-deposit aquifer system, although the focus was on other aquifer systems. These include the Midwestern Basins and Arches, Michigan Basin, Central Midwest, Northern Midwest, Northern Great Plains, and High Plains.

Water use

Public-supply water use of ground water is a key factor in prioritizing NAWQA ground-water studies across the Nation and within the glacial-deposit aquifer system. The glacial-deposit aquifer system is the source for the largest withdrawals for public and domestic supply in the country. An estimated 13.5% of all water use in the country for domestic and public supply (which includes more than just drinking water) in 1990 was from the glacial-deposit aquifer system (Marilee Horn, USGS, personal communication, 2001). In 1990, an estimated 22.5 million people in the U.S. relied on the glacial-deposit aquifer system for public and domestic supply. Water from glacial-deposit aquifer system is continuing to be an important source of fresh water for a majority of the northern portion of the United States. Data indicate that there is an increasing trend in the amount of withdrawal from the glacial-deposit aquifer system in the States considered in this study. In 1995, approximately 32% of the population served by public supply in the area overlying the glacial-deposit aquifer system used ground water, but there is no indication of the portion of the ground water supplied by the glacial-deposit aquifer system (Solley and

others, 1998). In 1990, the combined public and domestic self-supplied water which serve as drinking water, accounted for over 50% of the withdrawals from the glacial-deposit aquifer system (fig. 2).

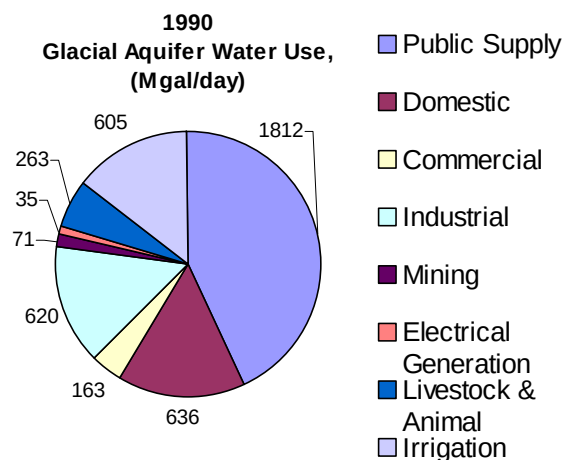


Figure 2 . Withdrawals for water use by category from the glacial and alluvial aquifer system in 1990 (adapted from Marilee Horn, USGS, pers. commun., 2001). Data by aquifer and all water use categories is not available more recent than 1990.

Water withdrawal information by aquifer is available by county from PSDB for 1990. These data can be aggregated by state to compare withdrawals for public and domestic supply (fig. 3) and population served by state (fig. 4) from the glacial-deposit aquifer system in 1990. In assessing the importance of the glacial-deposit aquifer system across the region, the States were grouped into East, Central, and West areas to compare usage (fig. 5). The glacial-deposit aquifer system served a greater population and has larger withdrawals in the central part of the glaciated area. Aquifer information was not collected in the national water-use compilation in 1995, but can be extrapolated for a State using actual withdrawals for ground water in 1995 and estimates of the percent of ground-water withdrawals from the glacial-deposit aquifer system based on 1990 data. The national water-use compilation in 2000 requested aquifer withdrawal information for public supply and irrigation by aquifer and State. Ground-water withdrawals by aquifer in each county has not been available since 1990.

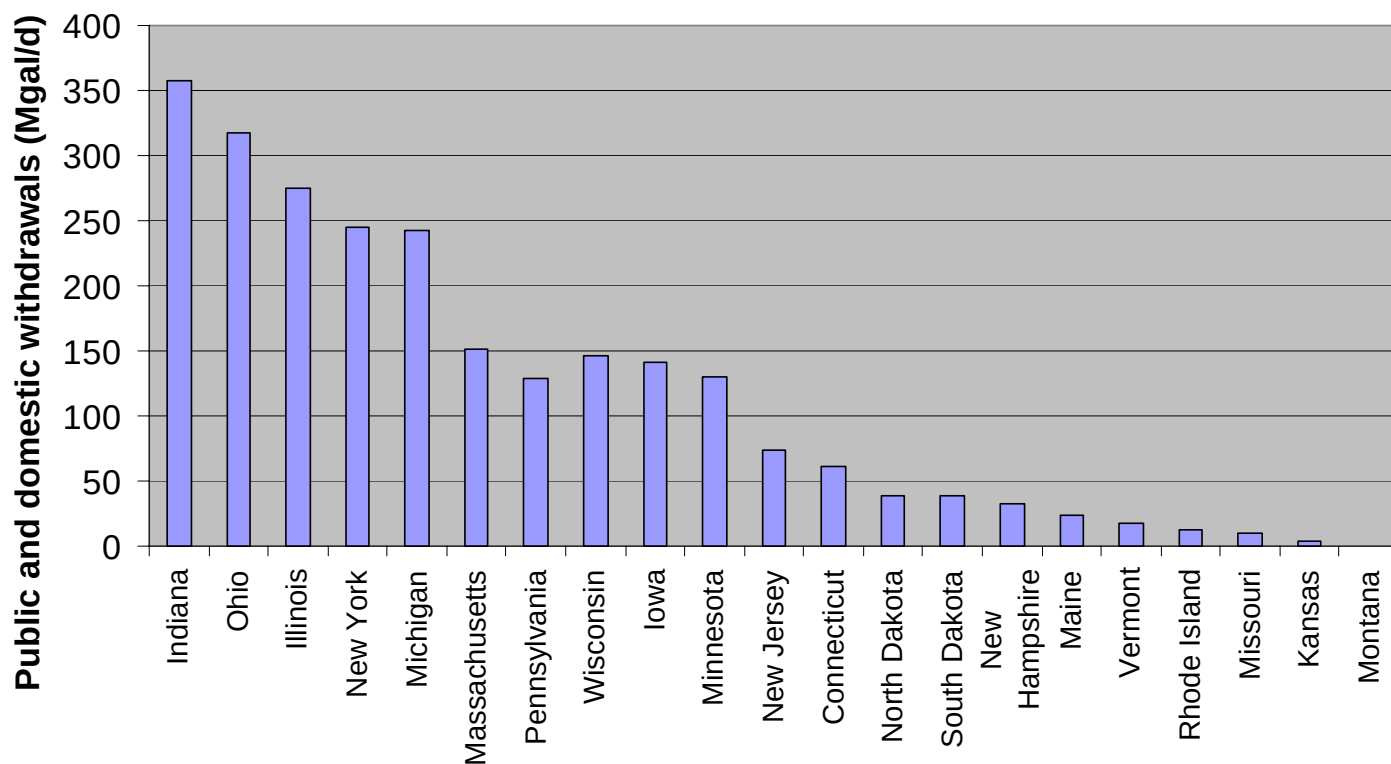


Figure 3. Water use for public and domestic withdrawals by State from the glacial and alluvial aquifer system, 1990 (adapted from Marilee Horn, USGS, pers. commun., 2001)

In addition to the large areas that are dependent on glacial-deposit aquifer system for water supply, there are various major population centers that draw large amounts of water from these aquifers (Durfor and Becker, 1965). Many large metropolitan areas in the region such as Chicago, Boston, Minneapolis/St. Paul, and Detroit do not use the glacial-deposit aquifer system for the main water supply, but the surrounding suburbs and outlying areas often rely on the glacial-deposit aquifer system for drinking water. These are the fastest growing areas of new residential development.

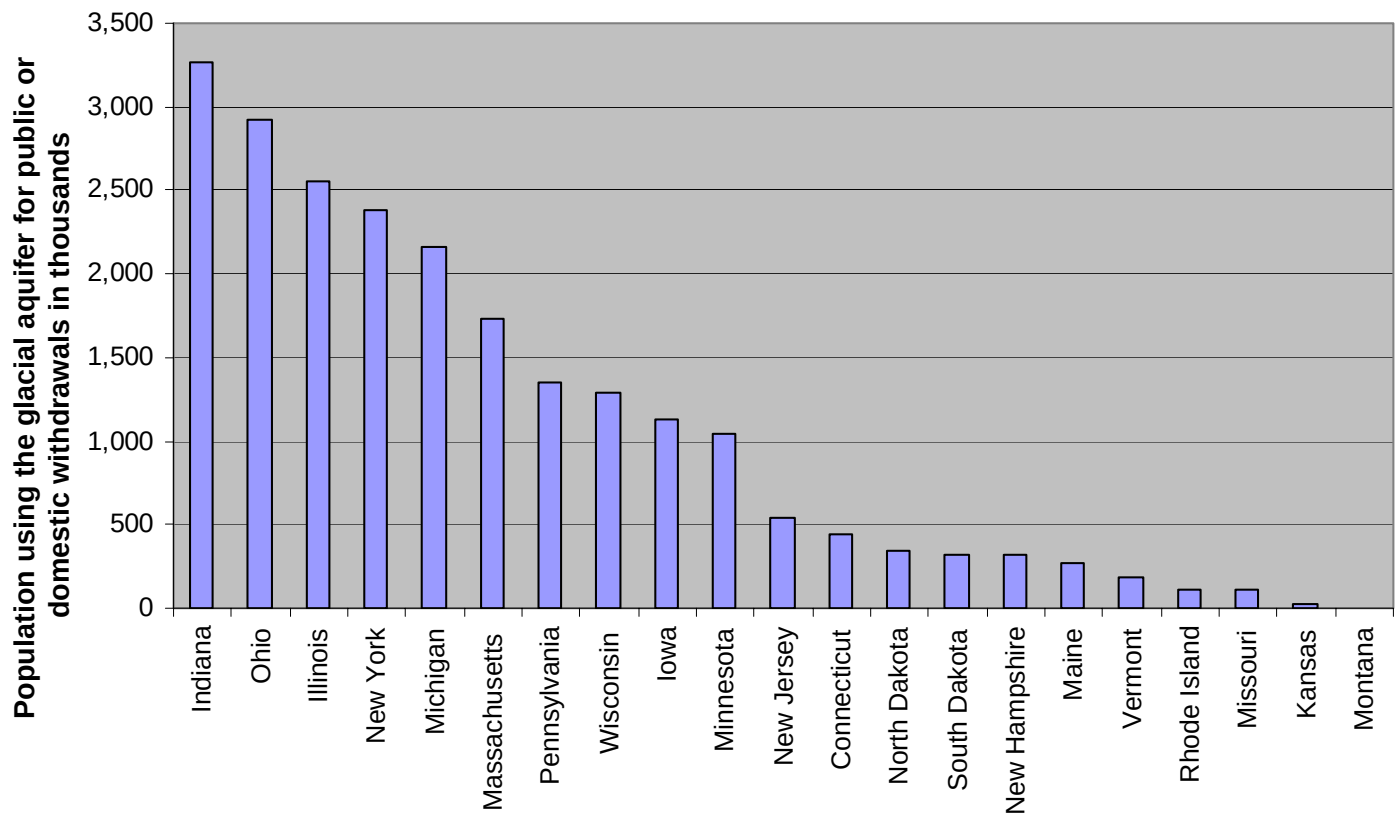


Figure 4. Population served from the glacial and alluvial aquifer system in 1990 (adapted from Marilee Horn, USGS, pers. commun., 2001).

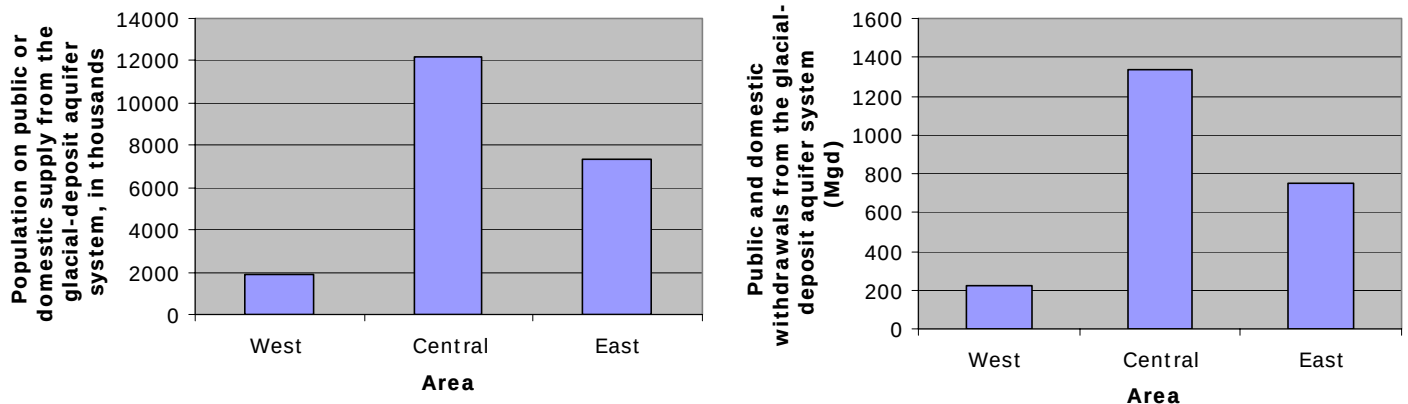


Figure 5. Comparison of population served for public or domestic supply and withdrawals from the glacial and alluvial aquifer system in the East, Central, or West areas in 1990 (adapted from Marilee Horn, USGS, pers. commun., 2001).

The largest cities that depend on this source for their fresh water (for which water-use estimates are available) are the cities of Chicago, Illinois and Dayton, Ohio that use 90 and 80 Mgal/d, respectively. Suburbs of Boston and NYC rely on the glacial-deposit aquifer system, especially in areas of new residential growth. Average daily withdraws in Detroit, Michigan are 25 Mgal/d from glacial-deposit aquifer system. Des Moines, Iowa also pumps about 15 Mgal/d. Sioux Falls, South Dakota and Indianapolis, Indiana both draw approximately 12 Mgal/d. Minneapolis and St. Paul use the Cambrian-Ordovician aquifer for ground-water supply, but recharge to the bedrock aquifer is through the overlying glacial-deposit aquifer and confining units. Most large cities in the study area are located near large water bodies such as rivers. Yield often is increased when supply wells are located in glacial sediments near streams. There are many public-water supply wells (such as in Dayton, Peoria, Indianapolis, Akron, Albany, Kansas City, Des Moines, and Cedar Rapids) located near these rivers and streams that rely on the induced infiltration of surface water to recharge and filtrate ground water to the public-supply wells.

The trend for the regional scale water use from 1990 to 1995 can be expected to continue as the population is dependent on this water source. The increases mostly are public supply and domestic self-supply--85% of the total increase. Population in these areas consumed an additional 173 million gallons per day of water, 7% increase, from these aquifers in 1995 than in 1990. As the majority of these two categories are used for drinking water, the water quality on glacial systems is especially important as a public health issue.

Key points on water use:

- The Central States of Indiana, Ohio, and Illinois have the largest withdrawals for "drinking water" from the glacial-deposit aquifer system.
- Water use information is not consistently available for the glacial-deposit aquifer system. In the 2000 water-use compilation, limited data were collected by aquifer for an entire State. Some ground-water-use information is available in PSDB by county and has been assigned an aquifer based on ancillary information. *Need to coordinate with Marilee Horn on this data base.*
- Water use information by aquifer for public and domestic supply is the primary need. The scale would ideally include information by well which could be aggregated as needed. Well characteristics, such as well type or screen interval, might be useful explanatory factors for water quality. This water-use need was relayed to the NAWQA Water Use Task Force.
- Many public-supply wells in the glacial-deposit aquifer system are near streams and possibly induce infiltration from streams that would potentially affect water quality. Site-specific information on water withdrawal would be needed to assess this effect.

Land Use

The most extensive land use over the glacial-deposit aquifer system is agriculture (fig. 6). Major urban areas include Chicago, Minneapolis, Detroit, New York City, Boston, and St. Louis. Most of the cities are along major rivers or the Great Lakes. Residential growth is greatest in the suburbs that are along the periphery of these cities, and these suburban areas include the greatest ground-water withdrawals for drinking water. The highest density of people live in the States along the east coast in the glaciated area, but the most people using the glacial-deposit aquifer system for 'drinking water' live in Indiana, Ohio, and Illinois.



Figure 6. Land use over the glacial and alluvial aquifer system.

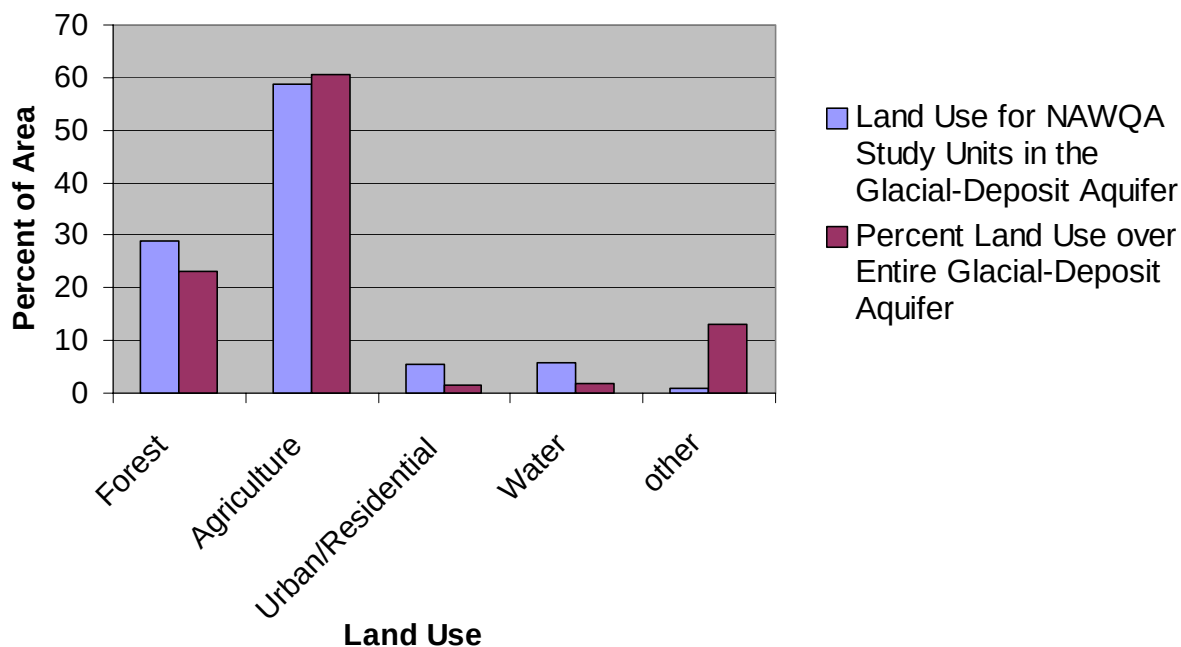


Figure 7. Major land-use categories over the glacial and alluvial aquifer system compared to percent of land-use area represented by the combined land use areas within all study units overlying the glacial-deposit aquifer system.

The effect of land use on shallow water quality is the focus of NAWQA land-use studies. The NAWQA study units cover an area representative of the entire land use over the glacial-deposit aquifer system (fig. 7). The land-use studies in the glacial-deposit aquifer system represents the distribution of land use in the study area.

Key points on land use:

- Agriculture is the major land use.
- Major urban cities by population and water use from the glacial-deposit aquifer system include Chicago, Detroit, Minneapolis, Boston, and NYC. All of these cities use surface water, such as the Great Lakes, Mississippi River, , but ground-water use from the aquifer is expanding, particularly in the suburban areas surrounding these large metropolitan areas.
- Analyses confirms that the distribution of land-use studies for NAWQA in Cycle I, and the proposed land-use studies by the Cycle II NAWQA Implementation team (NIT), closely resemble the distribution of land uses in the East, Central, and West glaciated area.

Physiography, Geology and Hydrogeology

The physiography of the glaciated area is based on topography, rock type, structure, and geologic and geomorphic history. The two largest physiographic areas include Appalachian Highlands, and Interior Plains (Fenneman and Johnson, 1946). The Interior Plains can be divided into two sections--east and west of the Mississippi River--as a distinction in the source of the glacial lobes that deposited material in these two areas. This division of the glaciated area into East, Central and West allows for a good comparison in areas of similar physiography and origin of glacial material (fig. 8).

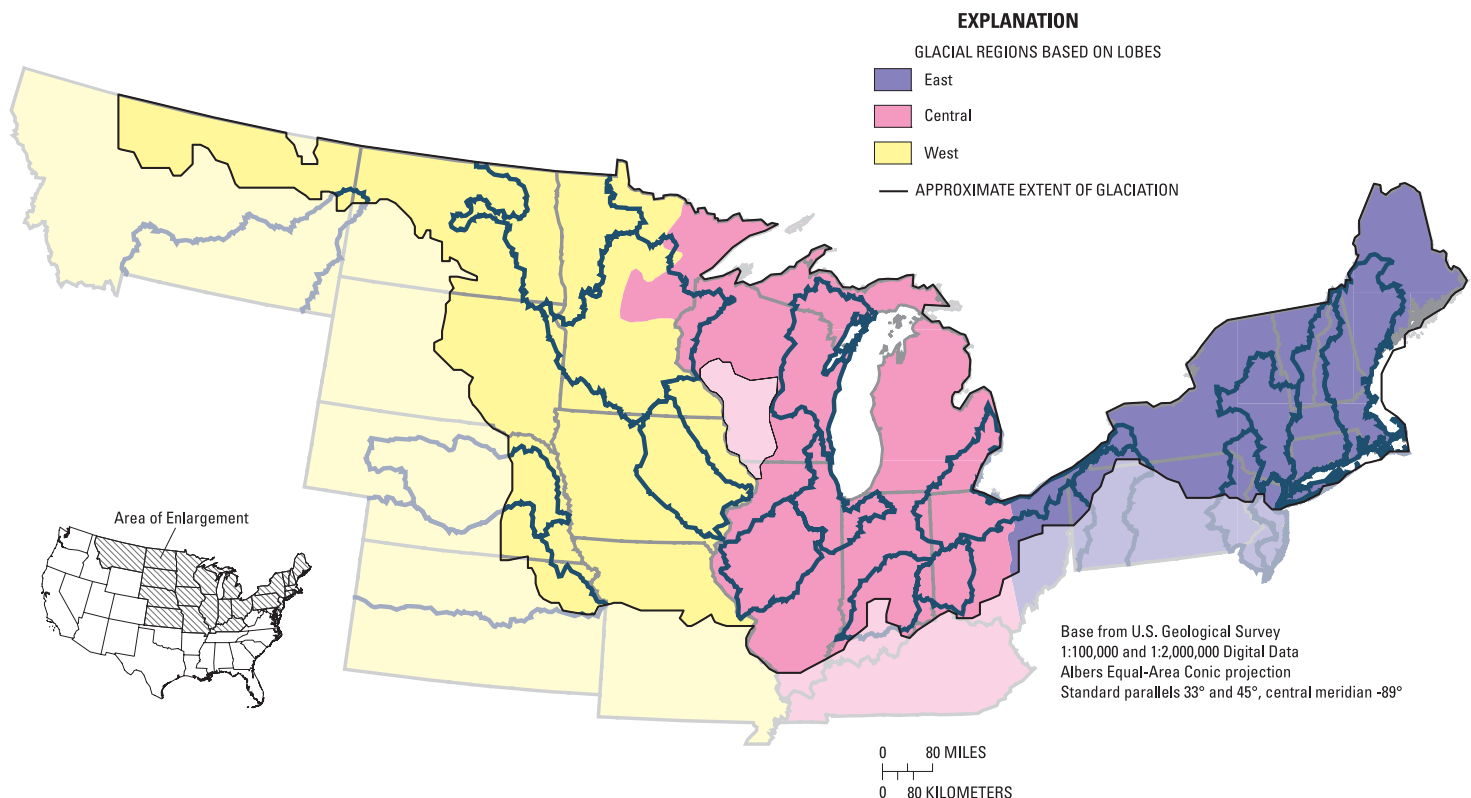


Figure 8. Division of the glacial and alluvial aquifer system into East, Central, and West area based on physiography and source of glacial material.

Geology and hydrogeology of the bedrock and glacial deposits is important because in this part of the country the aquifers are stacked, so there are hydraulic and geologic connections between the aquifer systems. In many parts of the country, there is only one principal aquifer system but in the area of glaciation the glacial-deposit aquifer system is stacked on top of other principal aquifers, such as the Cambrian-Ordovician aquifer system and the New York-New England crystalline rock aquifers. The flow characteristics and water quality may be very different between the bedrock and glacial, but both aquifers are important sources of drinking water. The hydraulic connection between bedrock and overlying glacial deposits may effect water quality in the glacial-deposit aquifer system. For example, in central Illinois the high arsenic concentrations appear to correlate with high chlorides that are indicative of the underlying bedrock aquifer chemistry (Panno and others, 1994).

Geologically, the uppermost bedrock and glacial deposits are related. The bedrock served as source material for the glacial deposits. Consequently, the mineralogy of the glacial sediments varies in the glacial deposits, partially due to underlying bedrock type. This can affect the trace element chemistry. The uppermost bedrock across the glaciated area ranges from Tertiary to Pre-Cambrian in age (fig. 9). The rock types range from igneous and metamorphic rocks in the East to sedimentary carbonates in the Central area to igneous rocks in the far West area. The Eastern area from Maine to Pennsylvania is part of the northeastern Appalachian Mountains. The rocks underlying the glacial deposits are intrusive igneous and metamorphic rocks of Paleozoic age with water bearing openings of joints and faults and hydraulic conductivities of 0.3 to 50 m/d (Heath, 1988a). Metamorphic and intrusive igneous rocks are also present in northern Wisconsin and Minnesota, but are older Pre-Cambrian rocks with hydraulic conductivities of 0.1 to 30 m/d (Heath, 1988a). A belt of folded Paleozoic sandstone, shale, limestone, and dolomite just east of the Appalachian metamorphic rocks runs from Maine, Vermont, and New York through Pennsylvania. Water-bearing openings in the folded sedimentary rocks consist of steeply-dipping joints, faults, and solution openings in carbonate rocks with hydraulic conductivities of 3 to 300 m/d (Heath, 1988a). Most of the bedrock underlying the glaciated area in the Central and Western area consists of flat-lying to gentle-dipping, consolidated and semiconsolidated rocks of sandstone, shale, limestone, and dolomite. The rocks are of Paleozoic age in the Central area and parts of the West area, but farther west the flat-lying rocks are younger Mesozoic and Cenozoic age. Water-bearing openings in these flat-lying rocks consist of joints along bedding planes and across beds, faults, solution openings in carbonate rocks, and where the rocks are semiconsolidated, interconnected pores (Heath, 1988a). Hydraulic conductivities of the flat-lying rocks in the Central area ranges from 3 to 300 m/d (Heath, 1988a).

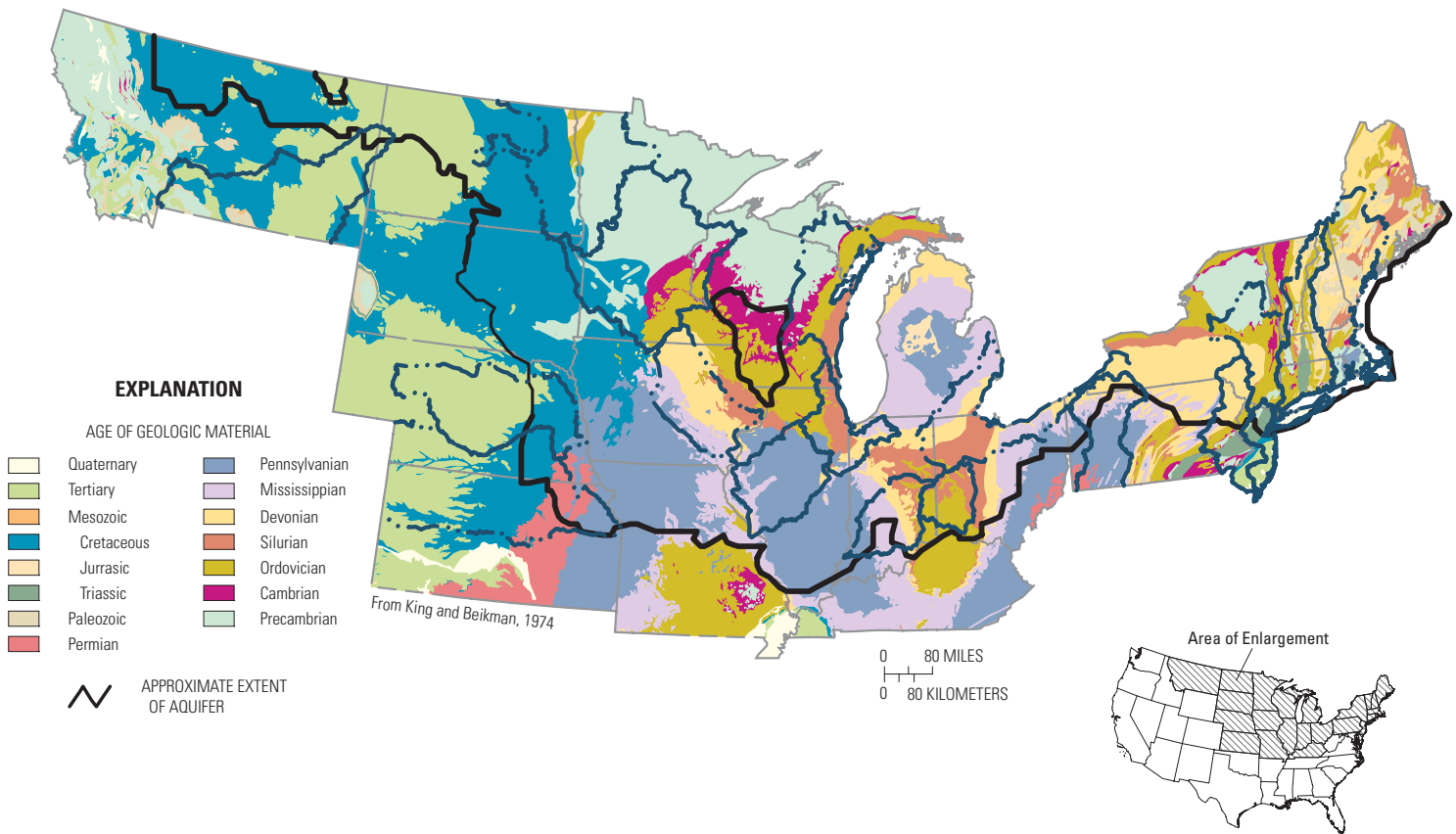


Figure 9. Uppermost bedrock underlying the glacial-deposit aquifer system (based on King and Biekman, 1974).

Twenty-one States in the north and northeastern United States are blanketed by deposits left by a series of continental glaciers that covered the area during the Pleistocene. The Pleistocene Epoch of the Quaternary Period ranges from approximately 1.6 mya to 11,000 years ago. Some geologists use Quaternary and Pleistocene synonymously. The Pleistocene deposits can range from a thin veneer to as much as 1,200 feet thick. In approximately the last 2 million years, the continental glaciers that have advanced from the north drastically have reshaped the landscape through erosion of bedrock and preexisting surficial deposits, and through redeposition of these eroded materials. Because most human activities are concentrated on or within the upper few hundred feet of the earth's surface, it is on or within these deposits that we derive significant water supplies, dispose of our wastes, build our cities, and make countless land-use decisions (Kempton and others, 1991).

The glacial deposits often are considered as one aquifer for simplicity of aquifer nomenclature, when two or more units are stratigraphically or texturally distinct with varying natural water quality. When all glacial deposits are grouped into one aquifer, it makes it easier hydrologically to represent these deposits, but leads to the belief that all glacial deposits have similar hydrogeologic characteristics throughout the United States. The differences in genetic, lithic, stratigraphic, and geomorphic properties of the deposits making up the aquifer will determine its hydrologic properties. A regional framework of

similar hydrostratigraphic and hydrogeomorphic deposits needs to be established to better understand the water quality and hydrologic characteristics of the glacial-deposit aquifer system.

Aquifer Nomenclature

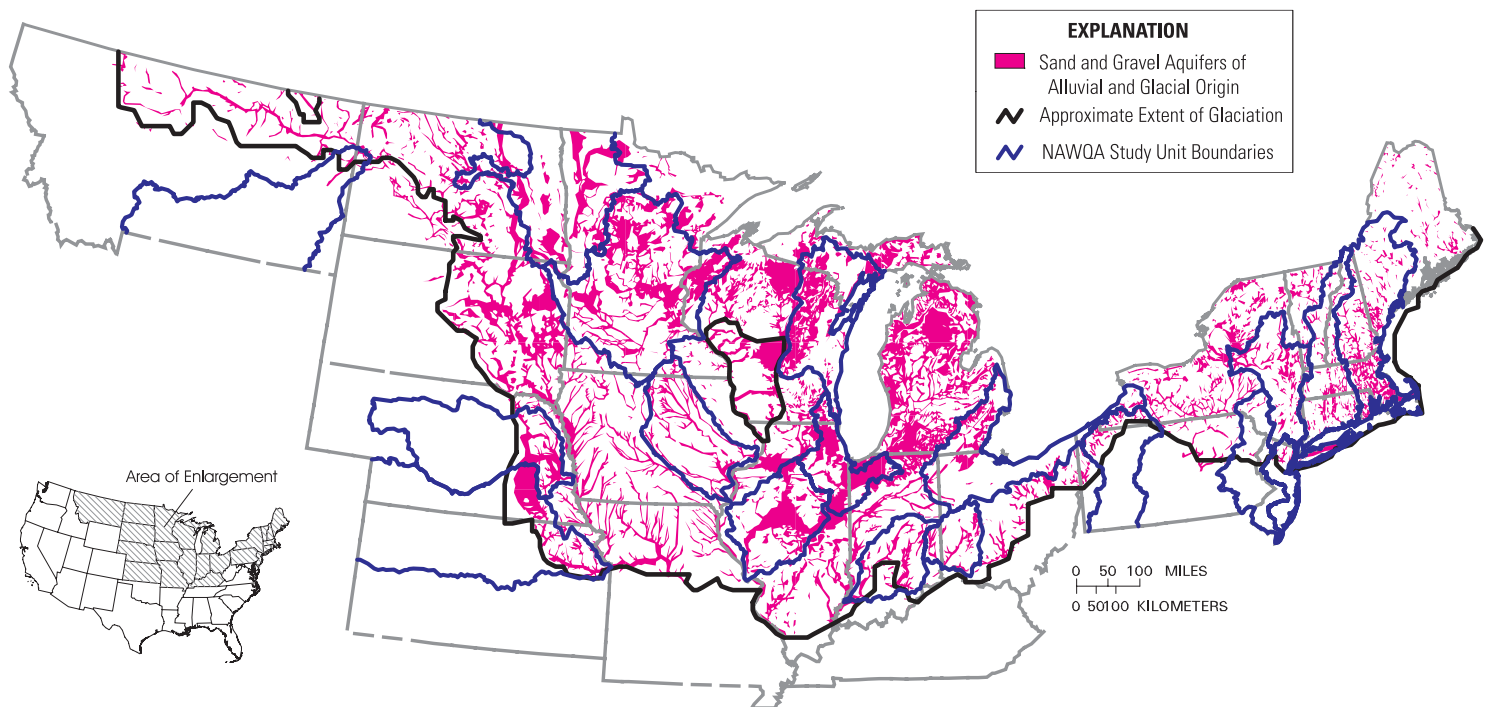
Nomenclature used in previous regional studies includes surficial sand and gravel, and alluvium as aquifer systems. The regional aquifer system described here is inclusive of unconsolidated material to the bedrock (including materials of glacial and alluvial origin) and is referred to as the glacial-deposit aquifer system. This nomenclature is consistent with the USGS lexicon (<http://www-sflorida.er.usgs.gov/lexicon/html/aqname.html#anchorG> (internal use)) of aquifer terms. There are at least six terms used in the lexicon for the glacial-deposit aquifer system--glacial deposit aquifer, glacial sand and gravel aquifer, glacial sheet-outwash deposit aquifers, upper glacial aquifer (Long Island), valley-fill outwash, buried valley, and outwash-plain deposit aquifers, and Cape Cod Aquifer. In another example, the USGS study of the Midwestern Basins and Arches Regional Aquifer System Assessment (RASA) includes the "surficial" aquifer to be glacial outwash, thin discontinuous lenses of permeable material within till, and alluvium of Holocene age that lies along streams and flood plains (Bugliosi, 1999).

There is no standard in naming a regional aquifer system and there are many inconsistencies in referring to the glacial-deposit aquifer system. The USGS has developed the Ground Water Atlas of the United States (<http://capp.water.usgs.gov/gwa/>) where the principal aquifers of the United States are mapped. Principal aquifers usually are defined by water use in the atlas. In the Ground Water Atlas the "sand and gravel aquifers of alluvial and glacial origin" are one aquifer. The four major type of deposits mapped as 'sand and gravel aquifers of alluvial and glacial origin' are: valley-fill aquifers, blanket sand and gravel aquifers, glacial-deposit aquifers, and stream-valley aquifers. The 'stream-valley' aquifers often are composed of Holocene alluvium that is confined to the current stream valley. The Holocene alluvium that forms productive aquifers in many river valleys in the glaciated area is derived from reworked glacial deposits, and it is not distinguished from the glacial deposits in regional aquifer nomenclature (<http://sr6capp.er.usgs.gov/aquiferBasics/sandgravel.html>). 'Stream-valley' aquifers south of the line of continental glaciation often are grouped with other unconsolidated deposits. Thus, the precedence is to include alluvial and glacial deposits as one aquifer system.

The 'sand and gravel aquifers of alluvial and glacial origin' map (fig. 10) developed for the Ground Water Atlas includes the following:

- Surficial aquifer system (Olcott, 1995; Lloyd and Lyke, 1995);
- Coarse-grained stratified outwash and ice-contact deposits (Olcott, 1995);
- Sand and gravel aquifers at or near land surface and alluvium along streams and rivers (Trapp and Horn, 1997);

- Glacial outwash, coarse-grained glacial-lake sediment and coarse- and fine-grained alluvium (Olcott, 1992);
- Coarse-grained glacial deposits, stream-valley alluvium or basin fill (Whitehead, 1996);
- Coarse-grained glacial deposits and stream-valley alluvium (Miller and Appel, 1997); and
- Stream-valley aquifer (Miller and Appel, 1997).



Sand and gravel aquifers of alluvial and glacial origin (from USGS Ground Water Atlas, 1997)

Figure 10. Sand and gravel aquifers of alluvial and glacial origin.

Other local or sub-regional maps of the glacial-deposit aquifer have been developed (Randall, 2002). Randall notes that the delineation of aquifers from surface material can be misleading because the distribution of aquifers is not coincident with the surficial distribution of coarse-grained stratified drift (Randall, 2002). For example, some of the coarse-facies deposits constitute productive aquifers but are buried beneath fine-grained facies, and thus, are not depicted on surficial geology maps; other aquifers are coarse-grained surficial deposits that are not considered as aquifers because the deposits rest on shallow bedrock and are thinly saturated. Randall (2002) indicated that the surface representation of materials does not show the vertical dimension that is important in defining aquifers. Yet, for the purposes of a wide regional characterization of 21 States, the surficial deposits may be the best representation to begin to define areas that are potential aquifers.

On a regional scale, including 21 States, there is not the feasibility to assess local differences, but some generalizations based on water quality and hydraulic properties need to be made using available

information. One of the most relevant regional maps to this workplan shows the thickness and character of Quaternary sediments (Soller, 1998). Although, Soller (1998) mapped the thickness and character of the Quaternary, it was based on available information, and there still are deficiencies because of lack of information especially in the subsurface (Kempton and others, 1991). Ideally, a three-dimensional map, similar to the stack-unit maps in Illinois (Berg and Kempton, 1988), would provide lithic, stratigraphic, and geomorphic information at the land surface down to bedrock. With the maps from Soller (1998), there are two types of glacial-deposit aquifer system material that can be distinguished on a regional scale--coarse-grained and fine-grained deposits.

Hydraulic Characterization

Bedrock valleys often bound the glacial-deposit aquifer system in the eastern glaciated area, but valleys are wider and incised in glacial material in most of the Central and West glaciated area. The configuration of the bedrock valley or trench is dependent upon former stream competence, the history of flow and glacial conditions, and bedrock lithology. Generally, glacial deposit thickness and lateral extent increase downstream and with the size of the Pleistocene rivers (Sharp, 1988). The nomenclature and hydraulic properties of the glacial-deposit aquifer system changes appreciably from east to west north of the line of continental glaciation:

East

There are over 5,000 aquifers composed of sand and gravel deposited by or in glacial meltwater in the glaciated eastern area (Kontis and others, in press). These aquifers form the glacial-deposit aquifer system and are hydraulically independent of one another but have similar hydraulic properties, similar modes of recharge and discharge, and similar interchange of water with regional streams that flow across them (Kontis and others, in press). In the eastern section of the glaciated area the glacial deposits are within bedrock valleys. Many of these valleys contain streams that are connected to the glacial-deposit aquifer system. The glacial deposits in these scoured valleys were reworked to form the "valley-fill glacial" aquifer that includes recent alluvium and reworked glacial deposits. Most "valley-fill glacial" aquifers in the East have a blanket of fine-grained till overlying the bedrock and under the stratified drift. The last retreat of the glacial ice left the bedrock valleys partially filled with sand and gravel intermixed with fine-grained glacial-lake deposits. The Corning aquifer, in New York, is an example of a "valley-fill glacial" aquifer that was deposited by glacial meltwater streams and is characteristic of many such aquifers in glacial deposits in the Appalachian Plateaus (Olcott, 1995). The valleys in which the glacial-deposits are incised is a flat-lying shaly carbonate bedrock.

Aquifer geometry can be affected by the width and depth of valleys in the East. These relations described in the next two paragraphs are adapted from Randall (2002). The stratified drift in most narrow, shallow valleys (less than 100 ft) consists largely of ice-contact deposits. In deep valleys, basal coarse

proximal deposits and surficial coarse deposits commonly are separated by appreciable thicknesses (up to 100 ft) of very fine sand, silt, and clay. Transmissivity of stratified drift is roughly proportional to saturated thickness in the narrow, shallow valleys where ice-contact deposits predominate, but this generalization cannot be extended to deeper valleys. Various studies have reported that an increase in depth to bedrock is likely to be accompanied by a comparable increase in thickness of very fine sand, silt, and clay. In deep valleys, transmissivity generally does not correlate well with depth to bedrock or saturated thickness of stratified drift (Randall, 2002).

The stratified drift in valleys that are unusually broad and deep is largely fine grained, presumably because the amount of coarse sediment available during deglaciation was insufficient to fill the large lakes that developed. In the broad valleys, widely scattered coarse ice-contact deposits occupy only small fractions of the proglacial lake bottom or valley floor.

The most productive and widely used aquifer system in the eastern States is the "surficial" aquifer system (Olcott, 1995)--which translates to the glacial-deposit aquifer system in the area of study. The "surficial" aquifer system is defined as deposits of sand and gravel, which for the most part are individual valley-fill deposits of outwash and ice-contact materials land down in numerous bedrock valleys by glacial meltwater. The principal exception is the sheet-type deposits of the Cape Code aquifer and the upper aquifer in glacial material on Long Island, NY. In the Ground Water Atlas of the United States there are differences in nomenclature by State in reference to the glacial-deposit aquifer system (Trapp and Horn, 1997 Pennsylvania and New Jersey: Olcott, 1995 New York and Massachusetts):

- New York (Long Island) unnamed surficial deposits, Upper Pleistocene deposits, Gardiners clay, Jameco gravel
- Massachusetts Cape Cod glacial aquifer
- Pennsylvania and New Jersey Holocene alluvium, Pleistocene deposits, glacial drift

The term "glacial drift" is often used for all types of glacial deposits regardless of particle size or degree of sorting of material (American Geological Institute, 1972).

Extensive valley-train deposits can extend for many miles in Pennsylvania and fill the Allegheny and Susquehanna River valleys (Trapp and Horn, 1997). Sand-and-gravel deposits in valleys of Pennsylvania and New Jersey deposited along the valleys of major streams form productive aquifers (Trapp and Horn, 1997). The rivers that flow south such as the Allegheny and Ohio Rivers have their head waters in glaciaded materials and the reworked glacial materials form productive aquifers; whereas, the alluvium of northward-flowing rivers such as the Kanawha in West Virginia or the Monongahela River in Pennsylvania are composed of glacial material that has been weathered and eroded from exposed sedimentary rocks. This finer-grained material from the sedimentary rocks has lower ground-water yields so is a less productive aquifer (Trapp and Horn, 1997).

The hydraulic characteristics of the glacial-deposit aquifer system have wide variability (**table 1**). The bedrock valleys are from 0.5 to 3 mi across and aquifer thickness in the valleys ranges from less than 50 ft to 500 ft. Horizontal hydraulic conductivities range from less than 1 ft/d to over 300 ft/d depending on the mixture of coarse and fine-grained sediment. Few data are available on vertical hydraulic conductivities, but in Rhode Island in near-stream deposits the vertical hydraulic conductivity was 5 ft/d. In places with appreciable till or fine-grained deposits the vertical hydraulic conductivity was orders of magnitude less than 5 ft/d. Transmissivities range from 3000 to slightly greater than 10000 ft²/d.

Central

In a regional context, Illinois, Indiana and Ohio, contain some of the most productive aquifers in the coarse-grained glacial deposits (Lloyd and Lyke, 1995). Coarse-grained deposits of glacial origin are collectively called the "surficial" aquifer system in the central part of the glaciated area (Lloyd and Lyke, 1995). The "surficial" aquifer can be further refined by inferences to the lateral extent of the aquifer material. For example in Indiana, the glacial-deposit aquifer system is divided into four groups: surficial sand and gravel aquifers, buried sand and gravel aquifers, sand and gravel within buried preglacial bedrock valleys, and discontinuous sand and gravel aquifers (U.S. Geological Survey, 1994). The surficial sand and gravel aquifers include outwash, outwash-fan deposits, isolated hills and ridges of ice-contact stratified drift, and Holocene alluvium. The Upper Wabash River Basin is characteristic of the central glaciated area in Indiana. Here the surficial sand and gravel is from 0 to 80 ft thick and the range of well yields is from 20 to 1,350 gallons per minute (U.S. Geological Survey, 1994).

The distribution of sediments within the glacial-deposit aquifer system can be inferred from the depositional setting. The thickness of glacial deposits in shallow valleys often is a measure of the scouring effect of the adjacent river since the last glaciation. For example, the deepest scouring effect along the Illinois River occurs during the spring floods and in the winter when ice jams cause the river to deepen its channel to pass beneath the ice. The effect of scour, in combination with channel migration, has been to produce an upper blanket of recent alluvium and glacial material that coarsens with depth as a result of successive periods of scour and deposition, with the coarsest particles settling out first (Walker and others, 1965).

In the Ground Water Atlas of the United States there are differences in nomenclature by State in reference to the aquifers of Quaternary or younger age (Lloyd and Lyke, 1995 for Kentucky, Ohio, Indiana, Illinois and Midwest RASA: Olcott, 1992 for Michigan and Wisconsin):

- Northern Kentucky alluvial aquifer
- Western Ohio unconsolidated, coarse- and fine-grained aquifers
- Indiana glaciofluvial, glacial outwash, and Wisconsin till
- Illinois sand and gravel aquifers

- Northern Midwest RASA drift aquifer
- Wisconsin sand and gravel aquifer
- Michigan lacustrine sand, outwash and glaciofluvial deposits, till

There is a wide range of hydraulic properties of the glacial-deposit aquifer system (table 1). In general, the largest sustained potential yields from the glacial-deposit aquifer system in the central area are obtained from wells located in river valleys where the aquifer and the river are hydraulically connected (Lloyd and Lyke, 1995). Under such hydraulic conditions, large withdrawals from a well near a river probably will cause the water level in the well to decline until it is below river level. The gradient created will induce water to move from the river to the well, and/or capture water that would have flowed to the river. Where there is induced infiltration, yields of 2,000 gpm are common and maximum yields may exceed 4,000 gpm in these areas (Lloyd and Lyke, 1995). The thickest glacial-deposits near streams in this area are present in the Mississippi River Valley at East St. Louis, IL. The aquifer system is about 100 ft thick and is hydraulically connected to the Chain of Rocks Canal and the Mississippi River (Lloyd and Lyke, 1995). Some of the overall thickest glacial deposits are in buried bedrock valleys, such as the Mahomet Buried Bedrock Valley in Illinois, which can contain more than 500ft of glacial material.

The variability in hydraulic characteristics (table 1) of the glacial-deposit aquifer system creates variability in the usefulness of the aquifer as a resource. Because the Central part of the glaciated area has little topographic relief there are not sharply defined valleys on a regional scale and deposits are flat-lying. The thickness of aquifer material near streams is from less than 50 ft to 400 ft, but can range up from 200 to over 1,000 ft in some flat-lying areas (Joseph and Eberts, 1994). Horizontal hydraulic conductivities range from less than 1 ft/d to over 1000 ft/d depending on the mixture of coarse and fine-grained sediment, but there is little data on vertical hydraulic conductivities. Transmissivities range from 100 to slightly greater than 50,000 ft²/d, although in areas of fine-grained till the transmissivities can be less than 1 ft²/d.

West

The regional aquifer characterization of the western glaciated area indicates the glacial-deposit aquifer system consists of the "surficial" aquifer (as referred in Minnesota and Iowa) and the "unconsolidated-deposit" aquifer (as referred in North Dakota, South Dakota, and Montana). It is the most widespread and extensively used aquifer in the West area of the glacial deposits. The mapped density of the glacial-deposit aquifer system near streams is greater in Minnesota and Iowa compared to North Dakota, South Dakota, and Montana. The glacial-deposit aquifer system consists chiefly of stratified sand and gravel, ice-contact deposits, and alluvium (Olcott, 1992). The aquifer system in North Dakota, South Dakota, and Montana includes the hydrogeologic settings of: a broad band of continental glacial deposits, and narrow valleys along major streams (primarily in southeastern Montana and locally in northwestern North Dakota, and western South Dakota) (Whitehead, 1996). The glacial-deposit aquifer system

consisting of sand and gravel deposited near streams in the central part of the West area generally is thin, narrow bands that are less productive than other parts of the glacial-deposit aquifer system, except in Minnesota where there are many broad outwash sand plains (Whitehead, 1996).

There are differences in nomenclature by State in reference to the glacial-deposit aquifer system that is defined in the Ground-Water Atlas as the "surficial" or "unconsolidated-deposit" aquifer system (Olcott, 1992 for Minnesota and Iowa: Whitehead, 1996 for Montana, North Dakota and South Dakota: Miller and Appel, 1997 for Nebraska and Kansas):

- | | |
|--|--|
| • Southeastern Minnesota | undifferentiated drift aquifer |
| • Iowa | sand and gravel aquifer |
| • Montana, North Dakota, and
South Dakota (Williston Basin) | alluvium and glacial deposits |
| • Nebraska and Kansas | valley-fill deposits and dune sand or alluvial
deposits |

In Iowa, the important glacial-deposit aquifer consists of reworked coarse-grained glacial and alluvial material along streams and buried sand-and-gravel deposits along ancient erosion channels in the bedrock surface (Olcott, 1992). The extent of tills, which often are fine-grained in this area, and coarse sands are reflective of changes in transmissivity and potential connection of surface and ground waters. In Missouri, the extent of continental glaciation is approximately south to the Missouri River. The glacial deposits in this area and Kansas, are pre-Illinoian and, thus, are older than in other adjacent States which have younger Wisconsinan deposits at the land surface. The glacial deposits along the Missouri River are important aquifers from the Iowa-Missouri State line to the junction of the Missouri and Mississippi River (Miller and Appel, 1997).

The hydraulic characteristics of the glacial-deposit aquifer system in the west is varied (table 1). The near-surface valleys are flatter than valleys in the east area and can range from 1 to 10 mi across. The aquifer thickness in the valleys ranges from less than 100 ft to 300 ft. Horizontal hydraulic conductivities range from less than 1 ft/d to 328 ft/d depending on the mixture of coarse and fine-grained sediment, but in near-stream areas the hydraulic conductivities can be greater than 2,000 ft/d (Heath, 1988). Few data on vertical hydraulic conductivities are available for the aquifer in the West. Transmissivities range from less than 100 to slightly greater than 50,000 ft²/d.

Table 1. Hydraulic characteristics of the glacial and alluvial aquifer system from published reports.

Area	Aquifer Name	Valley Width (miles)	Thickness (ft)	Thickness of aquifer (ft)	Vertical Conductivity (ft/d)	Horizontal Conductivity (ft/d)	Transmissivity (ft ² /d)	Storage coefficients or specific yield	Well yield (gpm)	Reference
<u>EAST</u>										
eastern Connecticut	till			15		0.04 to 24				Melvin, Stone, Craft and Lane, 1995
eastern and central Connecticut			40 to 120				1500 to 12500			Melvin, Stone, Craft and Lane, 1995
Connecticut	lower Quinnipiac valley aquifer		>200	100						Randall, 2002
New York, Vermont, New Hampshire, Connecticut, Massachusetts, Maine, Rhode Island	valley-fill glacial aquifers - outwash deposits		10 to 150						10 to 400	Olcott, 1995
New York, Vermont, New Hampshire, Connecticut, Massachusetts, Maine, Rhode Island	valley-fill glacial aquifers - ice-contact deposits		35 to 150						10 to 1000 (till <1 to 3)	Olcott, 1995
New York, Vermont, New Hampshire, Connecticut, Massachusetts, Maine, Rhode Island	Cape Cod glacial aquifer		60 to 200						100 to 1000	Olcott, 1995
New York, Vermont, New Hampshire, Connecticut, Massachusetts, Maine, Rhode Island	Upper glacial aquifer on Long Island		50 to 600						50 to 1000	Olcott, 1995
Maine	Little Androscoggin River Valley aquifer	<1 to 2		150		150 to 200 (ice-contact deposits): 15 to 80 (outwash deposits): 4 (till)				
New York	Corning aquifer	0.5 to 1		60					50-1000	GW Atlas
Connecticut	stratified drift (coarse grained)					170		0.36		Melvin, Stone, Stone, and Trask, 1992
Connecticut	stratified drift (fine grained)					.0001-.82		0.29		Melvin, Stone, Stone, and Trask, 1992
Connecticut	till					.003 to 2.7		.04-.28		Melvin, Stone, Stone, and Trask, 1992
New York	Susquehanna River valley aquifer		0-500	150						Randall, 2002
Massachusetts	Taunton River valley aquifer			200 20-80						Randall, 2002
Massachusetts	western Cape Cod aquifers (glaciofluvial)					240 to 350				Masterson and others, 1997
Massachusetts	western Cape Cod aquifers (glaciolacustrine)					150 to 280				Masterson and others, 1997
Massachusetts	western Cape Cod aquifers (glaciolacustrine offshore)					30 to 150				Masterson and others, 1997
Massachusetts	western Cape Cod aquifers (glacial moraine)					10 to 150				Masterson and others, 1997

Massachusetts	western Cape Cod aquifers (till)			1			Masterson and others, 1997
Massachusetts, Connecticut, Rhode Island,	till			.0022 to .0023 to 22.7	65.2		Melvin, deLima, and Stone, 1992
New Hampshire	valley-fill aquifer (sand)			<3 to 190			Mack and Lawlor, 1992
New Hampshire	valley-fill aquifer (gravel)			250 to >300			Mack and Lawlor, 1992
Dover, New Hampshire	buried valley aquifer (Pudding Hill aquifer)	>100		approx 150	3000		Mack and Lawlor, 1992
New Hampshire	Saco River valley glacial aquifer	1 to 3	10-185	11 to 97			Tepper and others, 1990
southern Rhode Island	stratified-drift aquifer	approx 1		134 5 (median)	11,400 (median)		Dickerman and others, 1997
New Jersey	surficial aquifer system	<350				130 to 800	Trapp and Horn, 1997
Pennsylvania	surficial aquifer system					400 to 750	Trapp and Horn, 1997
Pennsylvania	alluvium on the Allegheny River					200 to 3000	Trapp and Horn, 1997

CENTRAL

				Thickness from 5 to 400, Kh//Kz from 2:1 to 30:1, Kh generally 10 to 600 ft ² /d, T generally from 500 to 5000 but can exceed 4000 ft ² /d and S from 10-1 to 10 - 5 500, change this to 2,000 or more gpm in outwash and 1 to 10 gpm in till 500 gpm in outwash and 1 to 10 gpm in till (median) 102 (median) 0.05 to 0.3			
Iowa, Minnesota, Wisconsin, Michigan	surficial aquifer system	50 to 400					Olcott, 1992
Mississippi River	alluvium						Sharp, 1988
United States	Central Glaciated Plains			6.6-980	1080--22,000	53-528	Heath, 1988
Indiana	surficial sand and gravel in Kankakee River Basin		20 to 100			200 to 600	USGS, 1994
Illinois, Indiana, Ohio	surficial aquifer system	1 to 300			500 to 50,000	100 to 500	Lloyd and Lyke, 1995
eastern Indiana	glacial-deposits aquifers					0.00002 to 0.38	Joseph and Eberts, 1994
western Ohio	glacial-deposits aquifers			.0001 to .77	0.33 to 1000	0.0002 to 0.3	Joseph and Eberts, 1994; Bugliosi, 1999 (yield)
western Ohio	glacial-deposits aquifers (till)				1.54 to 2.07	0.015 to 0.0261	Joseph and Eberts, 1994

WEST

United States	Western Glaciated Plains			0.66-328	269--27,000	53-528	Heath, 1988
Missouri	Missouri River Valley alluvial aquifer	2 to 10	90 (average)	80		100 to 3,000	Miller and Appel, 1997
Missouri and Kansas	glacial-drift aquifer		100 to 200		200 to 13,000 (Kansas)	10 to 1,000	Miller and Appel, 1997
High Plains - Nebraska and Kansas	valley-fill deposits and dune sand or alluvial deposits						Miller and Appel, 1997
United States	Alluvial Valleys			98 to 6,600	2,150--54,000	106-5,300	Heath, 1988

North Dakota, South Dakota, and Montana	unconsolidated- deposit aquifers	<300 ft in glacial outwash but <100 ft in alluvium along stream valleys	1 to 1,000	Whitehead, 1996
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Key points on geology and hydrogeology:

- Glacial deposits are a heterogeneous mixture of clay, sand and silt. Aquifers in the study area within these deposits (of glacial and alluvial origin) are hereafter referred to as the glacial-deposit aquifer system.
- The glacial-deposit aquifer system is mostly in valleys in the east, and is referred to in USGS reports as 'stratified-drift aquifer', although the nomenclature is varied. The glacial-deposit aquifer system in the central and western area is more flat-lying except along river valleys.
- The glacial-deposit aquifer system in the area of buried valleys in the central and western is composed of some of the thickest deposits (excluding thick layers in North Dakota and Michigan).
- The hydraulic properties of the glacial-deposit aquifer system are varied in the east, central and western part of the United States north of the line of continental glaciation. Transmissivities and hydraulic conductivities are similar by grain size across the glaciated area.

Regional Framework for the Glacial-Deposit Aquifer System

The regional framework consists of 3 primary factors: (1) physical setting of the aquifer which may affect continuity of deposits, (2) intrinsic susceptibility which is an indication of how water moves through the aquifer, and (3) natural vulnerability which refers to the degree to which natural sources are present. Land use, as an indication of anthropogenic vulnerability, can be overlaid on this regional framework. Many common natural and anthropogenic factors provide a unifying framework for making comparative assessments of water quality within and among NAWQA study units overlying the glacial-deposit aquifer system. The key in developing a regional framework for the glacial-deposit aquifer system is to determine the primary factors affecting water quality in the aquifer system. The three factors of natural vulnerability, intrinsic susceptibility, and physical setting can be broadly determined for the glacial-deposit aquifer system by:

1. Natural vulnerability --source material--physiography and glacial lobes (fig. 8)
2. Intrinsic susceptibility--surficial material--texture of deposits (fig. 12)
3. Physical setting--aquifer geometry--depositional setting (fig. 11)

Natural Vulnerability

The glaciated area was divided into three major glacial regions based on differing source material-- East, Central, and West. The purpose of dividing the glacial-deposit aquifer system by source material is to

incorporate natural vulnerability into the framework. Numerous studies have been done on glacial sediments that show distinct geochemical differences in the sediment based on source area and sediment size (Randall, 2001; Shilts, 1995; Shilts, 1992; Shacklette and Boerngen, 1984). Weathering and leaching can dissolve and mobilize many constituents from the sediments that will affect the natural ground-water chemistry. Recently, there has been some focus on the affect of glacial sediments on geochemical changes in the aquifer, particularly in an agricultural area of Minnesota (Bohlke and others, 2002). From a regional perspective, it may be expected that denitrifiication coupled with oxidation of Fe phases (plus or minus organic Carbon) has reduced the concentration of NO_3 in ground water in agricultural areas underlain by glacial sediments (Bohlke and others, 2002). Changes in aquifer conditions, such as redox, may begin to mobilize chemical compounds within or absorbed to the source materials, and thus, continue to alter the natural ground-water chemistry. Regional variations in the source of glacial sediments might be used to predict the reactivity of redox-sensitive contaminants in the glacial-deposit aquifer system in the mid-continent region.

Physiography (Fenneman and Johnson, 1946) is used for the regional framework to define the

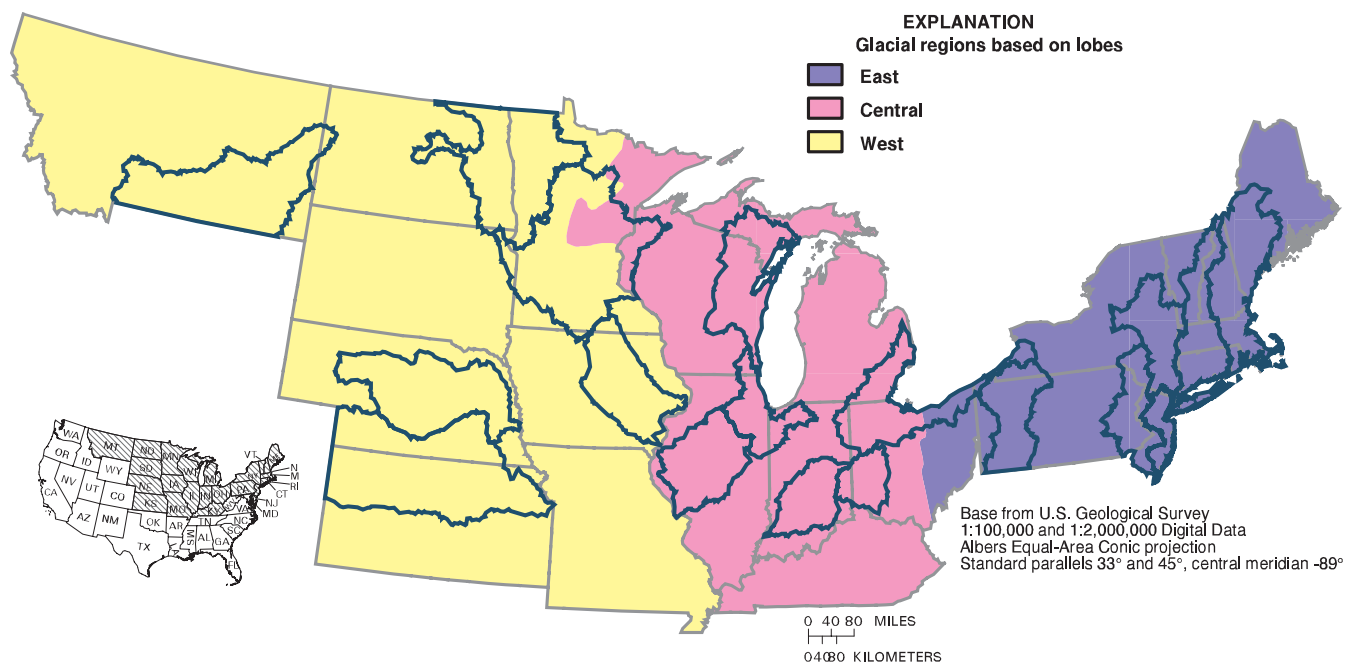


Figure 11. Division of the glacial-deposit aquifer system into East, Central, and West areas based upon physiography and source of glacial material.

source material of the glacial-deposit aquifer system. The physiographic map by Fenneman and Johnson (1946) represents distinctive areas having common topography, rock types and structure, and geologic and geomorphic history that are all factors affecting the origin of glacial materials. Combining the physiography map of Fenneman and Johnson (1946) with the boundaries of glacial lobes and sublobes as defined by Mickelson and others (1983) was the basis for the division of source material into East, Central, and West areas. The division of East and Central is the boundary between the Central Till Plains and the Appalachian Plateau (Fenneman and Johnson, 1946) in north-central Ohio. Mickelson and others (1983) have a similar distinction except the northern deposits near the Great Lakes are included in the same region as the Till Plains. The division between Central and West is based on the boundary between the Central Till Plains and the Western Lake deposits or Dissected Till Plains. This boundary follows the Mississippi River to Minneapolis, MN and then north of Minneapolis. The boundary is modified to more accurately represent the glacial lobe sources defined by Mickelson and others (1983). These boundaries are general guidelines for comparing water quality across the glaciated area, but local detail on source of glacial material may further refine these areas.

Intrinsic Susceptibility

The glaciated area also was divided into two types of surficial deposits--coarse- or fine- grained. The purpose of dividing the glacial-deposit aquifer system by surficial deposits is to incorporate intrinsic susceptibility into the framework. Intrinsic susceptibility refers to the ease of water to move through sediment. Numerous studies have been done on glacial sediments that determine differences in susceptibility based on material and texture (Arnold and Friedel, 2000; Wolock, D.M. and others, 2001; Berg and others, 1984). The property of sediments that describes the relative ease of water movement through the sediments is hydraulic conductivity--a major factor in the rate of ground water and contaminant

Table 2. Estimated horizontal hydraulic conductivities of typical glacial material in Illinois (modified from Berg and others, 1984)

<u>Glacial Material</u>	<u>cm/sec</u>	<u>Comments</u>
clean sand and gravel	1×10^{-3}	May be highly permeable.
fine sand and silty sand	1×10^{-5} to 1×10^{-3}	-----
silt (loess, colluvium, etc.)	1×10^{-6} to 1×10^{-4}	-----
gravelly till, less than 10% clay	1×10^{-7} to 1×10^{-5}	Often contains gravel/sand lenses or zones.
till, less than 25% clay	1×10^{-8} to 1×10^{-6}	Often contains gravel/sand lenses or zones.
clayey till, greater than 25% clay	1×10^{-9} to 1×10^{-7}	Often contains gravel/sand lenses or zones.

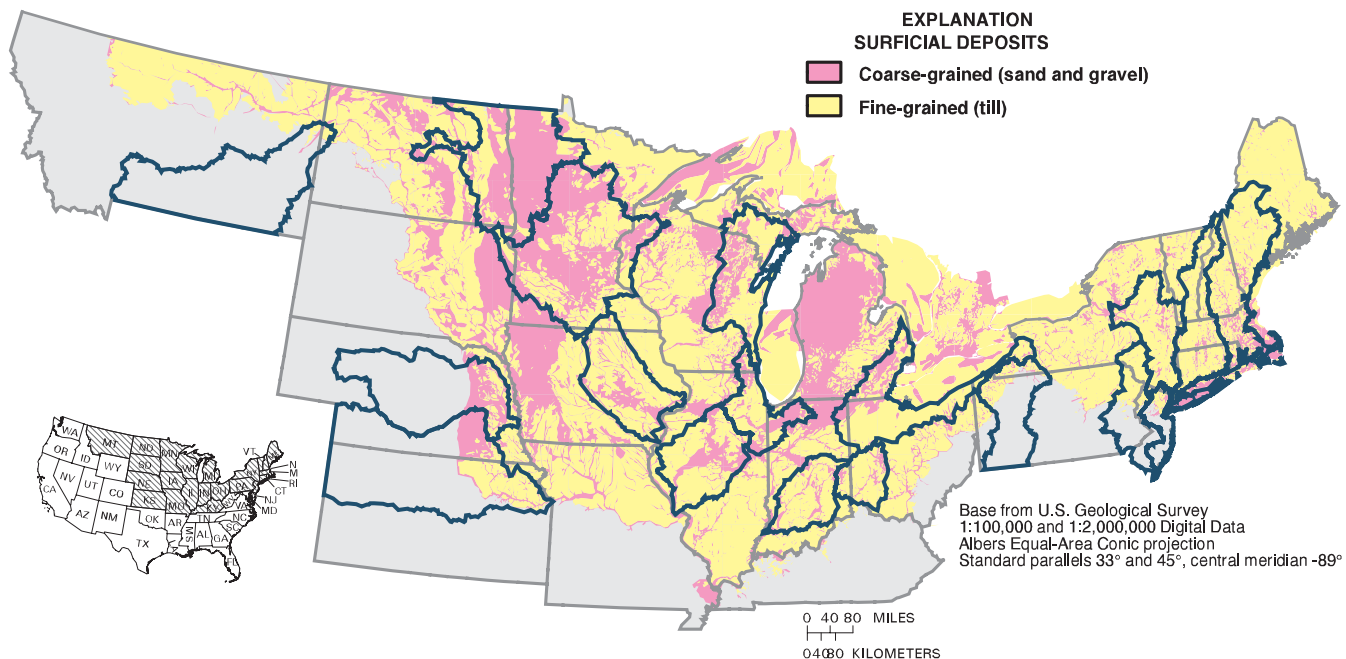


Figure 12. Location of coarse- and fine-grained deposits in the uppermost glacial deposits used to describe the relative intrinsic susceptibility.

movement. Hydraulic conductivities can be orders of magnitude different between fine-grained clays and silts, and coarse-grained sands (table 2). Varying horizontal and vertical hydraulic conductivities result for these materials similar to the varying textural ranges for the glacial sediments.

The spatial distribution of fine- and coarse-grained stratified drift is derived from the digital coverage by Soller (1998) (fig. 12). Coarse-grained stratified drift is defined by Soller (1998) for the glacial materials as consisting of layered sand and gravel, with less common silt and clay beds, deposited in fluvial, glaciofluvial, deltaic, and outwash-plain settings. The fine-grained stratified drift generally is clay, silt, and very fine sand, but includes lesser amounts of coarser material, commonly as interbeds (Soller,

1998). Till consists of poorly sorted sediments that are unstratified and composed of particles ranging in size from clay to large boulders. The regional glacial-deposit aquifer framework described in this workplan includes fine-grained stratified sediments and till to represent fine-grained material. Although there is a wide range of till hydraulic conductivity, considering the till as fine-grained material (10^{-10} to 10^{-4} cm/s) is given in Freeze and Cherry (1979).

Physical Setting

The glaciated area also was divided into two general patterns of aquifer geometry--valley-fill deposits, and layers or lenses. The valley-fill deposits are glacial deposits filling a bedrock valley (although some deep valleys in glacial till are present in the western part of the study area), and may be in connection to the land surface or buried (fig. 13). The purpose of dividing the glacial-deposit aquifer

system by aquifer geometry is to incorporate the physical setting of the aquifer. The physical setting indicates distribution and connectivity of aquifer material (potential lateral and vertical hydraulic connection). An understanding of the three-dimensional configuration and aquifer boundaries is a prerequisite to development and protection of the aquifers. Randall (2001) summarizes the need to know aquifer geometry in conjunction with surficial material: The distribution of stratified-drift aquifers is not coincident with the surficial distribution of coarse-grained stratified drift. For example, some coarse deposits constitute productive aquifers but are buried beneath fine-grained deposits and, thus, are not depicted on surficial geology or soils maps; other deposits are surficial but

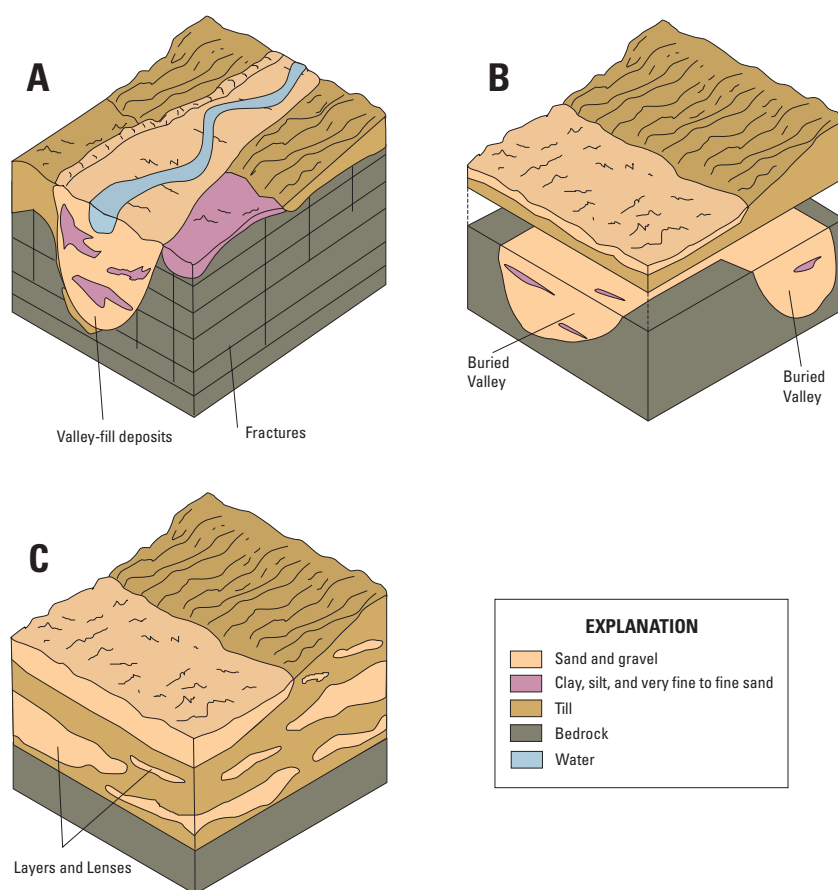


Figure 13. Example geologic cross-sections in the glaciated areas showing: A. Glacial fluvial and alluvial deposits in a bedrock valley in connection with the land surface; B. Buried bedrock valley not in connection with the land surface; C. Layers and lenses of sand and till not overlying a bedrock valley (modified from the USGS Ground Water Atlas).

can not be considered aquifers because they rest on shallow bedrock and are thinly or variably saturated. The interpretation of [site specific] information depends as much on the patterns of aquifer geometry the investigator expects or recognizes, as it does on the site-specific information.

Aquifer geometry is difficult to determine in layers and lenses, but the boundaries of an aquifer within a bedrock valley are more readily discerned. Most valley-fill aquifers in the northeastern United States (East area) are composed of stratified drift that is in connection to the land surface and bounded by bedrock. Some stratified valley-fill aquifers in the northeast contain surficial confining units, but this is not common. The valley-fill aquifers in the Central area often are buried beneath a thick sequence of fine-grained till and bounded by carbonate bedrock (for example, the Mahomet aquifer in Illinois and buried-valley aquifer near Dayton (Rowe, 1999)), but there are many valley-fill aquifers in river valleys that are connected to the land surface (for example, the valley-fill aquifer near Indianapolis and Mahomet-Sankoty aquifer near Peoria).

The development of the spatial distribution of buried valleys is difficult because a composite map showing buried valleys across the glaciated region of the United States is not available. The valley-fill aquifers near river valleys, for this study, were determined by buffering a digital coverage of streams by 5 km and overlaying this buffered coverage on the surficial materials map. Valley-fill aquifers were defined where the buffered stream and coarse-grained sediments intersected. This process identified most valley-fill aquifers in the East area and adequately represented the valley-fill aquifers in the West and Central area with some modification by study units. We attempted to develop the buried valley-fill aquifer map by drift thickness, but this became inappropriate because the glacial deposits in Michigan are so thick that one large buried valley the size of the State would result at the scale of map preparation.

We developed an outline of the buried valleys from current maps and references at a scale of 1:5M (Melhorn and Kempton, 1991; Herzog, Warner, etc, 1994; Univ. of Minnesota, Geology Dept., 2002). The lines showing the buried valleys were digitized and buffered by 2 miles to give a general location of buried valleys in Illinois, Indiana, and Ohio. To refine the location of buried valleys we plan to use an unpublished bedrock topography grid developed by David Soller (Geologic Division, Reston, 2003) to determine areas of sharp changes in bedrock elevation and use these areas to define buried valleys. The determination of valley-fill aquifer needs more local input for interpretation. Valley-fill aquifers within study unit boundaries have been determined by ground-water specialists in the study units and incorporated into the regional framework (fig. 14). If an area did not include a valley-fill aquifer, then it was assumed to include an aquifer in a layer or lens.

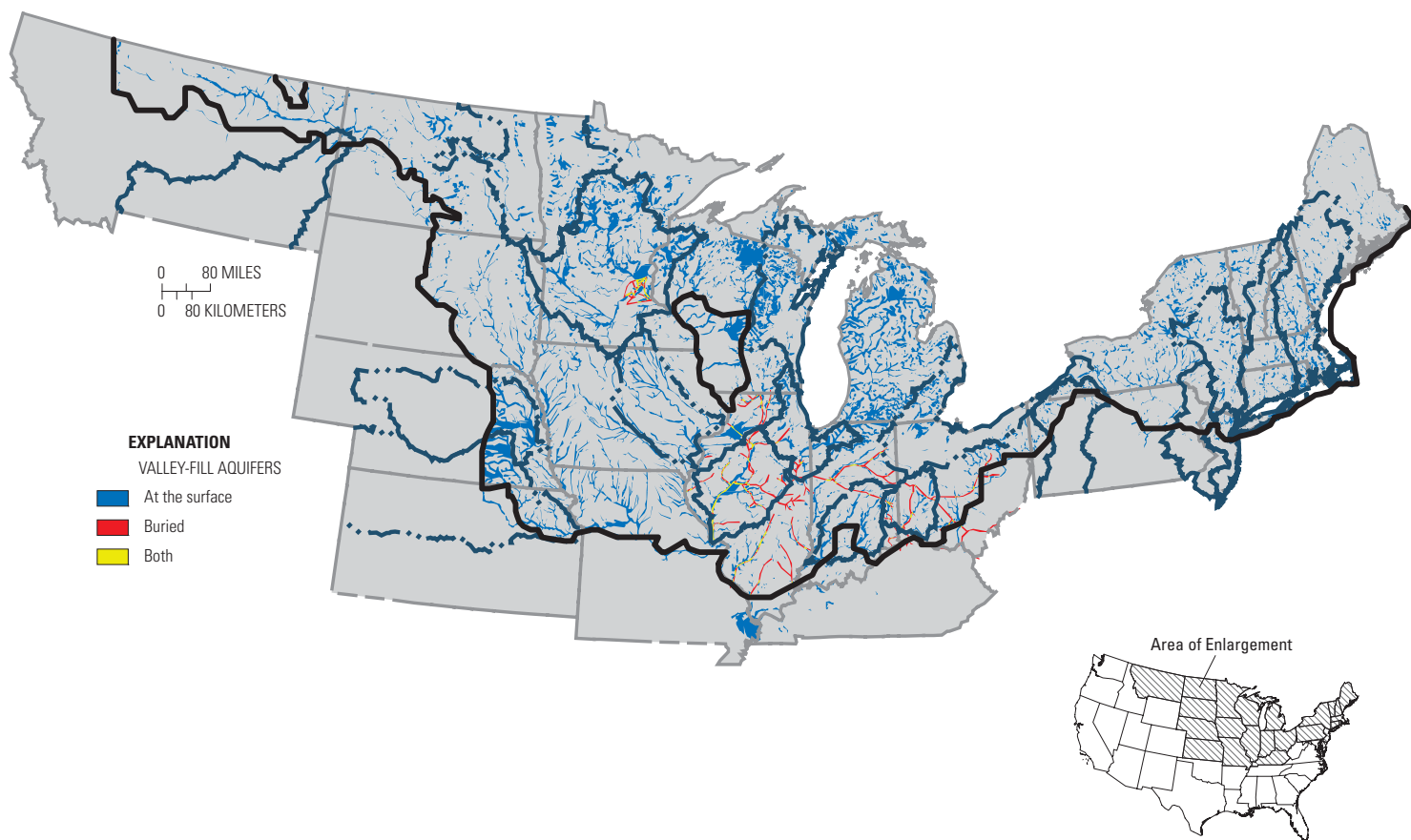
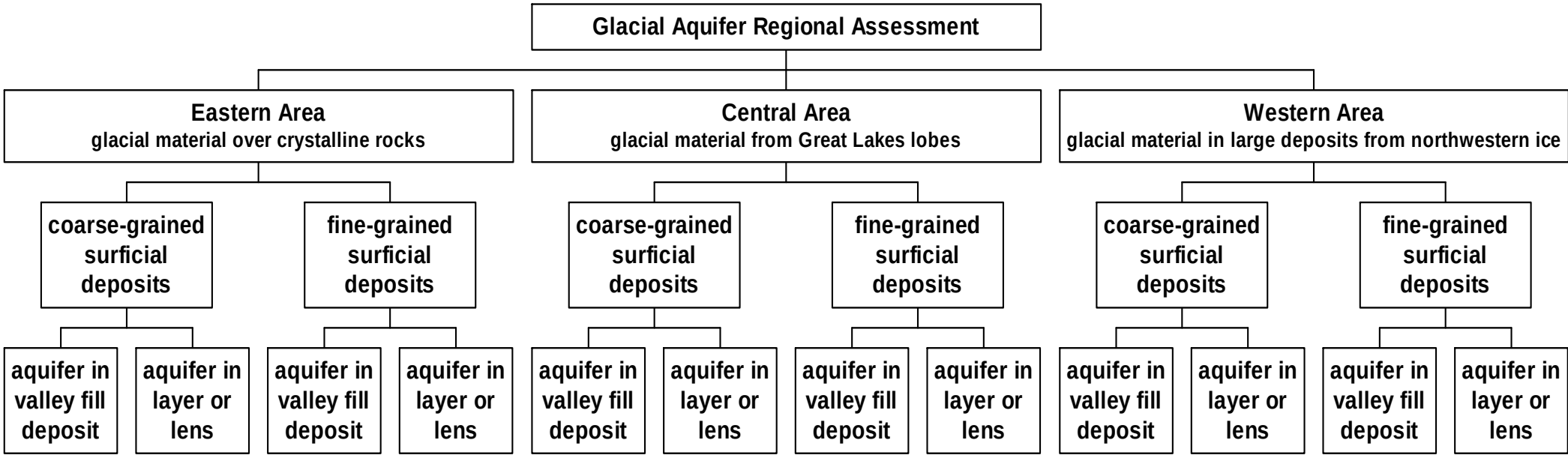


Figure 14. Location of valleys in connection with the land surface and presence of buried bedrock valleys.

Key points for regional framework:

- The regional framework is based on natural vulnerability, intrinsic susceptibility, and physical setting (fig. 15).
- Regional vulnerability is characterized by factors that may influence natural water quality, such as physiography and source of glacial lobes.
- Regional susceptibility is characterized by the texture of surficial materials, such as coarse or fine grained.
- A map of buried bedrock valleys and glacial valleys needs to be developed. An unpublished grid of bedrock topography (Dave Soller, USGS, Geologic Division) needs to be obtained to begin this digital mapping. A request from the regional aquifer coordinators, to develop this map was submitted to the group working on GIS ancillary data needs (email to Gail Thelin via Wayne Lapham in February, 2003).

Figure 15. Organization chart of the NAWQA studies within the glacial and alluvial aquifer system.



Water-quality issues

The glacial-deposit aquifer system is used extensively as a source of drinking water for public and domestic supply; therefore, water quality is an issue for the water managers, health officials, and the private well owner. Many natural contaminants are present in the glacial-deposit aquifer system because the source of the aquifer material is from various rock types containing a wide range of contamination sources, such as arsenic, uranium, radium, etc. The unconsolidated nature of the glacial materials make these deposits potentially susceptible to anthropogenic contamination. Although, the dominant land use over the glacial-deposit aquifer system is agricultural, there are many major population centers such as Chicago, Minneapolis-St. Paul, Detroit, Boston, New York, and St. Louis where urban practices are an issue.

Many local water-quality issues are present in the glacial-deposit aquifer system. Emerging contaminants have yet to be detected in the system, but within the NAWQA study units there are various common water-quality issues. The common water-quality issues across the glacial-deposit aquifer system include arsenic, pesticides, and induced infiltration of degraded surface water (fig. 18). Other issues in the glacial-deposit aquifer system that are important water-quality issues, but less ubiquitous include nitrate, radon, and VOCs. A conference call (12/01) among the GAPT summarized and prioritized the regional issues as follows:

Arsenic

- Arsenic concentration exceeds the recent (Jan. 2001) 10 ug/L drinking water standard in many areas of the glacial-deposit aquifer system.
- Arsenic is not frequently detected in stratified drift (Central and East), but when present arsenic concentrations are high (greater than 10 ug/L) within a study area.
- Arsenic concentrations in buried valley-fill deposits like the Mahomet aquifer are unusually high and occur frequently.

Pesticides

- Pesticides are found in the glacial-deposit aquifer system across the area except in the NECB, where there were no detections.
- Concentrations of transformation products are a larger issue than concentrations of parent pesticides. Transformation products are more frequently detected and in higher concentration than parent pesticides.

Induced infiltration

- Induced infiltration is a key process affecting water quality of ground water from wells near streams and this is an issue across the study area. Many wells completed in the glacial-deposit aquifer are located near streams, especially in the coarse-grained valley-fill aquifers.
- Induced infiltration can potentially mobilize or immobilize arsenic (NECB and MIAM, respectively).
- Induced infiltration may increase pesticide concentrations in ground water because of high pesticides in surface water.

Nitrate

- Nitrate concentration in the glacial-deposit aquifer system exceeding 10 mg/L is an issue in the West and Central area, and selected areas in the East (such as HDSN and LINJ).
- Nitrates are more of an issue in the coarse-grained rather than the fine-grained deposits.

Radon and radium

- Radon is present in the glacial-deposit aquifer system across the study area, but often at low concentrations (between 50 and 500 pCi/L).
- Radon is a priority issue in NECB and WMIC (>1,000 pCi/L).
- Radium is not present where sampled (NECB and UIRB), although data are limited.

VOCs

- Volatile organic compounds are a priority issue in LINJ and CONN.
- Volatile organic compounds are detected in urban areas in the Central area (Chicago/Milwaukee, Detroit, St. Louis), but not at high concentrations.

Other issues discussed as potential water-quality issues include: radionuclides, bacteria, microbiologic contaminants, chloride, and boron. Ancillary issues, such as redox changes or denitrification in the aquifer may be critical in understanding the fate and transport of selected constituents in the glacial-deposit aquifer system.

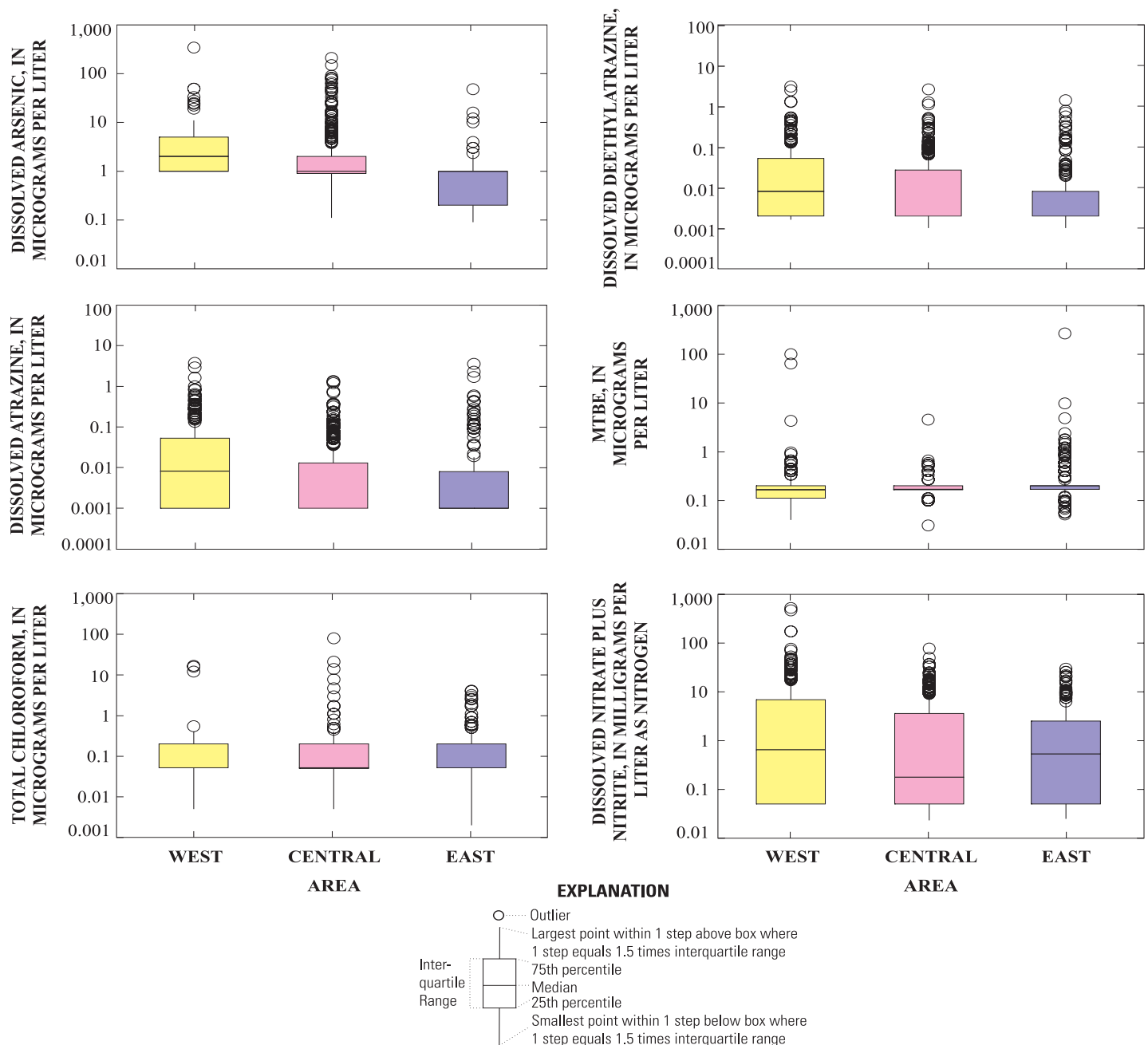


Figure 16. Range of concentrations of selected constituents (arsenic, atrazine, chloroform, deethylatrazine, MTBE, and nitrate) from NAWQA Cycle I data (glacial-deposit aquifer MAS and LUS data obtained from NAWQA data warehouse in November 2002).

Data from all NAWQA samples within the glacial-deposit aquifer system (from the NAWQA data warehouse) were retrieved for selected constituents of concern. A large effort was put into determining which wells were in the glacial-deposit aquifer system since there was no single parameter of 'principal aquifer'. Some NAWQA networks consisted of wells in bedrock and glacial material. The retrieval for all wells in the glacial-deposit aquifer was based on netcodes and lithologic or aquifer material. The samples were then assigned an area of east, central, or west based on the location of the netcode. Boxplots were developed to look at differences by area (fig. 16). The biggest difference for the selected constituents, by area, appears to be for arsenic. The area of east, central, and west is

delineated partly based on natural vulnerability--and differences in arsenic concentrations may be a reflection of these differences in natural vulnerability (ie., natural sources). Differences in trace element concentrations, such as arsenic, are likely due to differences in natural sources and conditions for mobilizing it.

Comparing ground-water data of similar age would facilitate the discussion of water-quality differences across the glacial-deposit aquifer system (fig. 17). Ground-water data collected as part of Cycle I was synthesized by Curtis Price (USGS, pers. commun., 2003), based on input from all study units. This data is not currently (3/3/03) in the NAWQA data warehouse, but there are plans to incorporate this data. The age data for the glacial-deposit aquifer system was determined based on netcode. In the glacial-deposit aquifer system, there are approximately 495 wells with tritium analyses, 187 wells with CFC analyses, 46 wells with tritium/helium analyses, and 38 wells with SF₆ analyses. The largest number of tritium samples were taken from 1996 to 1998 (over 430). The largest number of CFC analyses was in 1999 (83 analyses).

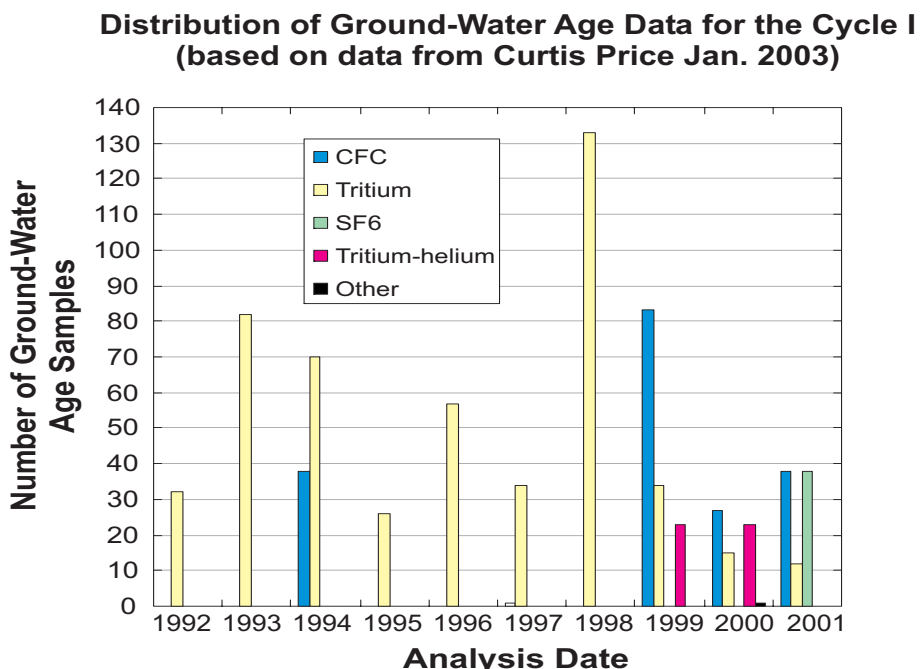


Figure 17. Ground-water age dating information collected by February 2003 (Curtis Price, U.S. Geological Survey, personal communication, 2003).

Key Points on Water-Quality Issues:

- Processes such as induced infiltration, redox, and dissolution are important across the region because the effect is not limited to one group of contaminants.
- Current definition of water-quality issues is based on knowledge of the data collected in NAWQA Cycle I studies and input from District hydrologists.
- The more precise age-dating for recently recharged ground water (CFC and tritium/helium) was completed by the 07 study units.

	WEST	CENTRAL	EAST
PROCESSES	Induced Infiltration		
	Chemical Dissolution		
	Redox		
	Arsenic		
CHEMISTRY	Pesticides		
	Nitrate		
	Radon		
	VOCs		

Figure 18. Water-quality issues within the regional glacial and alluvial aquifer system .

Cycle I Studies

Major aquifer studies

The objective of the major aquifer studies (MAS) (referred to as Study-Unit Survey (SUS) prior to 1999) is to assess the occurrence and distribution of the ground-water quality in the major aquifers within a study unit. The major aquifers were defined by the study units and prioritized by study units based on water use for domestic or public water supply. The distribution of MASs across the glacial-aquifer system is one of the only ways to address the gaps in a regional context (fig. 19-21).

Information on water use by aquifer is not available, but this information would help in prioritizing areas that need MASs. Major aquifer studies were distributed evenly among three study areas by water

use within the regional framework of valley fill deposits (6 MASs) and layer or lenses (8 MASs) in Cycle I (table 3 and table 4):

Major Aquifer Studies in valley fill deposits in Cycle I

- Three in the eastern area
- Two in the central area
- One in the western area

Major Aquifer Studies in layers or lenses in Cycle I

- None in the eastern area.
- Four in the central area
- Four in the western area (although 3 of these were in the REDN which is not a CycleII study

unit)

Key Points on MAS:

- There are no MASs in layer or lenses in the east area because this physical setting is not present.
- Another MAS in the central area in valley-fill deposits and the west area in valley-fill deposits would be useful for the regional characterization of occurrence and distribution in valley-fill deposits of the glacial-deposit aquifer system.

East Glacial Region

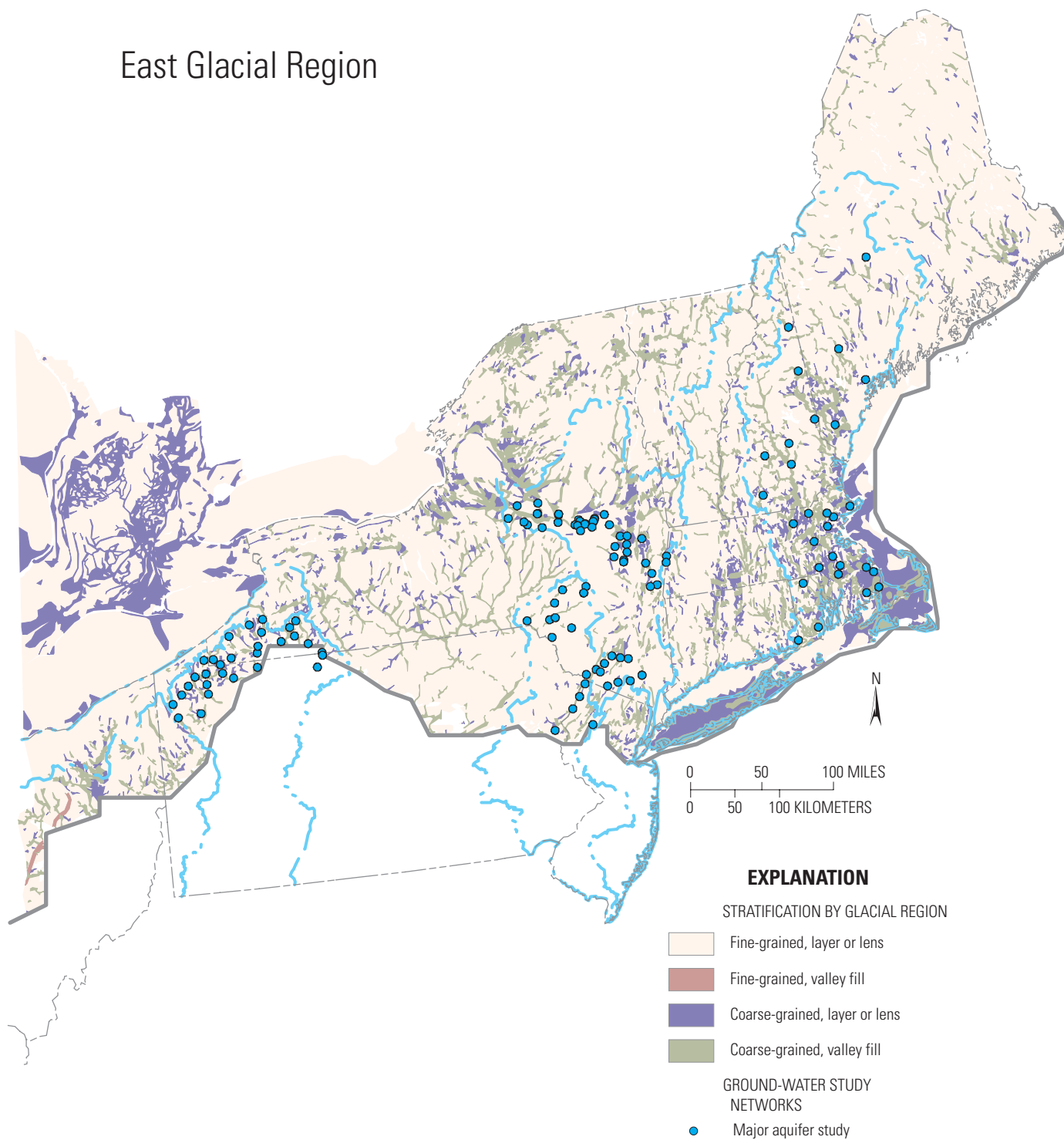


Figure 19. Location of major aquifer study (MAS) wells in the eastern area of the glacial and alluvial aquifer system.

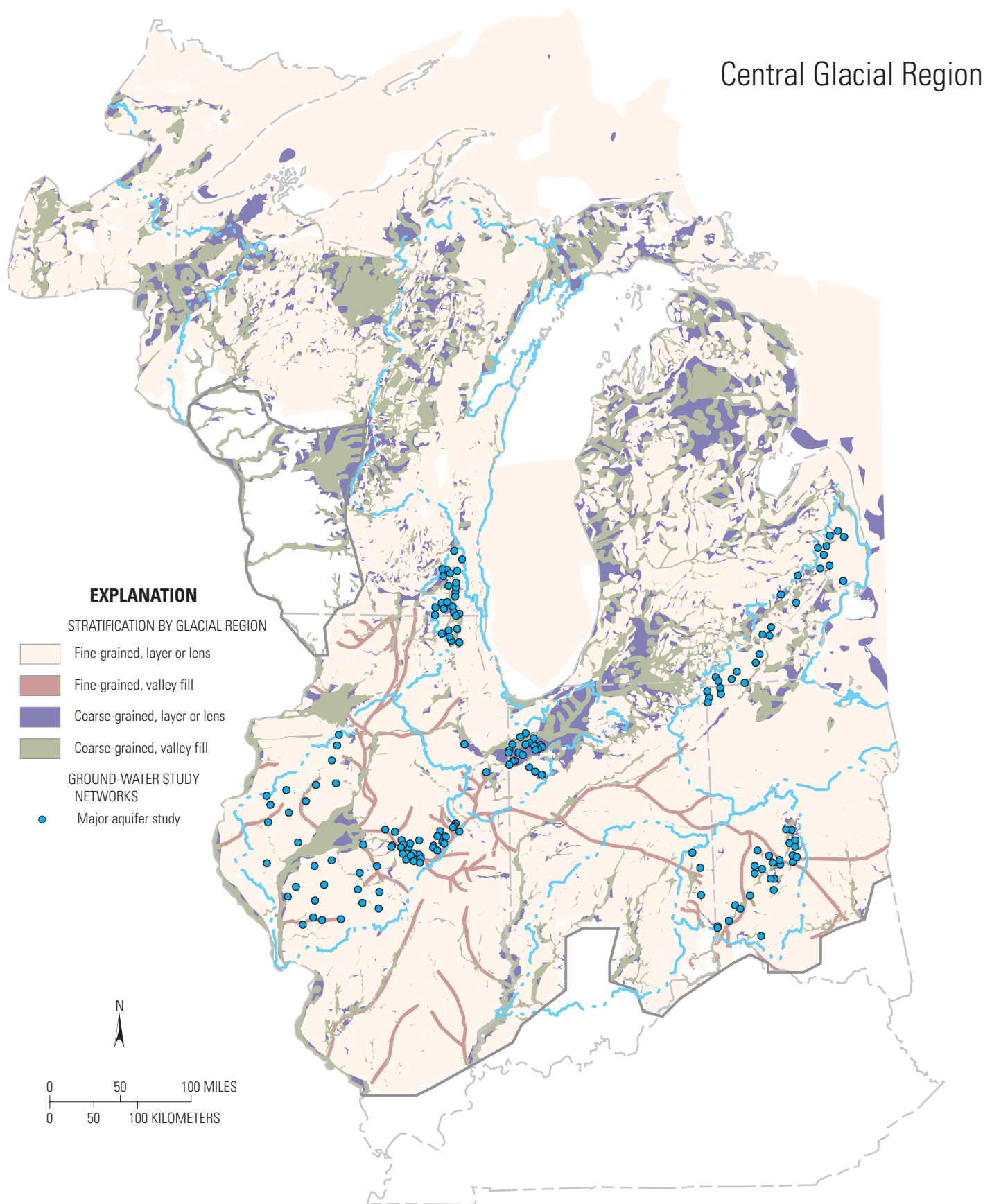


Figure 20. Location of major aquifer study (MAS) wells in the central area of the glacial and alluvial aquifer system.

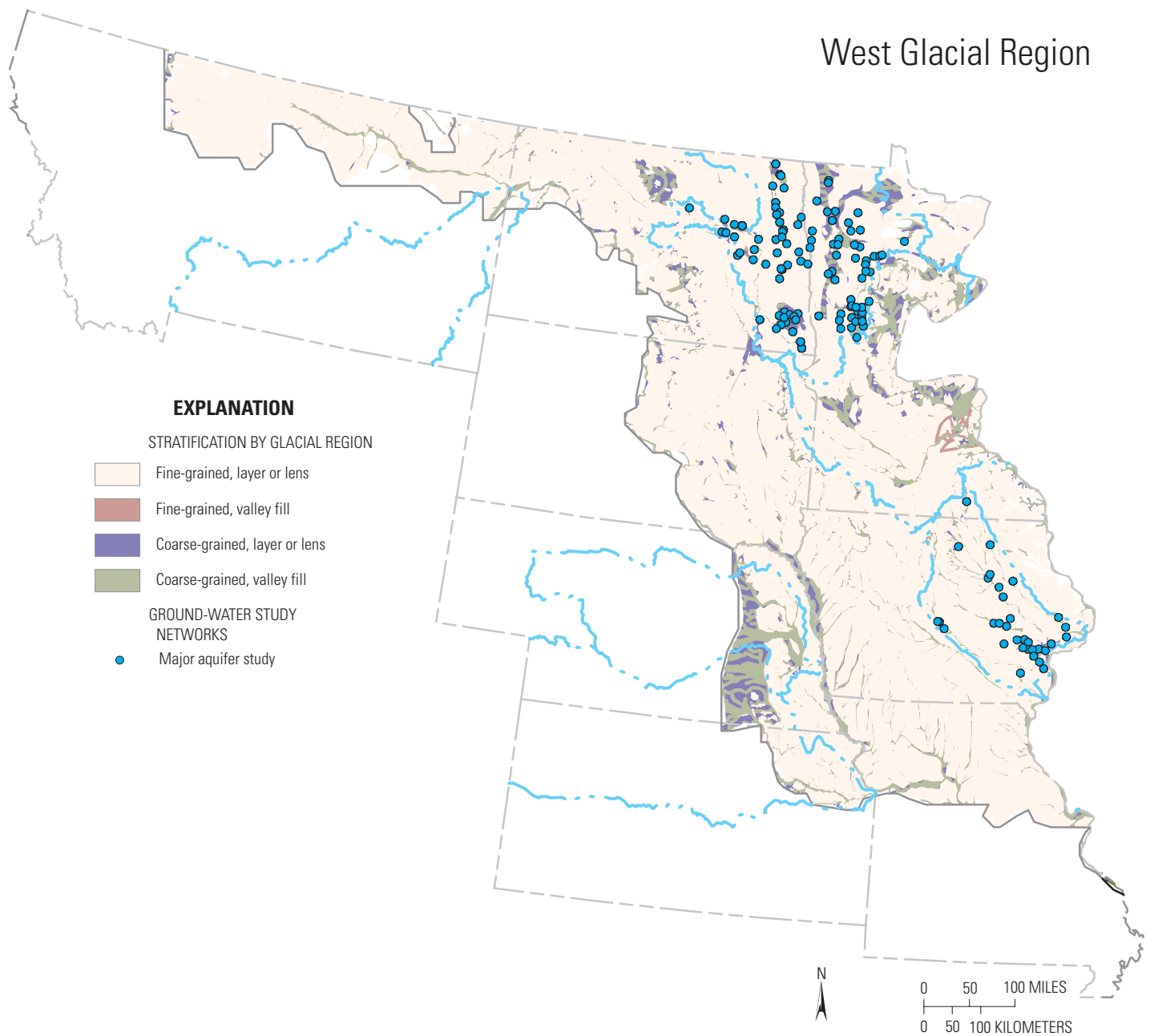


Figure 21. Location of major aquifer study (MAS) wells in the western area of the glacial and alluvial aquifer system.

Table 3. Ancillary information on major aquifer studies in the glacial and alluvial aquifer system (originally from June 2002 and updated from gwplan.xls in January 2003).

AREA	SURFICIAL MATERIAL	VALLEY OR LAYER	CYCLE II RESTART YEAR	NETCODE	# WELLS	TRENDS IN NETWORK IN CYCLE II TRENDS	OTHER NESTED PROGRAM TANC	OTHER NESTED PROGRAM SWA
CENTRAL	COARSE	LAYER	--	UIRBSUS1	23	NO	--	--
CENTRAL	COARSE	LAYER	1	WMICSUS2	30	NEW	--	--
CENTRAL	COARSE	VALLEY	1	MIAMSUS1	30	YES (cycle III)	--	--
CENTRAL	FINE	LAYER	4	LERISUS1	28	YES	--	--
CENTRAL	FINE	LAYER	--	LIRBSUS2	27	NO	--	--
CENTRAL	FINE	LAYER	--	UIRBSUS2	27	NO	--	--
CENTRAL	FINE	VALLEY	4	LIRBSUS1	30	YES	--	--
EAST	COARSE	VALLEY	--	ALMNSUS2	30	NO	--	--
EAST	COARSE	VALLEY	1	CONNSUS2	30	NEW	CONNtanc	CONNdwgs1
EAST	COARSE	VALLEY	--	DELRSUS3	16	NO	--	--
EAST	COARSE	VALLEY	7	NECBSUS3	30	YES	--	--
EAST	COARSE	VALLEY	--	HDSNSUS1	46	NO	--	--
EAST	FINE	VALLEY	4	HDSNSUS2/CONNSUS3	NA	NEW	--	--
WEST	COARSE	LAYER	1	HPGWSUS4	30	NEW	--	--
WEST	COARSE	LAYER	--	REDNSUS1	29	NO	--	--
WEST	COARSE	LAYER	--	REDNSUS2	25	NO	--	--
WEST	COARSE	LAYER	--	REDNSUS3	24	NO	--	--
WEST	COARSE	LAYER	--	REDNSUS4	42	NO	--	--
WEST	COARSE	VALLEY	4	EIWASUS2	32	YES	--	--

Table 4---Number of wells in Major Aquifer Surveys (MAS) by State (from file table_mas_state_count_120302.xls in December 2002).

	Major Aquifer Study Wells by State																			
	IA	ID	IL	IN	KS	MA	MD	ME	MI	MN	MO	ND	NE	NH	NJ	NY	OH	PA	RI	WI
Su Code Summ																				
almnsus2																14		16		
delrsus3															1	9		6		
eiwasus2	31									1										
hdsnsus1																48				
lerisus1									23								5			
lirbsus1			30																	
lirbsus2			30																	
miamsus1				3													27			
necbsus3						16		4						7					3	
rednsus1										7		13								
rednsus2										22										
rednsus3												14								
rednsus4										19		23								
uirbsus1			7																	20
uirbsus2			2	21																

Land-Use Studies

The objective of the Land-Use Studies (LUS) is to assess the affect of land use on shallow ground-water quality. The LUS are designed to examine natural and human factors that affect the quality of shallow ground water that underlies key types of land use (Lapham and others, 1995). The wells are in the uppermost part of the glacial-deposit aquifer system, generally with the top of screen just below the lowest anticipated level of the water table (figs. 22-24). Most land-use wells were installed as 2" monitoring wells. Well location was based on targeted land use over a major aquifer. The design of previously sampled and planned land-use studies shows the distribution of studies to be 58% (18 studies) in agricultural areas, 35.5% (11 studies) in urban areas, and 6.5 percent (2 studies) in forest areas that is similar to the percent land use overlying the glacial-deposit aquifer system.

Land-use studies in the urban areas for Cycle I included Chicago/Milwaukee, Indianapolis, Dayton, Detroit, Manchester/Hamden, Albany, Boston, Minneapolis, and other smaller cities in Iowa (table 5). Agricultural areas were widespread in the central and western areas. The areas covered by land-use studies in the REDN and UMIS are smaller in aerial distribution than in other study units. The urban LUS wells in the glacial-deposit aquifer were monitoring (258 wells), public supply (8), and other well types (2) in Cycle I. The agriculture LUS wells were monitoring (449), domestic (5), and other (2) in Cycle I. Three land-use studies in the central area and one in the western area were completed in fine-grained deposits, but none of the land-use studies in the east were in fine-grained deposits.

Key Points on Cycle I LUS:

- The urban land-use studies address most major cities except NYC.
- Land-use studies in fine-grained deposits are most common in the central area.
- More LUSs are completed in agricultural land-use areas than other areas.

East Glacial Region

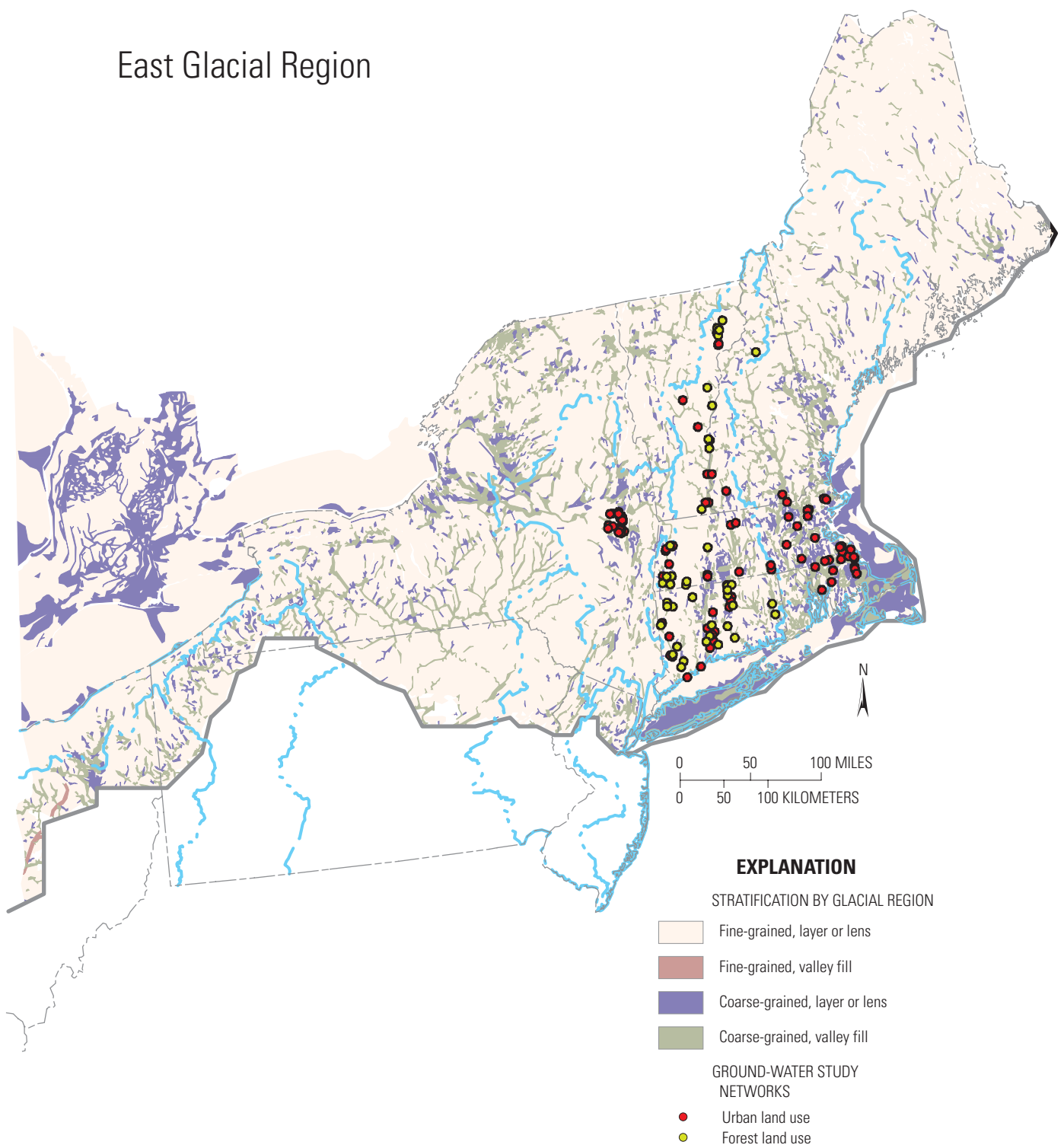


Figure 22. Location of land-use study (LUS) wells in the eastern area of the glacial and alluvial aquifer system.

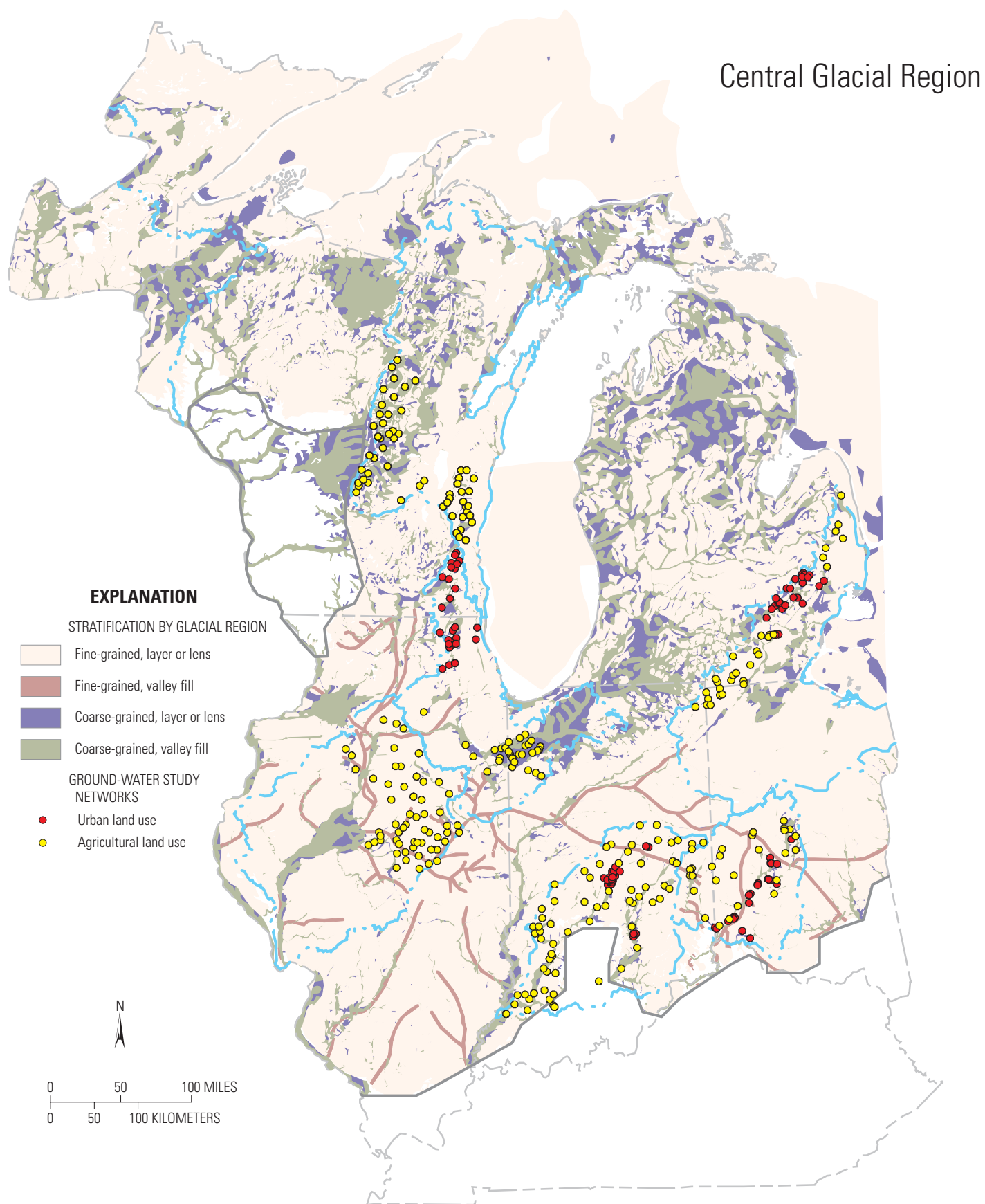


Figure 23. Location of land-use study (LUS) wells in the central area of the glacial and alluvial aquifer.

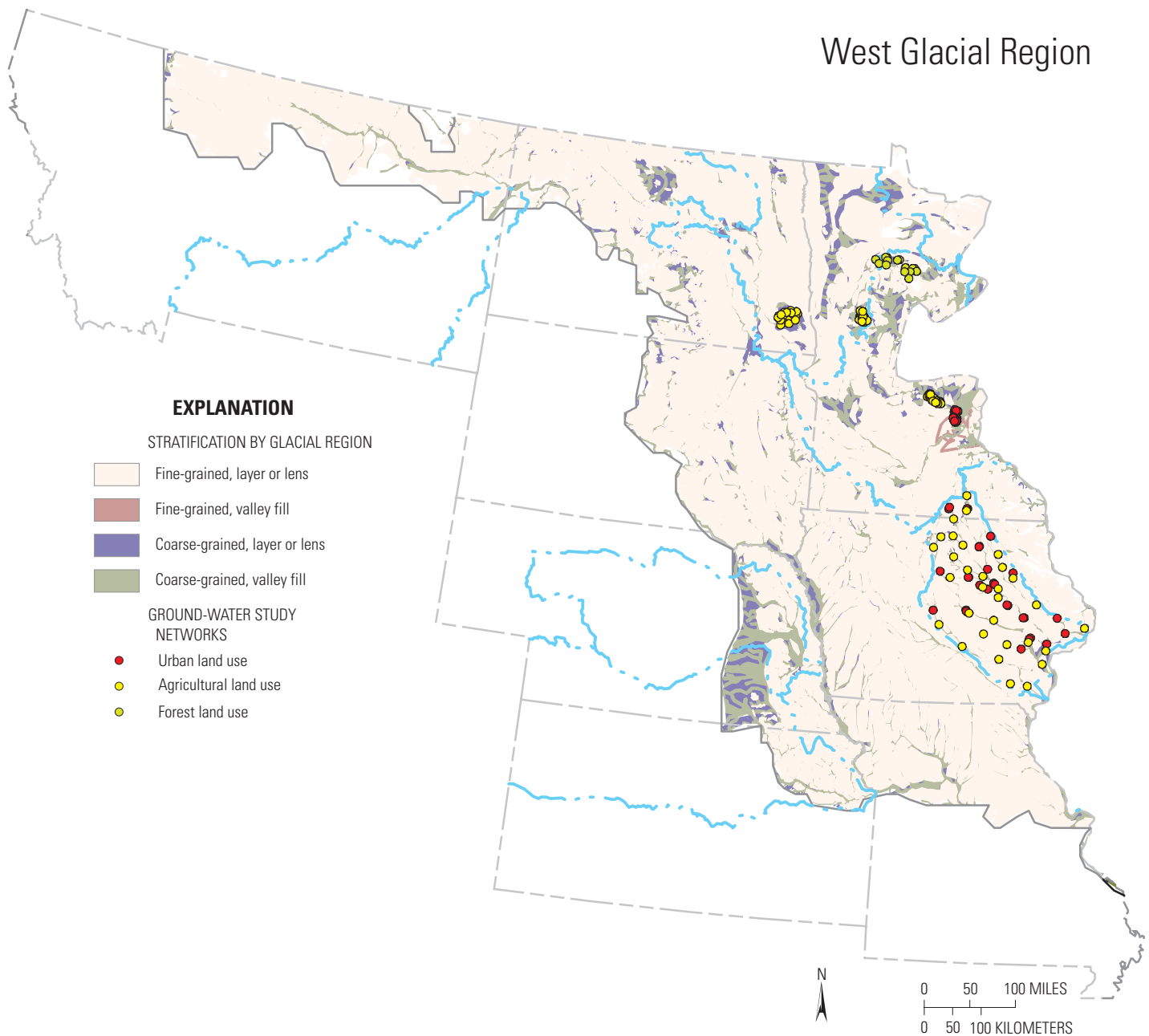


Figure 24. Location of land-use study (LUS) wells in the western area of the glacial and alluvial aquifer system.

Table 5. Land-use studies in the glacial and alluvial aquifer system (June 2002)*.

AREA	SURFICIAL MATERIAL	VALLEY OR LAYER	NAME	CYCLE II YEAR	NETCODE	# WELLS	TRENDS IN NETWORK IN CYCLE II				MAJOR LAND USES (CITY or CROP)	AVERAGE 1990 POPULATION (PEOPLE PER KM2) **
							TRENDS RANK	TOPICAL TANC	FLOW PATH RANK*	SWA***		
CENTRAL	COARSE	LAYER	URBAN	4	LERILUSRC1	30	YES (10)	--	FLOW (13)	--	DETROIT	266.38
CENTRAL	COARSE	LAYER	AG	7	UIRBLUSCR1	23	YES (2)	--	FLOW (9)	--	CROP70	--
CENTRAL	COARSE	LAYER	AG	1	WMICLUSAG2	28	YES	--	FLOW (12)	--	CROP50	13.4
CENTRAL	COARSE	VALLEY	AG	1	MIAMLUSCR1	26	YES (89)	--	--	--	CROP70	--
CENTRAL	COARSE	VALLEY	URBAN	1	MIAMLUSRC1	--	YES (CycleIII)	--	--	--	DAYTON	--
CENTRAL	COARSE	VALLEY	AG	1	WHITLUSCR3A	24	--	--	FLOW (33)	--	CROP70	111.93
CENTRAL	COARSE	VALLEY	URBAN	1	WHITLUSUR1	--	--	--	--	--	INDIANAPOLIS	--
CENTRAL	COARSE	VALLEY	URBAN	1	WHMILUSRC1	--	--	--	--	--	INDIANAPOLIS	--
CENTRAL	FINE	LAYER	AG	4	LERILUSCR1	30	--	--	--	--	CROP70	111.74
CENTRAL	FINE	LAYER	AG	4	LIRBLUSCR1	28	--	--	--	--	--	38.12
CENTRAL	FINE	LAYER	AG	4	LIRBLUSCR2	29	--	--	--	--	--	24.9
CENTRAL	FINE	LAYER	URBAN	7	UIRBLUSRC1	26	YES (5)	--	FLOW (24)	--	CHICAGO	--
CENTRAL	FINE	LAYER	AG	1	WHITLUSCR1	21	YES (4)	--	FLOW(4)	--	CROP70	133.92
CENTRAL	FINE	LAYER	AG	1	WHITLUSCR2	19	YES (9)	--	--	--	CROP70	22.23
CENTRAL	FINE	LAYER	AG	1	WMICLUSAG1	23	YES (8)	--	--	--	CROP50	49.8
CENTRAL	FINE	VALLEY	URBAN	4	LIRBLUSRC1	NEW	YES (NEW)	--	FLOW (34)	--	ST. LOUIS	--
EAST	COARSE	LAYER	URBAN	4	LINJLUSURB3	NEW	YES (NEW)	--	FLOW (28)	--	NYC	--
EAST	COARSE	VALLEY	AG	1	CONNLUSAG1	40	YES(7)	--	--	--	?	--
EAST	COARSE	VALLEY	FOREST	1	CONNLUSFO1	--	--	--	--	--	--	--
EAST	COARSE	VALLEY	URBAN	1	CONNLUSRC1	--	--	--	--	CONNdwgs1	--	--
EAST	COARSE	VALLEY	URBAN	1	CONNLUSURB1	--	--	--	--	--	--	--
EAST	COARSE	VALLEY	AG	4	HDSNLUSAG1	--	--	--	--	--	--	--
EAST	COARSE	VALLEY	URBAN	4	HDSNLUSUR	--	--	--	--	--	--	--
EAST	COARSE	VALLEY	URBAN	7	NECBLUSRC1	25	YES (7)	--	FLOW (17)	--	BOSTON	--
WEST	COARSE	LAYER	AG	1	HPGWLUSAG3	NEW	YES (NEW)	--	--	--	--	--
WEST	COARSE	LAYER	AG	NS	REDNLUSAG2	29	--	--	--	--	CROP30	1.17
WEST	COARSE	LAYER	AG	4	UMISLUSCR1	28	YES (3)	--	FLOW (15)	--	CROP70	--
WEST	COARSE	LAYER	FOREST	4	UMISLUSFO1	15	--	--	--	--	FOREST10	19.36
WEST	COARSE	LAYER	URBAN	4	UMISLUSRC1	27	YES (3)	--	FLOW(4)	--	MINNEAPOLIS	143.5
WEST	COARSE	VALLEY	AG	4	EIWALUSCR1	31	YES (7)	--	FLOW (18)	--	CROP70	33.24
WEST	COARSE	VALLEY	URBAN	4	EIWALUSRC1	--	--	--	--	--	--	--
WEST	FINE	LAYER	AG	1	CNBRLUSAG1	NEW (20-22)	YES (NEW)	ACT study	FLOW PLANNED	--	--	--

* From NITCycleIIguidance.xls last update listed on the Web as 6/02

**From Molly's worksheet Molly_wu_gw_000609.xls on 7/01

*** From groundwater_cycleII_nov0601_pz0c5io5.xls from Web updated

Cycle II Plans

Status and Trends

Studies planned in the glacial-deposit aquifer system are illustrated in figure 25 and 26, and summarized in table 6 and 7. The NIT plan for Cycle II has slightly more agricultural studies (networks), than urban studies (fig. 25). The biennial trend sampling includes the same number (30) of urban and agricultural land use wells (except for the larger number of agricultural sites in WHMI? -- see table 7) and an equal number of MAS sites.

There are 8 new studies planned in the glacial-deposit aquifer system: 4 MAS, 3 Urban LUS, and 1 Ag LUS (table 6 and fig. 26).

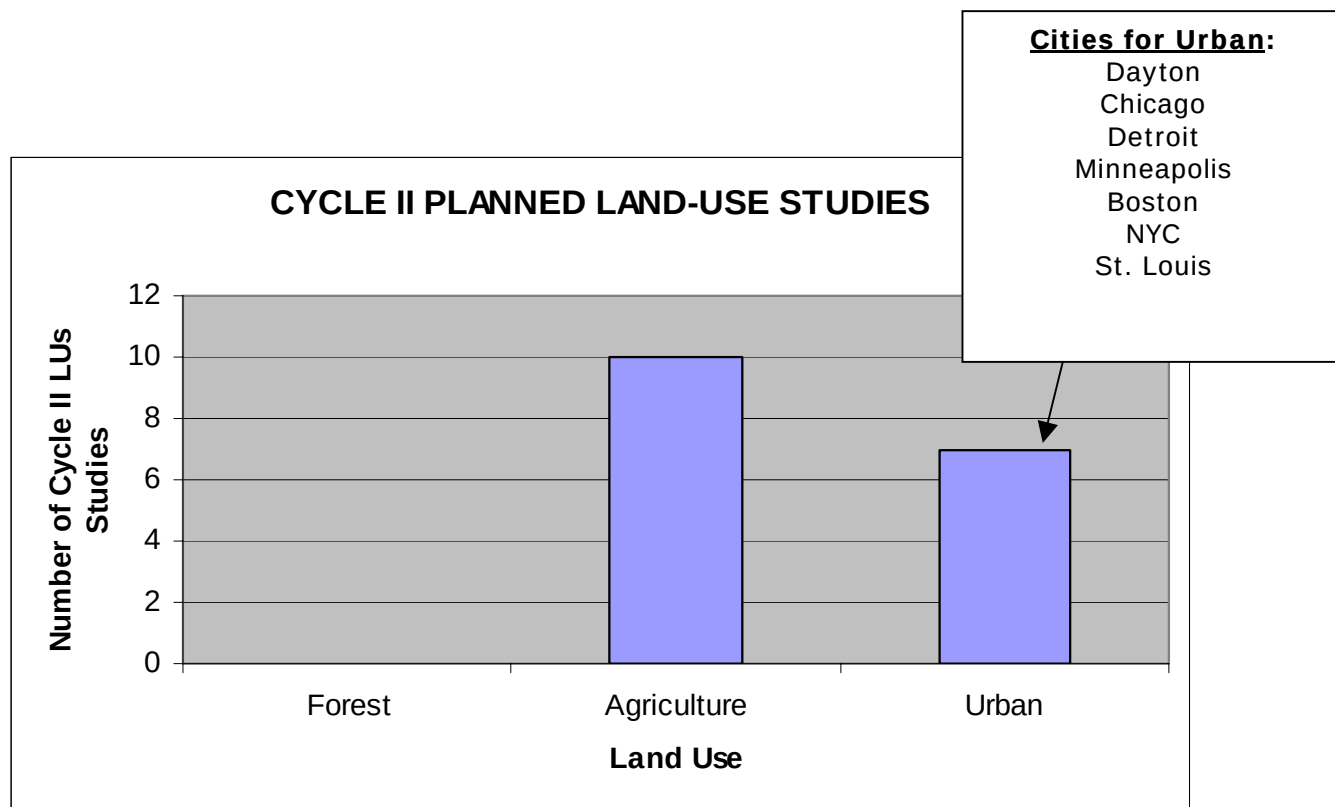


Figure 25. Distribution of land-use studies in NAWQA Cycle II by major land-use category as projected in the NIT plan.

Table 6. The NAWQA cycle I accomplishments, cycle II plans, and GAPT planning team recommendations. [Data from ground-water planning data base January 2003--modified PA for hpgwsus4 and kanslusag. Flow path recommendations from file TgwFSS. GAPT recommendations are in underlined blue type.] **GAPT needs to prioritize.**

Aquifer System		Pilot and Cycle I			Cycle II									TANC	ACT
		Occurrence and Distribution			New Status			Trends							
		MAS	LUS	FPS	NMAS	NLUS	SWA	RMAS	RLUS	RFPS	RSWA				
East	Fine-grained at land surface				hdsnsus2		Albany								
East	Coarse-grained at land surface	almnsus2 delrsus3 necbsus3	connlusag1 connlusfo1 hdsnlusag1 hdsnlusur necblusrc1 connlusurb1	connfps1	connsus2	linjlusurb3 connlusrc1 hdsnlusag	Hartford/ Springfield CT Boston Providence NYC NYC-Long Island	necbsus3	necblusrc1	connlusrc1 necblusrc1		conntanc1 linjlusurb3			
Central	Fine-grained at land surface	lerisus1 lirbsus1 lirbsus2 uirbsus2	leriluscr1 lirbluscr1 lirbluscr2 uirbluscr1 whitluscr1 whitluscr2 wmiclusag1	whitfpsag1 whitfpsag2		lirbluscr1	Chicago/ Milwaukee St Louis Detroit	lerisus1 lirbsus1	whitluscr1 uirbluscr1	whitluscr1		lirbsus1	whitluscr1		
Central	Coarse-grained at land surface	miamnsus1 uirbsus1 wmicnsus2 lerispcg1 miamspcb1	leriluscr1 miamluscr1 uirbluscr1 whitluscr3a whitlusur1 whmiluscr1 wmiclusag2 miamluscr1		wmicnsus2 lirbsus3		whmidwgs1 Peoria	miamnsus1 lirbsus3	miamluscr1 miamluscr1 wmiclusag2 leriluscr1 uirbluscr1	wmiclusag2 uirbluscr1 leriluscr1	whmidwgs1	whmidwgs1- miamnsus1- miamluscr1			
West	Fine-grained at land surface				EIWA till	cnbrlusag1	Quad Cities-- Moline, Davenport, Bettendorf, and Rock Island Des Moines							cnbrlusag1	
West	Coarse-grained at land surface	eiwasus2 redn redn hpgwsus4	eiwaluscr1 eiwalusrc1 rednlusag2 umisluscr1 umislusfo1 umislusrc1 eiwaspgw1		hpgwsus4	hpgwlsusag3 kansluscr	Minneapolis Cedar Rapids York, NE Waterloo/Cedar Falls in hpgwsus4	eiwasus2	eiwaluscr1 umisluscr1 umisluscr1 eiwaspgw1	hpgwsus4 eiwaluscr1 umisluscr1 umisluscr1		hpgwsus4		hpgwsus4	

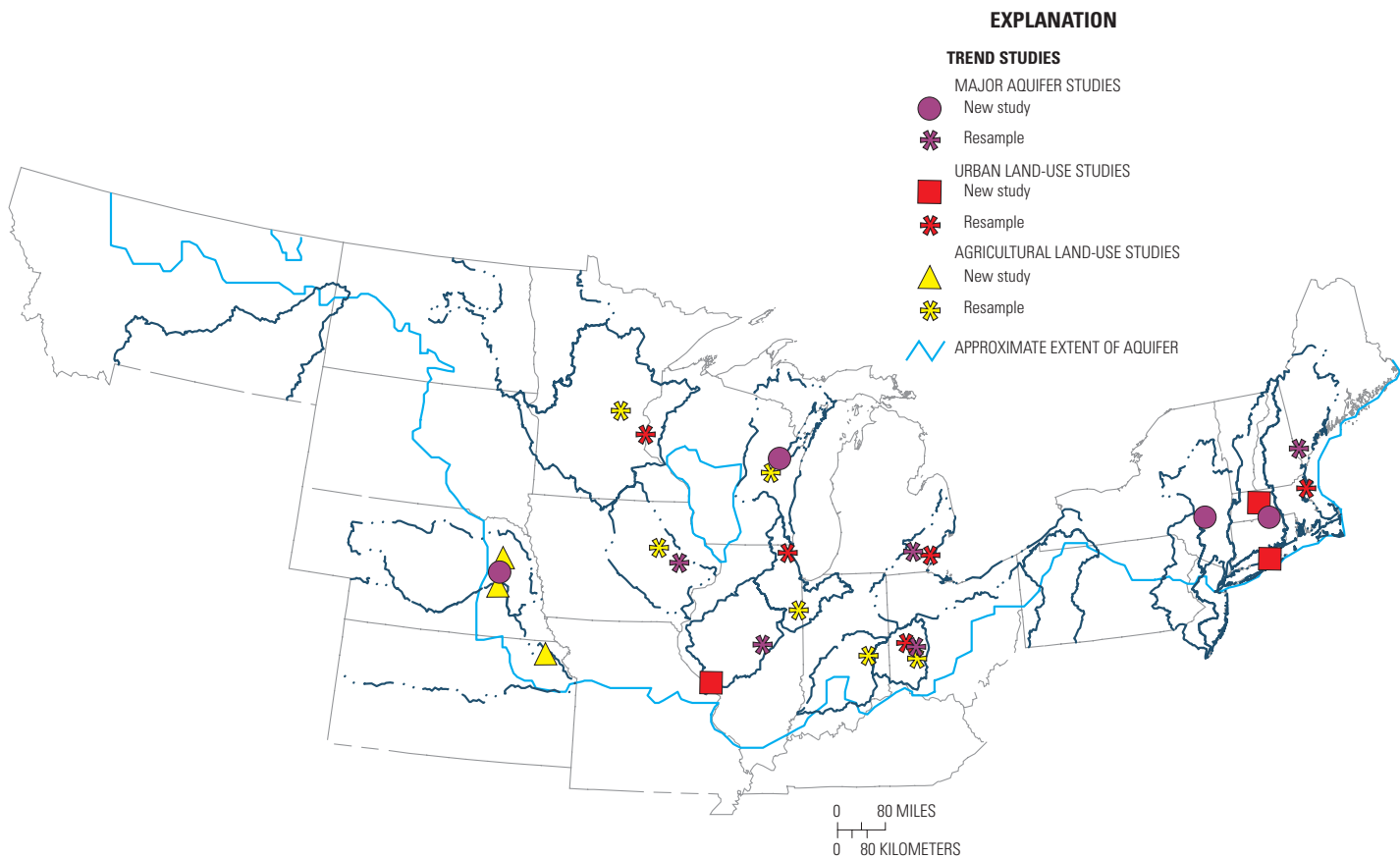


Figure 26. Location of trend sites in Cycle II as proposed in the NIT plan and shown in the NAWQA ground-water planning database (January 2003).

Key Points on Status and Trends:

Recommendations developed by the GAPT have been incorporated into the NIT plan as follows:

- Drop the initial Urban LUS proposed for Milwaukee because it is redundant with the Chicago/Milwaukee Urban LUS planned for resampling by the UIRB.
- Develop two HDSN/CONN MASs that would be complimentary. The assessment of aquifers under the fine-grained deposits in the eastern area is lacking. The first MAS, which is to be done by the CONN, would concentrate on coarse-grained sediments at the land surface and the second MAS, to be done by the HDSN, would concentrate on the fine-grained deposits at the land surface. (Because of time constraints and lack of information, the MAS initiated by the CONN was not able to incorporate areas in the HDSN.) There still needs to be work done, before the HDSN MAS is initiated, to assess if the ground-water resource under the fine-grained deposits is used for drinking water.

The following are comments/recommendations not currently (6/17/03) included in NIT plan:

- New work in the eastern area coarse-grained deposits is not a regional priority because this is not a data gap. There are an abundance of studies in the eastern area looking at coarse-grained deposits in valley-fill material.
- There is an absence of agricultural land-use studies in the eastern area for Cycle II. HDSN may be a likely candidate for an agricultural land-use study.
- Coarse-grained layers and lenses in the central area, such as Green River lowland near the Quad Cities or the Havana lowland near Peoria, are not well characterized in the present NIT plan.

Table 7. Trend samples by network type (adapted from gw planning data base in January 2003).

TRENDS - Biennial Sampling

(from GW Planning Database on 1/6/03)

	<u>Number of</u> <u>MAS wells</u>	<u>Number of</u> <u>Urban LUS</u> <u>wells</u>	<u>Number of Ag</u> <u>LUS wells</u>	<u>Number of</u> <u>Reference</u> <u>Wells</u>	<u>Sample Year</u>
CNBR			5	3	2004
CONN	5	5		3	2004
DELR					
EIWA	5		5	3	2002
HDSN					
HPGW					
KANS					
LERI	5	5			2002
LINJ					
LIRB	5				2002
NECB	5	5		2	2003
UIRB		5	5	1	2003
UMIS		5	5	3	1999, 2000, 2001, 2002
WHMI	5	5	20	4	1999, 2000, 2004
WMIC			5	2	2004

Source-water assessment studies

The NAWQA source-water assessment (SWA) component is part of the status and trends networks. These studies are new to Cycle II and focus on source water in major metropolitan areas. Generally, there is a SWA study where there is a TANC study, but also there are SWA in areas not included in TANC. The attached table shows the cities originally considered for inclusion in the SWA studies (Table 8) (Rick Clawges, USGS, pers. commun., 2002). It is estimated that there will be 10 SWA in the glacial-deposit aquifer system. Fifteen of the 22 suggested study areas are within 04 study unit boundaries.

Three areas have been selected in for the 01 studies. These include small towns in the HPGW, Hartford/Springfield in the CONN and Dayton in the WHMI. The city of Dayton was not one of the metropolitan areas originally considered for inclusion in the source-water studies, but Dayton is nested within a MAS and a TANC special study.

Table 8. Cities overlying the glacial-deposit aquifer system considered for NAWQA source-water assessment study (data from Rick Clawges, 2002, and updated with GAPT recommendations).

GAPT Recommended Priority (priority 1 means study already underway)	Study				Other aquifer used in area
	State	City	Unit	Glacial Region	
	1 CO-NE	Small towns	HPGW	C	
	1 CT	Hartford/Springfield	CONN	E	
	IA	Cedar Rapids	EIWA	W	
	IA	Des Moines	EIWA	W	
	IA	Waterloo/Cedar Falls	EIWA	W	
	IA-IL	Quad Cities	EIWA	W	Silurian
	IL	Bloomington-Normal	LIRB	C	--
	IL	Champaign			--
	IL	Chicago/Milwaukee	UIRB	C	Cambrian- Ordovician
	IL	Peoria	LIRB	C	--
	IL	Rockford	UIRB	C	Cambrian- Ordovician
	1 IN	Dayton	WHMI	C	--
	IN	Decatur	LERI	C	--
	IN	Indianapolis	WHMI	C	
	KS-MO	Kansas City	KANS	W	
	MA	Boston	NECB	E	
	ME	Portland and surrounding areas	NECB	E	
	MI	Detroit	LERI	C	
	MN	Minneapolis-St. Paul	UMIS	W	Cambrian- Ordovician
	MO-IL	St. Louis	LIRB	C	
	1 NE	York	CNBR	W	
	NY	Albany	HDSN	E	
	NY	New York City	LINJ	E	
	NY	NYC--Long Island	LINJ	E	NACP
	OH	Akron	LERI	C	
	RI	Providence	NECB	E	

Process and Understanding

The process and understanding topics that relate to ground water are the Transport of Natural and Anthropogenic Contaminants to Community-supply (TANC) wells and Agricultural Chemical Transport (ACT) (table 9). There are ACT studies in the WHMI, and HPGW. It is estimated that there would be between 6-10 TANC studies in the glacial-deposit aquifer system. There are 2 TANC studies in the 01 study units that include small-scale work in the CONN and WHMI (from <http://dg73dohclb.er.usgs.gov/tanc/> in summer 2002). The small-scale work of TANC is detailed and process-oriented, while the large-scale work is a regional analysis of chemical transport to public-water supplies. The goal of TANC is to determine the primary anthropogenic and natural contaminant sources, aquifer processes, and well characteristics that affect the transport and transformation of contaminants along flow paths to representative aquifers used for water supply. This goal is to be accomplished through the objectives listed below (Sandy Eberts, USGS, pers. commun., 12/30/02):

- **Objective 1:** Characterize anthropogenic activities, and geologic and hydrologic factors that are related to sources of contaminants in aquifers used for water supply.
- **Objective 2:** Determine how hydrologic factors that affect the physical transport of contaminants.
- **Objective 3:** Identify the primary chemical characteristics and transformation processes that affect concentrations of contaminants along dominant flow paths from recharge areas to supply wells.
- **Objective 4:** Evaluate the effects of well characteristics and well-field management on the transport of contaminants to supply wells.
- **Objective 5:** Determine which factors can be used for extrapolation to areas with little or no water-quality data and define strategies that can be used to prevent/reduce the likelihood of contamination of supply wells.

Table 9. Potential process and understanding work planned in the 2001 study units within the glacial and alluvial aquifer system.

Tentative Topical Team Assignments for 01 Study Units - Subject to Change						
				Transport of Natural and Anthropogenic Contaminants to Community Supply Wells		
SU	Agricultural Chemicals	Nutrient Enrichment	Urban Stream Ecosystems	Arsenic	Anthropogenic Contaminants	Mercury Accumulation
CNBR	Yes	Yes	No	Yes	Yes	No
CONN	No	No	Yes	Yes	Yes	Yes
WHMI	Yes	Yes	No	Yes	Yes	Yes
WMIC	No	Yes	Yes	No	No	Yes

Reports

Cycle I Reports

Reports published by study units on Cycle I data were summarized in a spreadsheet based on FY03 workplans. The purpose of the literature review is to identify gaps in publishing of NAWQA ground-water research, and to help identify which SU having expertise in a given topic based on previous publications. It is the goal of the GAPT to help make recommendations for regional reports and identify potential key researchers for a given topic.

A review of reports completed in Cycle I and those planned for Cycle II is given in figure 27. All reports listed in FY03 workplans that are related to ground water, within the glacial-deposit aquifer system, based on the report title were included in summarizing published material. The study units with most reports published on pesticides included CNBR, EIWA, HDSN, and MIAM. The study units with most reports published on volatile organic compounds include CONN and UMIS. The LINJ had the most reports on VOCs, but none of the cycle I data in the LINJ was from the glacial-deposit aquifer. The study unit with most reports published on trace elements is the LIRB. The other study units generally had even distribution of reports by category (generally one report in various categories).

Key Points on Cycle I Reports:

- Most reports for Cycle I focused on pesticides, although a large number of reports were on topics related to VOCs in ground water.
- Few reports were published on trace elements.
- Published report emphasis varied by study unit: 4 SU had a focus on pesticides, 3 SU had a focus on VOCs, and 1 SU had a focus on trace elements. Various study units published multiple reports on nutrients.

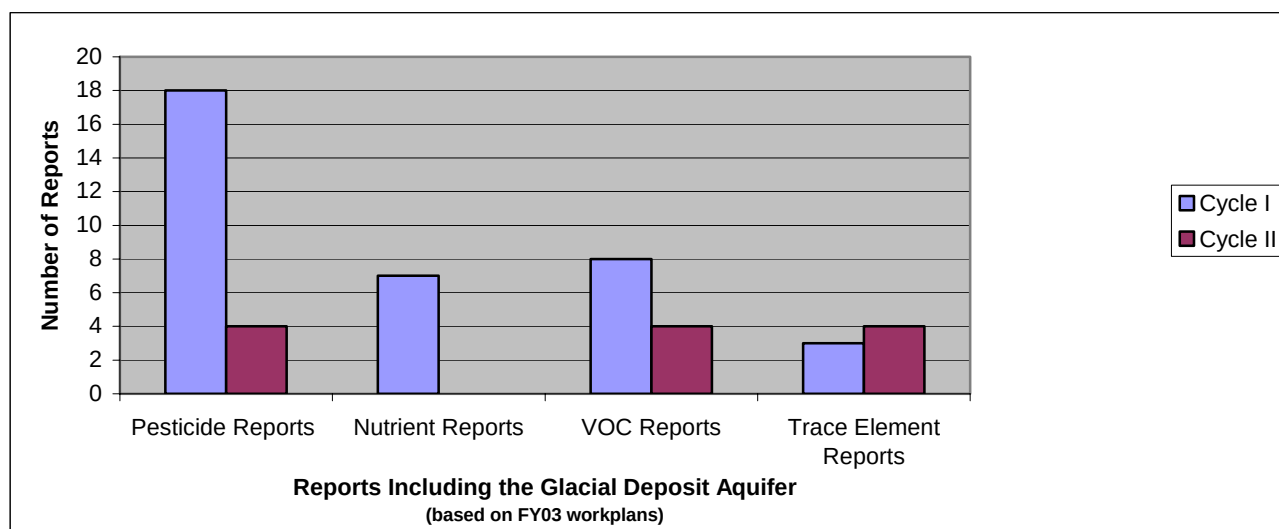


Figure 27. Reports written in Cycle I and planned reports for the '01 study units for Cycle II based on FY03 workplans (note that this does not include completed reports in the '01 SU because they were not available in the workplans).

Table 10. Number of ground-water reports (relating to the glacial and alluvial aquifer system) by study unit and chemical-quality topic.

Study Units in the Glaciated Area	Pesticide	Nutrient	VOC	Trace Element
	reports in glacial	reports in glacial	reports in glacial	reports in glacial
CNBR		2		
CONN				3
DELR				2
EIWA	5	3		
HDSN	3			
HPGW				
KANS				
LERI	1	1	1	
LINJ				
LIRB	3	1	1	3
NECB			1	
UIRB	1			
UMIS	3	2	4	
MIAM	2		1	
WHMI	1			1
WMIC	2	2	1	

Cycle II Reports

The GAPT proposes that a "summary-type" report be written that summarizes the Cycle I occurrence data for the glacial-deposit aquifer system. This report would allow work done in Cycle II to be compared or included within the glacial-deposit aquifer system based on water-quality data collected in Cycle I. This type of regional summary of NAWQA data has not been done in the past, but should be consistent among regional aquifers. A "summary-type" report for each principal aquifer would limit the redundancy of regional analyses by many study-units and allow a comparison between and within a principal aquifers. A report team of representatives from various study units would need to be established.

Key Points on Cycle II Reports:

- A regional summary report of Cycle I data needs to be completed for the glacial-deposit aquifer system.
- Reports related to water-quality affects from induced infiltration may be a key issue for cycle II.
- GAPT needs to develop a proposed regional report list.

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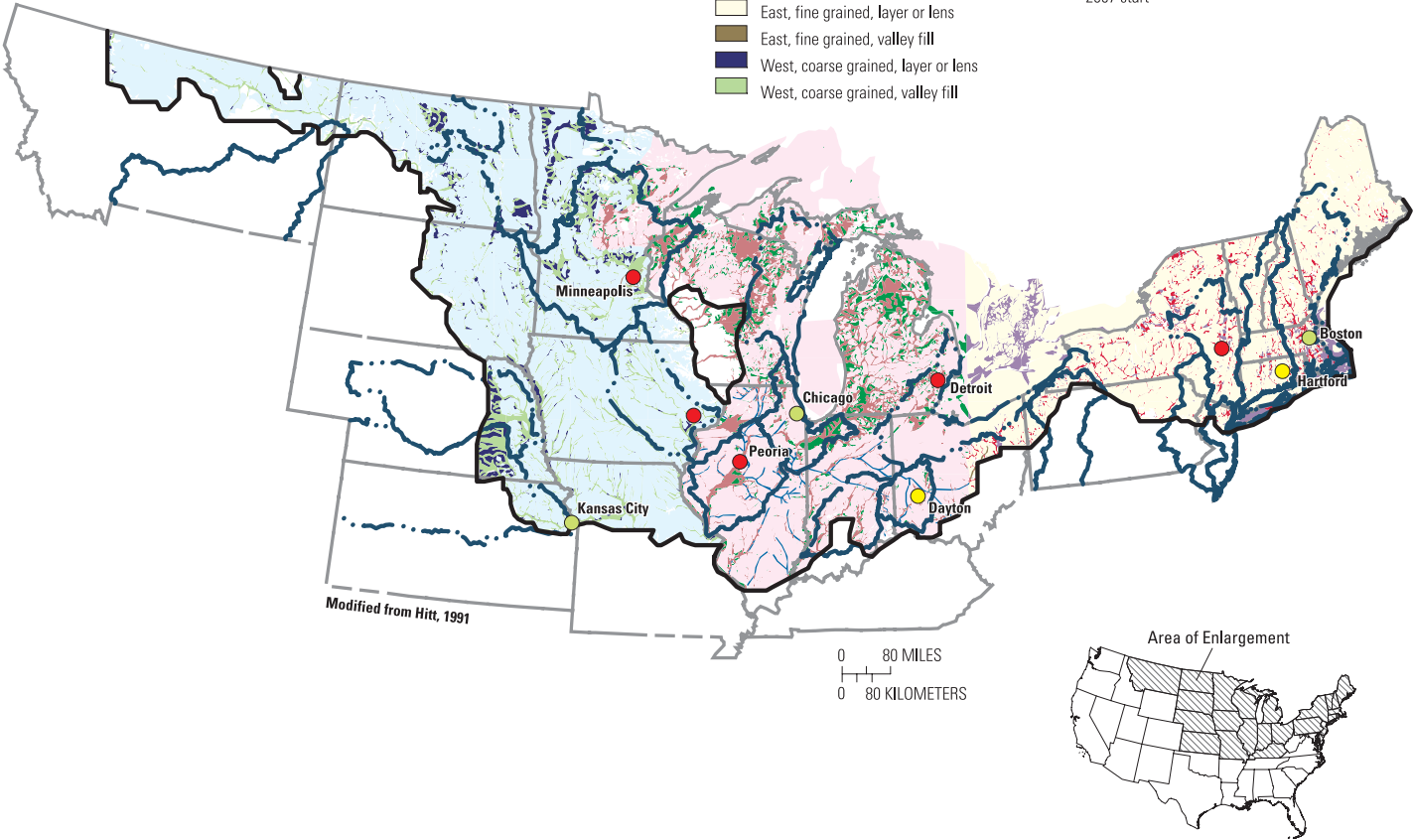
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Appendix A --Additional Maps

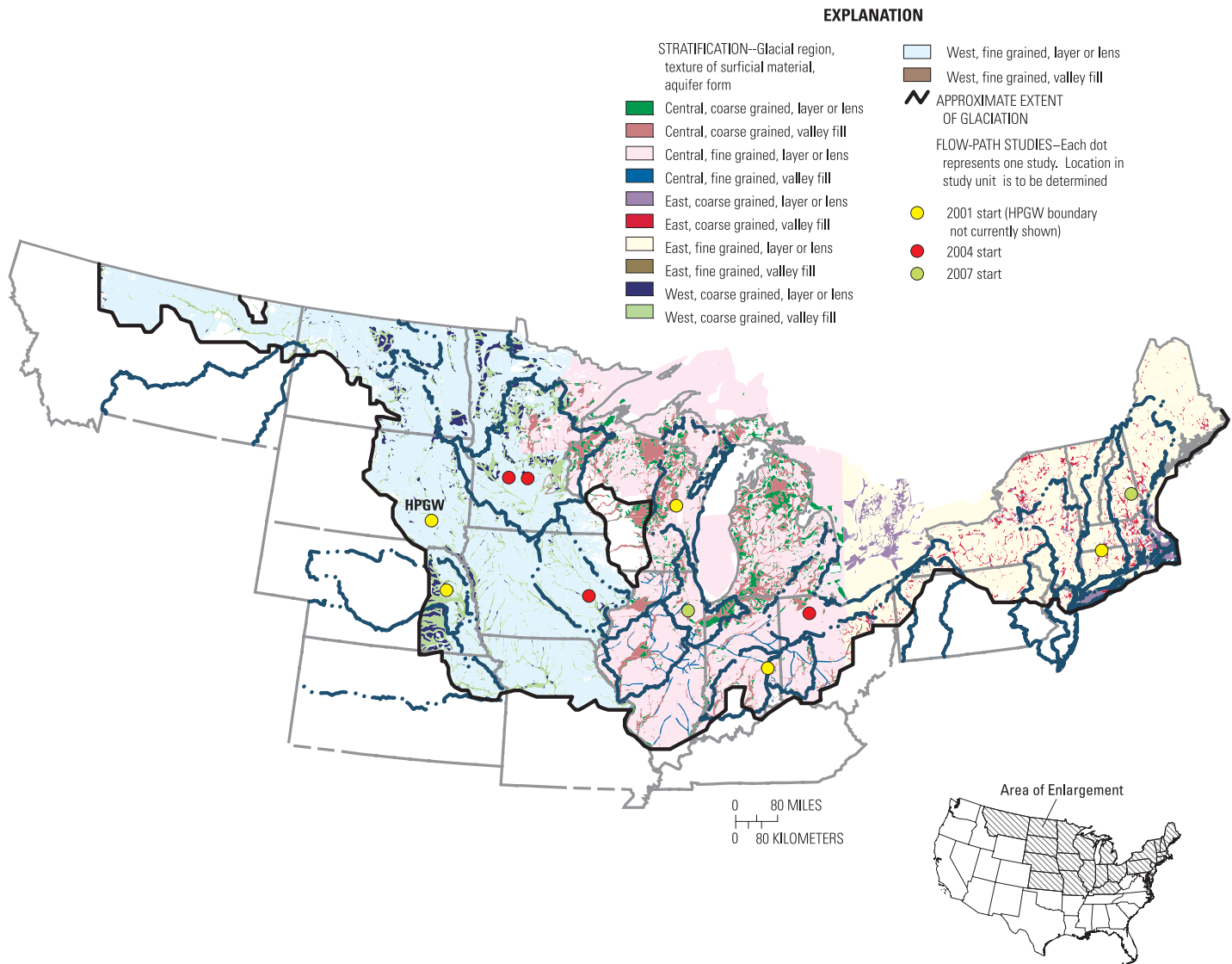
Potential Source-water
Studies

EXPLANATION

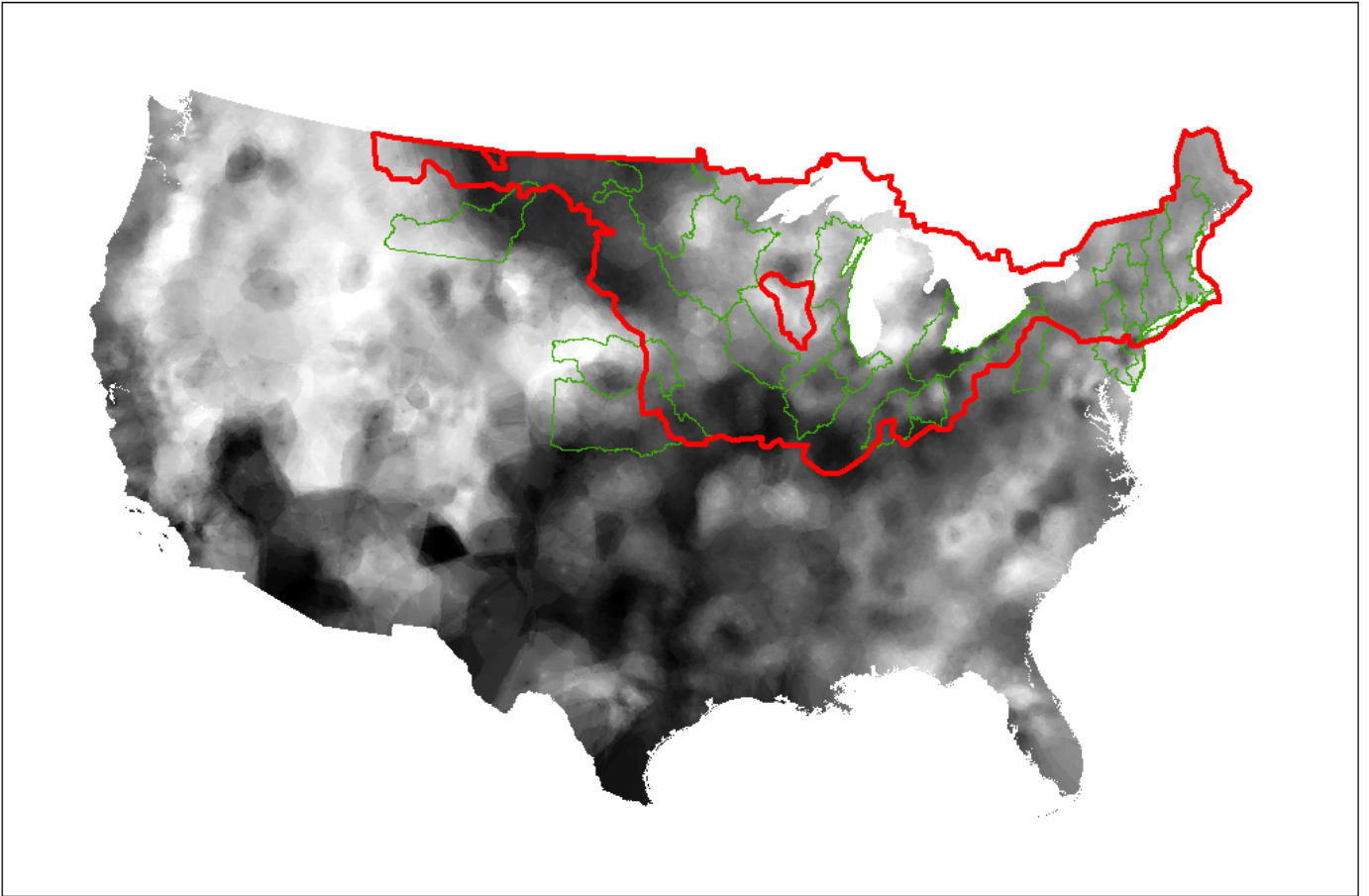
- STRATIFICATION--Glacial region,
texture of surficial material,
aquifer form
- Central, coarse grained, layer or lens
 - Central, coarse grained, valley fill
 - Central, fine grained, layer or lens
 - Central, fine grained, valley fill
 - East, coarse grained, layer or lens
 - East, coarse grained, valley fill
 - East, fine grained, layer or lens
 - East, fine grained, valley fill
 - West, coarse grained, layer or lens
 - West, coarse grained, valley fill
- West, fine grained, layer or lens
- West, fine grained, valley fill
- APPROXIMATE EXTENT
OF GLACIATION
- SOURCE WATER ASSESSMENT
STUDIES
- 2001 start
 - 2004 start
 - 2007 start



Flow-path studies



Base-flow Index



Map of base-flow index values from Dave Wolock (7/29/03). Darker areas are low BFI values and lighter areas are high BFI values. Lighter areas indicate where a larger percent of streamflow is from ground water.

Appendix B -- Cycle II Studies

NEW MAS - CONNSUS2

MAS Name: Glacial Aquifer (netcode connsus2)

Years sampled: No MAS was done for Cycle I, but three land-use studies were conducted in which shallow wells in glacial aquifers (stratified-drift aquifers) were sampled from 1992-95.

Objective: Document the ground-water quality in the confined or unconfined stratified-drift aquifers.

Location: The stratified drift aquifers consist of many hydraulically discrete glacial aquifers located in the primary and secondary valleys of the CONN in New England.

Background: The CONN-NAWQA study unit extends from the Canadian border to coastal Connecticut and includes an area of about 15,750 square miles. The study unit is characterized by diverse population density ranging from the sparsely populated, rural agrarian and wilderness areas of northern Vermont and New Hampshire to the densely populated urban areas of southwestern Connecticut and the south-central part of the Connecticut River valley. The principal cities of Hartford, Springfield, Bridgeport, and New Haven are all located in the southern part of the study unit. The climate differs considerably within the study unit, but is generally temperate and humid. Annual precipitation averages about 43 inches and ranges from about 34 inches at places in the northern end of the Connecticut River valley to more than 65 inches in some mountainous regions.

Stratified-drift aquifers occupy many of the principal and secondary river valleys of the CONN and the northeastern U.S. More than 1,000 individual, hydraulically discrete, glacial aquifers are located in valleys of the CONN alone. These aquifers are highly permeable, have a shallow (<30 ft) water table, and are highly susceptible to contamination from human activities at the land surface. The age of ground water, as determined by tritium and ³helium concentrations, was from 0.9 to 22.6 years (Mullaney and Grady, 1997). Most of the study area lies in Region 16 (wet, mountains) within the Hydrologic Landscape Regions for assigning aquifer susceptibility, although much of the lower Connecticut Valley lies in Regions 7, 2 and 4 (wet, plains). Stratified-drift aquifers are the exclusive ground-water supply for urban-suburban areas, and fractured-bedrock aquifers are primarily used for rural domestic supply.

Approach: Wells will be sampled in the stratified-drift aquifers of the CONN study unit. Land-use studies, including urban and agricultural(?), a source-water assessment, and a flow-path study(?) will be nested within the MAS. The MAS will include sampling of supply wells so that deeper parts of the aquifer, and ground water that contributes to

public-water supply, will be represented. The study will relate variations in ground-water quality to natural and human factors.

Water-Quality Issues Addressed: As part of the Cycle I NAWQA results in the CONN, VOCs were detected in 62% of wells in urban areas and 38% of wells in agricultural areas where surficial aquifers were sampled from 1992 to 1995 (Grady and Mullaney, 1998). Five of the 25 compounds detected—benzene, 1,2-dibromoethane, naphthalene, tetrachlorethene, and trichloroethene—exceeded MCLs or health advisories. MTBE was the most frequently detected VOC. Chloroform, which was the second most frequently detected VOC, was measured in 32% of wells in urban areas. Nearly all MTBE detections in ground water were in Connecticut and Massachusetts where its use as a gasoline additive is required to reduce atmospheric concentrations of carbon monoxide and ozone from automobile emissions. Natural contaminants in both stratified-drift aquifers and bedrock aquifers include radon-222 and other radionuclides, such as radium-226 and radium-228. Arsenic has been found at concentrations above 10 ug/L in several bedrock wells in northeastern and southcentral Connecticut (Brown and Chute, 2001), and could provide a contaminant source to adjacent stratified-drift aquifers.

Wells will be sampled for a broad suite of major ions, VOCs, pesticides, nutrients, trace metals, and radionuclides. Collected data will be useful for assessing the distribution of a wide range of anthropogenic and natural compounds that could affect public drinking-water supply. Inorganic chemistry of samples from wells will be used to categorize ground-water quality in terms of 4 lithochemical groups, as done previously by Grady and Mullaney (1998).

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NEW MAS - WMICMAS2

1. MAS Name: Glacial Aquifer (socode wmicmas2)

Years sampled: This is a new MAS planned for Cycle II.

Objective: Document the ground-water quality in extensive, unconfined, sand and gravel deposits of the glacial aquifer.

Location: The Western Lake Michigan Drainages in Wisconsin and Upper Michigan.

Well type: Domestic

Background: The glacial aquifer was chosen for study because it is one of the most used aquifers in the study area and is one of the 16 principle aquifers chosen for study by NAWQA. Water use from the glacial aquifer in the WMIC was estimated to be about 59 mgd (1990). The primary uses of water from the glacial aquifer are public supply (28%), irrigation (25%), and domestic supply (18%). Land-use in the study area ranges from urban to agriculture to forest. Probable influences on water quality will include a wide range of natural and anthropogenic sources. In addition to this MAS, the glacial aquifer will be included in several other ground-water studies in the WMIC. These include an agricultural land-use study, a source-water assessment study, and a large-scale study associated with the “Transport of Contaminants to Supply Wells” topical team.

Approach: Thirty domestic wells, screened in the glacial aquifer, will be sampled. The wells will be randomly selected to provide a statistically valid representation of the water quality in the aquifer used for domestic supply. Wells will be sampled and analyzed for a broad suite of constituents including: major ions, nutrients, pesticides, VOCs, trace metals, and radionuclides.

Water-Quality Issues: Agricultural land use dominates the southern part of the study area where pesticides and nitrate have been detected at concentrations above the MCL in ground-water samples from the glacial aquifer. Natural contaminants of concern in the glacial aquifer include radon and arsenic. Radon has been detected at concentrations above 300 pci/L, and arsenic concentrations above 10ug/L have been measured in water samples from the glacial aquifer throughout the WMIC

RESAMPLE TREND -- WMICLUSAG2

LUS Name: Agricultural land-use study, corn and alfalfa overlying sand and gravel (socode wmclusag2)

Years sampled: Previously sampled in 1994. Plans to sample in FY02 and periodically throughout Cycle II as part of the trends network.

Objective: Document trends in the quality of shallow ground water in sand and gravel deposits of the glacial aquifer adjacent to land used to grow corn and alfalfa.

Location: The western part of the Western Lake Michigan Drainages in Wisconsin.

Well type: Monitor well installed by USGS.

Background: This network of wells is one of two agricultural land-use studies conducted in the WMIC during Cycle I (the other land-use study is called wmclusag1, corn and alfalfa overlying till). The agricultural land uses in the two study areas had similar crop rotations, pesticides used, and nitrogen application rates. The geohydrology of the two areas was quite different however. The surficial deposits in the area of wmclusag2 were more permeable and the soils had a lower content of organic matter than wmclusag1. The water table in the area of wmclusag2 was significantly deeper than in wmclusag1 and the age of the ground water was generally younger. The differences in geohydrologic characteristics have a significant influence on the quality of ground water in the two areas. The concentrations and percent detections of agricultural chemicals in ground-water samples were higher in wmclusag2 than in wmclusag1.

The young ground-water and susceptibility to contamination make the area of wmclusag2 a suitable place to study trends in ground-water quality as it relates to changes in land-use practices. The wells of this study will be included in the NAWQA Cycle II trends network.

Approach: Thirty well locations, adjacent to field growing corn/alfalfa, were randomly selected throughout the study area. Monitor wells (2 inch pvc with 5 foot screens) were installed near the water table using hollow-stem augers. Wells were sampled and analyzed for a broad suite of constituents including: major ions, nutrients, pesticides, VOCs, and radionuclides. During Cycle II, ground-water samples will be analyzed for major ions, nutrients and pesticides. The wells will be resampled in FY02 and a subset of those will be sampled biennially throughout Cycle II. Additionally, the subset of wells will be sampled quarterly during one of the biennial sampling years.

Water-Quality Issues: Nine different pesticides were detected in samples from wmclusag2. Atrazine and the metabolite deethyl atrazine were the most commonly detected pesticide. One or both of these constituents were found in 93% of the samples collected. The concentration of atrazine plus deethyl atrazine exceeded the MCL (3 ug/L) in a sample from only one well in the study area. Dissolved nitrate was detected in 93% of samples collected and 37% of samples exceeded the MCL of 10 mg/L.

RESAMPLE MAS - LIRBSUS1

MAS Name: Mahomet Aquifer (netcode lirbsus1)

Years sampled: 1996-98 (Cycle I) and planned for trend in Cycle II

Objective: Document the spatial variability in ground-water quality in the deep (>200 ft bls) confined glacial drift aquifer (Mahomet aquifer) and any water-quality trends that are apparent in the aquifer since 1994 in Illinois.

Location: The Mahomet aquifer is a deep glacial drift aquifer in east-central Illinois.

Well type: Domestic

Background: Buried bedrock valleys, filled with a thick sequence of glacial material, are present from West Virginia to Illinois and are sources for drinking water in many of these areas. A buried bedrock valley system extends from parts of West Virginia, through parts of Ohio, Indiana, and Illinois. This bedrock valley system, sometimes referred to as the Teays system, begins beyond the extent of glaciation near Charleston, WV toward Columbus, Ohio into Illinois (Melhorn and Kempton, 1991, GSA special paper). Tributary bedrock channels include areas north of Columbus, and directly through Cincinnati and Dayton, OH areas. The buried bedrock valley system in Indiana is north of Indianapolis and close to Lafayette, IN. In Illinois the valley continues through Champaign/Urbana, Bloomington, and finally terminates at the Illinois and Mackinaw Rivers near Peoria. There is controversy on the continuity of the entire bedrock valley from West Virginia to Illinois. Although the deposits may not be continuous over the entire valley extent, the thick sequence of these deposits in various parts of the valley is a source of drinking water supply.

This hydrogeologic setting of a thick sequence of glacial deposits within a buried bedrock valley underlies 1.26 million acres in east-central Illinois. Land use is predominantly agricultural--corn and soybean. Approximately, 800,000 people rely on drinking water from this deep glacial drift aquifer, the Mahomet aquifer (<http://www.mahometaquiferconsortium.org> on June 20,2001). Major cities utilizing the Mahomet aquifer include Champaign/Urbana (120,000), Bloomington/Normal (111,000), Decatur (45,000), and parts of Peoria (184,000). Many cities including Springfield, Illinois are considering pumping water from the Mahomet aquifer to supplement drinking water supply from surface-water sources. The depth to the Mahomet aquifer in Illinois is from 200 to 500 ft below land surface. Ground-water age is older than 1950 (based on tritium data), and ¹⁴C work done by the Illinois State Geological Survey indicates that the water maybe thousands of years old. The only known location where water recharges the aquifer from the surface at a relatively rapid rate is in Champaign County, where glaciers deposited thin layers of sand and gravel within the overlying clay. The aquifer has been modeled by the Illinois State Water Survey and is known to discharge to the Mackinaw and Illinois River.

Approach: Wells were randomly selected for the MAS network to provide a representative spatial coverage of the Mahomet aquifer within the LIRB. Sites were selected randomly within each of 30 relatively equal-sized, contiguous cells and an appropriate well (and 5 alternates) open to the Mahomet aquifer was located near each site. Selected wells are

typically used for domestic supply, were drilled after 1980, and screened at least 200 ft below land surface. Each well sampled, as part of the Cycle I network will be revisited. Five wells have been re-selected for trend sampling. These 5 were selected by randomly combining the 30 relatively equal-size contiguous cells into 5 larger areas. One of six wells in each of the five areas was selected to represent that area of the Mahomet aquifer based on representation of the area and availability to resample. These five wells will be sampled every other year as a trend network.

Water-Quality Issues Addressed: A network of 30 wells was sampled for a broad suite of major ions, pesticides, nutrients, trace metals, tritium, radon, and VOCs in 1996-98 (Table 1). These wells are planned to be resampled in Cycle II (2005). In addition to data collected in 1996-98, the Cycle II sampling will include pesticide transformation products and dissolved gases. Collected data will be useful for assessing the distribution of a wide range of natural and anthropogenic compounds that may affect the usefulness of the ground-water resource for human consumption. Arsenic is a major concern in this aquifer. Concentrations of arsenic range from the detection limit to 83 ug/L with over 65% of the wells having concentrations greater than 10 ug/L. The dominant form of arsenic is arsenite. Ground water samples collected in 1996-98 (5 of 30) contained trace amounts of pesticides that had never before been detected in the Mahomet aquifer. The VOCs detected in 63% of the samples from the Mahomet aquifer are assumed to be natural in occurrence. The concentration of VOCs was at or near the method detection limit and the most common detection was carbon disulfide possibly from natural sources.

Netcode: LIRBSUS1
 Aquifer: Deep (>200 ft) glacial drift aquifer - Mahomet aquifer
 Average well depth: 245 feet below land surface

	<u>schedule and/or</u> <u>lab code</u>	<u>method</u> <u>detection limit</u> <u>general</u>	<u>frequency of</u> <u>detection*</u>	<u>median</u> <u>concentration</u>	<u>maximum</u> <u>concentration</u>
TOTAL PESTICIDES	NWQL 2001 and 2050		31%		
Atrazine (ug/L)	LC39632	0.001	21%	<.001	0.0047
Metolachlor	LC39415	0.002	3%	<.002	0.004
Alachlor	LC46342	0.002	0%	<.002	<.002
deethylatrazine	Kansas lab	na	na	na	na
deisopropyl atrazine	Kansas lab	na	na	na	na
hydroxyatrazine	Kansas lab	na	na	na	na
metolachlor ESA	Kansas lab	na	na	na	na
metolachlor OA	Kansas lab	na	na	na	na
alachlor ESA	Kansas lab	na	na	na	na
alachlor OA	Kansas lab	na	na	na	na
TOTAL VOCs	NWQL 9090		63%		
MTBE (ug/L)	LC78032	0.1	0%	<.1	<.1
Arsenic (ug/L)	LC01000	1	83%	10	84
Radon (pCi/L)	LC01369		100%	160	730
Nitrate	LC00631	0.05	40%	0.05	0.09

*Frequency of detection includes all detections (even estimated and below mrl) for the first sample from each well. Exceptions include censoring methylchloride (chloromethane) to include only samples above 9.0 ug/L.

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RESAMPLE LUS – UIRB UrbanLus

LUS Name: Urban Land Use Study (netcode uirblusrc1)

Years sampled: 2000 (Cycle I), 5 wells sampled for trends in 2002 in Cycle II

Objective: Document the spatial variability in ground-water quality in the shallow (less than 50 feet) glacial deposits overlying a bedrock aquifer in recently urbanized land in northeastern Illinois and southeastern Wisconsin and any water-quality trends that are apparent.

Location: The study area is in northeastern Illinois and southeastern Wisconsin near Chicago, Ill., and Milwaukee, Wis.

Well type: Monitoring wells installed by the U.S. Geological Survey. Wells are constructed of 2 inch diameter polyvinyl-chloride casing and screens. Well screens are 5 feet long.

Background: The urban land-use study area is located in northeastern Illinois and southeastern Wisconsin and within the Wheaton Morainal Plain (99% of the study area), but is located also in the Chicago Lake Plain (less than 1% of the study area). The Wheaton Morainal Plain is composed of Wisconsinan Episode moraines and consists of clayey till of the Wadsworth Till Member/ Oak Creek Formation, and sand and gravel of the Haeger Till Member/New Berlin Formation. The Chicago Lake Plain is a flat, glacio-lacustrine deposit consisting primarily of clay and silt of the Carmi and Dolton members of the Equality/Atherton Formation (Arnold and others, 1999). Urban land use in the Upper Illinois River Basin (UIRB) accounted for about 17% in 1990, but is increasing rapidly because of recent urban expansion of the Chicago and Milwaukee metropolitan areas. The largest population increases from 1970 to 1990 occurred in McHenry and Dupage Counties, Ill. (Arnold and others, 1999). The glacial deposits are used as a source of drinking-water supply for municipal and domestic supplies in the study area.

Approach: Shallow ground water in the Quaternary deposits overlying a major bedrock aquifer located in the Great Lake Section underlies the study area that had recently changed from agricultural land use to urban land use. This recently urbanized study area was delineated based on the methods outlined in Squillace and Price (1996). Urban land use from the 1990 Geographical Information Retrieval and Analysis System (GIRAS) land-use/land-use change coverage (Hitt, 1995) was originally used to define the urban-land use area for this study. This urban land-use data was derived from 1970's land-use information and updated based on increasing population density obtained from 1990 population data. Because the 1990's land-use/land-use change data were dated, the urban areas defined around the rapidly urbanizing area of metropolitan Chicago were under-represented. At a later time in the study, 1993 land-use data (Vogelmann and others, 2001) became available. Although the land-use data were out of date by approximately 5 years, this 1993 land-use data defined urban areas temporally better than the 1990's land-use data. To better estimate the extent of urban areas around Chicago for the sampling time period of this study, a geographic information system (GIS) was used to combine these two land-use data sets and expand (buffer) the urban land-use areas by 500 meters on all sides.

Well site selections were randomly selected for the urban lus network to provide a representative spatial coverage of the study area. Sites were selected randomly within each of 30 relatively equal-sized, contiguous cells. Because of difficulties in obtaining permission and drilling resulting in dry holes, only 26 wells yielding water were successfully completed. Each well sampled, as part of the Cycle I network will be revisited. Five wells were selected and sampled for trends in 2002. These five wells will be sampled every other year as a trend network.

Water-Quality Issues Addressed: This network of 26 wells was sampled for a broad suite of compounds, including major ions, pesticides, pesticide transformation products, nutrients, trace metals, radon, and VOCs in 2000. Chlorofluorocarbon (CFC) samples, along with dissolved gas samples, as well as selected tritium-3 samples were collected and analyzed to estimate ground-water recharge dates. These wells are planned to be resampled in Cycle II (2005). Collected data will be useful for assessing the distribution of a wide range of natural and anthropogenic compounds that may affect the usefulness of the ground-water resource for human consumption.

Using laboratory reporting levels (LRLs), 5 of 21 (24%) wells had samples with 5 detections of 4 different VOCs; using information rich reporting levels, 14 of 21 (67%) wells had samples with 19 detections of 9 different VOCs. Using LRLs 18 of 25 (72%) wells had samples with 66 detections of 20 pesticides or pesticide transformation products; using information-rich reporting levels, 21 of 25 (84%) wells had samples with 102 detections of 27 different pesticides or pesticide transformation products. These results indicate that most of the wells are anthropogenically affected. No pesticide or VOC detection exceeded USEPA drinking-water criteria. Selected results are in the following table.

Netcode:	uirblusrc1				
Aquifer:	Shallow glacial aquifer in urban land use area				
Average well depth:	32.4 feet below ground surface				
	<u>Schedules and parameter codes</u>	<u>method detection limit general</u>	<u>frequency of detection*</u>	<u>median DETECTION concentration</u>	<u>maximum concentration</u>
TOTAL PESTICIDES	NWQL 2010, 2060, and OGRL(Kansas)		84%		
Atrazine (ug/L)	39632	0.001	44%	0.006	0.03
Metolachlor	39415	0.002	16%	0.007	0.01
Alachlor	46342	0.002	0%	<.002	<.002
deethylatrazine	04040	0.002	56%	0.006	e0.11
deisopropyl atrazine	04038	0.07	16%	e0.02	e0.04
hydroxyatrazine	50355	0.193	36%	e0.007	0.56
metolachlor ESA	61043	0.05	32%	0.53	2.86
metolachlor OA	61044	0.05	12%	0.62	1.71
alachlor ESA	50009	0.05	24%	0.22	0.53
alachlor OA	61031	0.05	8%	0.25	0.43
TOTAL VOCs	NWQL 2020		67%		
MTBE (ug/L)	78032	0.17	5%	0.2	0.2
Arsenic (ug/L)	01000	0.9	27%	2.7	11
Radon (pCi/L)	82303		100%	270	462
Nitrate	00631	0.05	58%	2.67	12.5
*Frequency of detection include: all detections (even estimated a below lrl) for the first sample from each well. Exceptions include censoring toluene.					

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RESAMPLE LUS – UIRB AgLus

LUS Name: Agricultural Land Use Study (netcode uirbluscr1)

Years sampled: 1999 (Cycle I), 5 wells sampled for trends in 2002 in Cycle II

Objective: Document the spatial variability in ground-water quality in the shallow (less than 50 feet) glacial deposits overlying a bedrock aquifer in agricultural land in northeastern Illinois and southwestern Indiana and any water-quality trends that are apparent.

Location: The study area is in northeastern Illinois and southwestern Indiana south of Chicago, Ill. northwest of Indianapolis, Ind.

Well type: Monitoring wells installed by the U.S. Geological survey. Wells are constructed of 2 inch diameter polyvinyl-chloride casing and screens. Well screens are 5 feet long.

Background: The agricultural land-use study area is located in the Till Plains Section. The majority of the wells are in the Kankakee Till Plain, but a few wells are in the Tipton Till Plain. Both of these areas are predominantly agricultural. The Kankakee Till Plain is an outwash plain formed by glacial flooding, with deposits being primarily outwash sand and gravel. The Tipton Till Plain's surficial deposits are mostly loamy till, lake clays and silt (Arnold and others, 1999). Depth to bedrock is frequently less than 50 feet. The glacial deposits are used as a source of drinking-water supply for municipal and domestic supplies in the study area.

Approach: Shallow ground water in the Quaternary deposits overlying a major bedrock aquifer underlies the study area that is primarily agricultural land use. Well site selections were randomly selected for the agricultural lus network to provide a representative spatial coverage of the study area. Sites were selected randomly within each of 30 relatively equal-sized, contiguous cells. Because of difficulties in obtaining permission and hitting bedrock before water, only 29 wells yielding water were successfully completed. Each well sampled, as part of the Cycle I network will be revisited. Five wells were selected and sampled for trends in 2002. These five wells will be sampled every other year as a trend network.

Water-Quality Issues Addressed: This network of 29 wells was sampled for a broad suite of compounds, including major ions, pesticides, pesticide transformation products, nutrients, trace metals, and radon in 1999. Chlorofluorocarbon (CFC) samples, along with dissolved gas samples, were collected and analyzed to estimate ground-water recharge dates. These wells are planned to be resampled in Cycle II (2005). Collected data will be useful for assessing the distribution of a wide range of natural and anthropogenic compounds that may affect the usefulness of the ground-water resource for human consumption.

Using information-rich reporting levels (LRLs), 24 of 29 (83%) wells had samples with 82 detections of 24 pesticides or pesticide transformation products. Nitrate was detected in 20 of 29 (69%) samples. Detections exceeding 2 mg/L occurred in 16 (55%) of the samples, and exceeded the USEPA drinking water MCL in 3 (10%) of the samples. These results indicate that most of these wells are anthropogenically affected by agricultural practices. No pesticide exceeded USEPA drinking-water criteria. Selected results are in the following table.

Netcode: Uirblusr1					
Aquifer: Shallow glacial aquifer in agricultural land use area					
Average well depth: 17.4 feet below ground surface					
	<u>Schedules and parameter codes</u>	<u>method detection limit general</u>	<u>frequency of detection*</u>	<u>median DETECTION concentration</u>	<u>maximum concentration</u>
TOTAL PESTICIDES	NWQL 2010, 2060, and OGRL(Kansas)		83%		
Atrazine (ug/L)	39632	0.001	17%	0.02	0.35
Metolachlor	39415	0.002	3%	0.48	0.48
Alachlor	46342	0.002	3%	0.95	0.95
deethylatrazine	04040	0.002	21%	e0.009	e0.41
deisopropyl atrazine	04038	0.07	7%	e0.04	e0.05
hydroxyatrazine	50355	0.193	34%	e0.03	e1.03
metolachlor ESA	61043	0.20	28%	0.60	9.08
metolachlor OA	61044	0.20	14%	2.61	4.49
alachlor ESA	50009	0.20	24%	0.51	3.06
alachlor OA	61031	0.20	3%	3.06	3.06
Arsenic (ug/L)	01000	1.0	38%	3.2	28
Radon (pCi/L)	82303		100%	260	695
Nitrate	00631	0.05	69%	4.50	17.3
*Frequency of detection includes all detections (even estimated and below lrl) for the first sample from each well.					

Bibliography

Arnold, T.L., Sullivan, D.J., Harris, M.A., Fitzpatrick, F.A., Scudder, B.C., Ruhl, P.M., Hanchar, D.W., Stewart, J.S., 1999, Environmental setting of the upper Illinois River Basin and implications for water quality: U.S. Geological Survey Water-Resources Investigations Report 98-4268, 67 p.

RESAMPLE TREND -- LERILUSRC1

LUS Name: LERI Urban Land-Use Study (lerilusrc1)

Years sampled: Fall-winter, 1996-97 (Cycle 1). Will be resampled during Cycle 2.

Objective: Document the spatial variability and trends of shallow-ground-water quality in a new residential area.

Location: A 4-county region on the far outskirts of the Detroit metropolitan area.

Well type: Monitor wells

Background: Glacial deposits in the Lake Erie-Lake St. Clair Basin are predominantly till. The northwestern part of the basin is one of the few areas where widespread deposits of sand/gravel occur at land surface. In this area, 3 discontinuous outwash plains are oriented in a NE-SW direction, roughly coincident with the intersection of Saginaw and Erie-Huron lobes. Outwash (predominantly sand/gravel) was deposited by meltwaters as the lobes separated and retreated. The deposits, typically 150-300 ft thick, occupy low areas between morainic hills that are predominantly till. The outwash plains are pitted with many small lakes and wetlands.

Sand/gravel occurs at land surface, and varied amounts of clay-rich till are interbedded with the sand/gravel at depth. In areas where there is little interbedded till, sand/gravel form a thick unconfined aquifer. However, in most areas, a significant amount of till occurs at depth, and the glacial deposits form a 2-layer aquifer system; a surficial unconfined aquifer overlies a deeper semi-confined or confined aquifer. The water table is typically 10-20 feet below land surface.

The area is on the far outskirts of Detroit, where rural/agricultural land is being converted to subdivisions and small strip malls. Surface water is used to supply Detroit and the most of its well-established suburbs. However ground water is important to Pontiac, Ann Arbor, many of the small towns and subdivisions on the far outskirts of the Detroit metropolitan area. A rough estimate is that approximately 27 Mg/day of ground water are used for domestic supply in the 4-county area. Most of the outwash is underlain by Mississippian-age shale and interbedded sandstone, which is generally not a reliable aquifer due to quantity and/or quality problems.

The LERI Urban Land-Use Study focused on the surficial layer of sand and gravel. From a water-quality perspective, this hydrogeologic unit is important because it is: (1) a source of domestic supply in some areas, (2) the source of recharge to deeper parts of the glacial aquifer, and (3) hydraulically connected to the many small lakes and wetlands that occur throughout the study area.

Approach: Well sites were randomly selected to provide a representative spatial coverage of an area with the following characteristics: (1) land use is recent residential/commercial, (2) glacial deposits are greater than 100 ft thick, (3) sand/gravel occur at land surface, and (4) bedrock is Mississippian shale interbedded with sandstone. Thirty monitor wells were installed and sampled for major ions, nutrients, trace elements, DOC, pesticides, VOCs, radon, and tritium. Four

samples were also analyzed for tritium/helium. Of the 30 wells, 28 were installed in private yards or common areas in subdivisions, and 2 were installed at metro parks. A LERI special study (lerispcg1) sampled 28 domestic- and small community-supply wells co-located with the monitor wells.

Water-Quality Issues Addressed: All samples contained ground water recharged after 1953, and more than 90% showed evidence of human activities in the form of nitrate, chloride and/or VOCs. Elevated concentrations of chloride are of anthropogenic origin, based on analysis of (1) Cl/Br ratios and (2) relations between concentration, well depth, and ground-water age. Predominant contaminant sources are interpreted to be septic systems and infiltration of runoff from paved surfaces. Pesticides were detected infrequently (7%), even though much of the area consists of well-maintained yards, parks, and golf courses.

In contrast, ground water recharged prior to 1953 (from co-located domestic wells) showed no evidence of anthropogenic contamination, but concentrations of natural contaminants, such as arsenic and iron, were higher.

Netcode: lerilusrc1
 Aquifer: Unconfined glacial outwash (sand & gravel)
 Average well depth: 26 feet below land surface

	<u>schedule and/or lab code</u>	<u>method detection limit general</u>	<u>frequency of detection*</u>	<u>median conc.</u>	<u>maximum conc.</u>
TOTAL PESTICIDES	NWQL 2001 and 2050		7%	nd	0.007
Atrazine (ug/L)	LC39632	0.001	0%	<.001	<.001
Metolachlor	LC39415	0.002	0%	<.002	<.002
Alachlor	LC46342	0.002	0%	<.002	<.002
deethylatrazine	LC04040	0.002	3%	<.002	.002E
deisopropyl atrazine		na	na	na	na
hydroxyatrazine		na	na	na	na
metolachlor ESA		na	na	na	na
metolachlor OA		na	na	na	na
alachlor ESA		na	na	na	na
alachlor OA		na	na	na	na
TOTAL VOCs	NWQL 9090		97%	nd	4.8
MTBE (ug/L)	LC78032	0.1	0%	<.1	<.1
Arsenic (ug/L)	LC01000	1	23%	<1	17
Radon (pCi/L)	LC01369		100%	310	690
Nitrate	LC00631	0.05	73%	0.74	18

*Frequency of detection includes all detections.

RESAMPLE MAS - LERISUS1

MAS Name: LERI Major Aquifer Study (lerisus1)

Years sampled: Summer, 1998 (Cycle I). Will be resampled during Cycle 2.

Objective: Document the spatial variability and trends in ground-water quality of sand and gravel aquifers overlain by till.

Location: A 10-county region of southeastern Michigan and northwestern Ohio.

Well type: Domestic wells

Background: Glacial sediments are predominantly clay-rich till that was deposited as end moraines or ground moraines by the Saginaw and Huron/Erie lobes. Deposits are typically 150-300 ft thick. Tills of the Saginaw lobe generally have a slightly higher sand content than those the Huron/Erie lobe. Lenses or layers of sand/gravel occur throughout the till, but their lateral extent and thickness is varied and poorly defined. In some cases, sand/gravel lenses are too thin to be detected from drill cuttings or noted on drillers' logs.

The till is saturated at depths of approximately 10-20 ft. Clay-rich tills have closely-spaced fractures that are visible from land surface to the water table. Hydraulic data indicate that fractures extend to depths of 25-35 ft, and occasionally much deeper.

Land use is a mixture of agricultural, rural, and residential/commercial. The glacial aquifer is the major source of ground water in the 10-county region. Domestic wells are typically 50-150 ft deep. The underlying bedrock—Mississippian-age shale and interbedded sandstone—is generally not a reliable aquifer due to quantity and/or quality problems.

The LERI Major Aquifer Study focused on sand/gravel aquifers overlain by till. National synthesis shows that ground water in this setting has a relatively low detection frequency of anthropogenic contaminants.

Approach: Well sites were randomly selected to provide a representative spatial coverage of an area with the following characteristics (1) glacial deposits are more than 100 ft thick, (2) till occurs at land surface, and (3) underlying bedrock is Mississippian-age shale interbedded with sandstone. Twenty-eight domestic wells were sampled for major ions, nutrients, DOC, pesticides, pesticide degradation products, VOC, radon, and tritium. Eighteen of the domestic wells are co-located with monitor wells installed for the Agricultural Land-Use Study (lerilusr1).

Water-Quality Issues Addressed: Aquifers are not completely isolated from land surface by overlying till. In domestic wells 50-100 ft deep, approximately 50% of samples were recharged after 1953. Twenty-one percent of samples contained at least one anthropogenic constituent (pesticide, nitrate and/or chloride). Anthropogenic contaminants were generally detected where the till matrix is relatively sandy. Trace concentrations of VOCs were detected in half of the samples, however, one or more of the detected compounds could be of natural origin. All samples had iron concentrations greater than the Secondary Maximum Contaminant Limit.

Appendix C -- Cycle I Studies

CYCLE I - LERISPCG1

Special Study Name: LERI Special Study—Urban Drinking-Water (lerispcg1)

Year sampled: Summer, 1997 (Cycle 1).

Objective: Document the quality of ground water used for drinking water in the same area that was sampled for the LERI Urban Land-Use Study.

Location: A 4-county region on the far outskirts of the Detroit metropolitan area.

Well type: Domestic and small community-supply wells

Background: Glacial deposits in the Lake Erie-Lake St. Clair Basin are predominantly till. The northwestern part of the basin is one of the few areas where widespread deposits of sand/gravel occur at land surface. In this area, 3 discontinuous outwash plains are oriented in a NE-SW direction, roughly coincident with the intersection of Saginaw and Erie-Huron lobes. Outwash (predominantly sand/gravel) was deposited by meltwaters as the lobes separated and retreated. The deposits, typically 150-300 ft thick, occupy low areas between morainic hills that are predominantly till. The outwash plains are pitted with many small lakes and wetlands.

Sand/gravel occurs at land surface, and varied amounts of clay-rich till are interbedded with the sand/gravel at depth. In areas where there is little interbedded till, sand/gravel form a thick unconfined aquifer. However, in most areas, a significant amount of till occurs at depth, and the glacial deposits form a 2-layer aquifer system; a surficial unconfined aquifer overlies a deeper semi-confined or confined aquifer. The water table is typically 10-20 feet below land surface.

The area is on the far outskirts of Detroit, where rural/agricultural land is being converted to subdivisions and small strip malls. Surface water is used to supply Detroit and the most of its well-established suburbs. However ground water is important to Pontiac, Ann Arbor, many of the small towns and subdivisions on the far outskirts of the Detroit metropolitan area. A rough estimate is that approximately 27 Mg/day of ground water are used for domestic supply in the 4-county area. Most of the outwash is underlain by Mississippian-age shale and interbedded sandstone, which is generally not a reliable aquifer due to quantity and/or quality problems.

The LERI Special Study focused on the sand/gravel deposits used as a source of domestic supply. Domestic wells are typically 50-150 ft deep. Some domestic wells produce from the surficial aquifer, but most produce from a deeper zone that is separated from the surficial aquifer by one or more layers of clay-rich till.

Approach: The well network consists of 28 domestic- or small-public-supply wells co-located with the Urban LUS monitor wells; 24 are private domestic wells, 2 are subdivision-supply wells, and 2 are supply wells for metro parks. The wells were sampled for major ions, nutrients, DOC, radon, and tritium. VOCs and pesticides were analyzed at the Michigan Department of Environmental Quality Lab, using a higher method detection limit than NWQL. Total arsenic concentrations were measured at the University of Michigan.

Water-Quality Issues Addressed:

About a third of waters from domestic wells were recharged before 1953, and these samples showed no evidence of anthropogenic activity. In contrast, most waters recharged after 1953 had elevated nitrate and/or chloride concentrations. Elevated concentrations of chloride are of anthropogenic origin, based on analysis of (1) Cl/Br ratios and (2) relations between concentration, well depth, and ground-water age. Predominant contaminant sources are interpreted to be septic systems and infiltration of runoff from paved surfaces. Natural contaminants, such as arsenic and iron, were more prevalent in older, deeper ground water. Forty-six percent of samples had total arsenic concentrations exceeding the proposed MCL of 10 ug/L.

Netcode: lerispcg1
 Aquifer: Glacial outwash (sand & gravel)
 Average well depth: 105 ft below land surface

	<u>schedule and/or</u> <u>lab code</u>	<u>method</u> <u>detection limit</u> <u>general</u>	<u>frequency of</u> <u>detection*</u>	<u>median conc.</u>	<u>maximum</u> <u>conc.</u>
TOTAL PESTICIDES*	MDEQ lab		nd	nd	nd
Atrazine (ug/L)	MDEQ lab	0.2	nd	<0.2	<0.2
Metolachlor (ug/L)	MDEQ lab	1	nd	<1	<1
Alachlor	MDEQ lab	0.2	nd	<0.2	<0.2
deethylatrazine		na	na	na	na
deisopropyl atrazine		na	na	na	na
hydroxyatrazine		na	na	na	na
metolachlor ESA		na	na	na	na
metolachlor OA		na	na	na	na
alachlor ESA		na	na	na	na
alachlor OA		na	na	na	na
TOTAL VOCs*	MDEQ lab		nd		
MTBE (ug/L)	MDEQ lab	1	nd	<1	<1
Arsenic (ug/L)**	Univ. of Mich.	0.5(?)	100%	8	31
Radon (pCi/L)	LC01369		100%	155	460
Nitrate	LC00631	0.05	36%	<0.05	5.9

* Pesticides and VOCs analyzed at MDEQ lab using higher detection limits than NWQL.

**Arsenic conc. are total; detection limits are lower than NWQL

CYCLE I - LERILUSCR1

LUS Name: LERI Agricultural Land-Use Study (leriluscr1)

Years sampled: Early summer, 1998 (Cycle 1).

Objective: Document the spatial variability of shallow-ground-water quality in an agricultural area.

Location: A 9-county region of southeastern Michigan, northwestern Ohio, and northeastern Indiana.

Well type: Monitor wells

Background: Glacial sediments are predominantly clay-rich till that was deposited as end moraines or ground moraines by the Saginaw and Huron/Erie lobes. Deposits are typically 150-300 ft thick. Tills of the Saginaw lobe generally have a slightly higher sand content than those of the Huron/Erie lobe. Lenses or layers of sand/gravel occur throughout the till, but their lateral extent and thickness is varied and poorly defined. In some cases, sand/gravel lenses are too thin to be detected from drill cuttings or noted on drillers logs.

The till is saturated at depths of approximately 10-20 ft. Clay-rich tills have closely-spaced fractures that are visible from land surface to the water table. Hydraulic data indicate that fractures extend to depths of 25-35 ft, and occasionally much deeper.

Land use is agricultural; corn, soybeans and small grains are grown in rotation. Tile drains and/or ditches are widely used to drain the fields. The glacial aquifer is the major source of ground water in the 9-county region. Domestic wells are typically 50-150 ft deep. The underlying bedrock—Mississippian-age shale and interbedded sandstone—is generally not a reliable aquifer due to quantity and/or quality problems.

The LERI Agricultural Land-Use Study focused on the layer of surficial till. Till overlain by row-crop agriculture is one of the most widespread environmental settings in the glaciated Midwest. The surficial till generally is not used as an aquifer, but its physical and/or geochemical properties may be partly responsible for the low frequency of agrichemical detections in ground water, relative to other agricultural areas of the Midwest.

Approach: Well sites were randomly selected to provide a representative spatial coverage of an area with the following characteristics: (1) land use is row-crop agriculture, (2) glacial deposits are more than 100 ft thick, (3) till occurs at land surface, and (4) underlying bedrock is Mississippian-age shale interbedded with sandstone. Thirty monitor wells were installed and sampled for major ions, nutrients, DOC, pesticides, pesticide degradation products, and tritium. Wells were drilled through the unsaturated surficial till, and well screens were set in the shallowest saturated sand/gravel stringer estimated to be capable of producing a volume of water sufficient for sampling. Eighteen of the monitor wells are co-located with domestic wells sampled for the LERI Major Aquifer Study (lerisus1).

Water-Quality Issues Addressed: Samples from 83% of monitor wells were recharged after 1953. Almost 60% contained either a pesticide (41%) or anthropogenic nitrate (38%). Degradates of alachlor and metolachlor were the most frequently detected pesticide compounds. Relatively high concentrations of dissolved solids and sulfate were detected in some wells, but it is not known whether the source is natural or anthropogenic.

The surficial till does not completely isolate the underlying aquifers from land surface. In co-located domestic wells that were 50-100 ft deep, approximately 50% of samples contained ground water recharged after 1953. Moreover, 21% of samples from domestic wells contained at least one anthropogenic constituent (nitrate, pesticide and/or chloride).