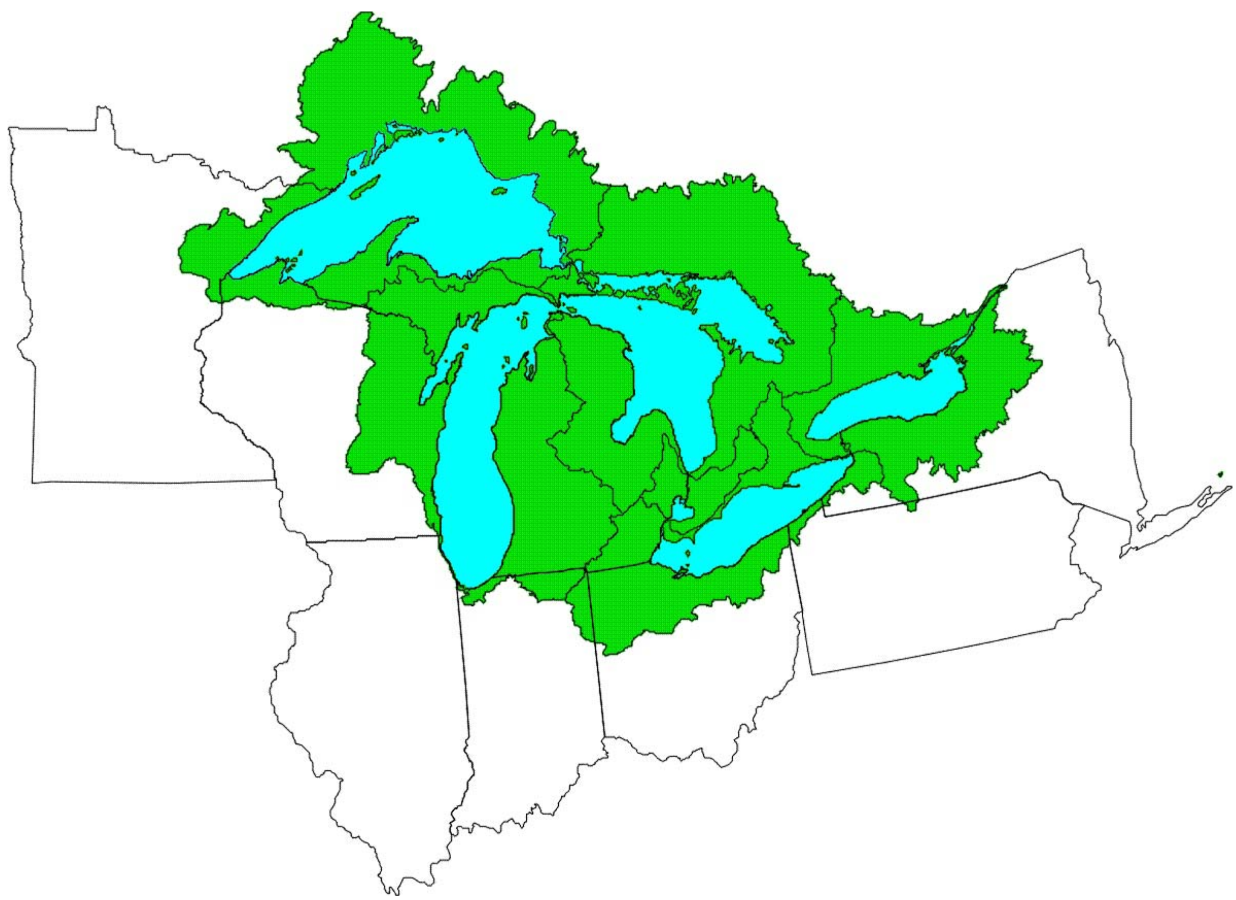
Improvements to the Great Lakes – St. Lawrence River Biohydrological Information Base

In response to Public Law 106-53, Water Resources Development Act of 1999, Section 455(b), John Glenn Great Lakes Basin Program, Great Lakes Biohydrological Information

Appendix B: Geology and Groundwater



September 2004

US Army Corps of Engineers®

Measurement Converter Table

U.S. to Metric

Length
feet x 0.305 = meters
miles x 1.6 = kilometers

Volume
cubic feet x 0.03 = cubic meters
gallons x 3.8 = liters

Area
square miles x 2.6 = square kilometers

Mass
pounds x 0.45 = kilograms

Metric to U.S.

Length
meter x 3.28 = feet
kilometers x 0.6 = miles

Volume
cubic meters x 35.3 = cubic feet
liters x 0.26 = gallons

Area
square kilometers x 0.4 = square miles

Mass
kilograms x 2.2 = pounds

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APPENDIX B:

Geology and Groundwater

Introduction

Groundwater is an important source of water for all who live within the Great Lakes - St. Lawrence River region and one of the region's most important natural resources. As a source of water, most large public water suppliers in the Great Lakes - St. Lawrence River region obtain water from the lakes themselves; however, 8.2 million people (approximately 22 percent) within the watershed depend on groundwater for drinking water (Grannemann, et al, 2000). Groundwater is also used for irrigation, industrial, commercial and domestic purposes. Similarly, fish and other wildlife are dependent upon groundwater as a major contributor to flow in streams and rivers, which impacts wetland habitats for plants and animals and affects lake levels. Therefore, the sound management of the Great Lakes groundwater resources is critical to the economic, social and environmental fabric of the region.

Background

To better understand the significance of groundwater and how it occurs within the Great Lakes - St. Lawrence River region, it is essential to first understand the nature of the region's groundwater system.

Contrary to some beliefs, groundwater does not collect in underground lakes or flow in underground rivers. In fact, groundwater is simply the subsurface water that fully saturates pores or cracks in soils and rocks to form an aquifer. An aquifer is defined as a subsurface bed that can store and transmit groundwater to supply wells. More than 1,000 cubic miles of groundwater are stored within the Great Lakes - St. Lawrence River basin as a large subsurface reservoir from which water is slowly released. This volume of water is approximately equal to that of Lake Michigan. (Grannemann, et al, 2000)

Groundwater discharges to streams, lakes and wetlands and is captured by pumping water from aquifers for domestic, agricultural and industrial use. Recent U.S. studies have estimated that groundwater makes a significant contribution to the overall water supply in the Great Lakes - St. Lawrence River basin. Indirect groundwater discharge (the exit of groundwater into surface waters) accounts for approximately 22 percent of the U.S. supply to Lake Erie, 33 percent of the supply to Lake Superior, 35 percent of the supply to Lake Michigan and 42 percent of the supply to Lakes Huron and Ontario (Holtschlag and Nicholas, 1998). Groundwater's contribution to stream flow is significant because, among other things, it ultimately affects lake levels (International Joint Commission, 2000). The absolute percentage of direct groundwater seepage into the Great Lakes has not yet been determined; however, estimates of direct discharge in specific areas have been calculated. Despite this potential data gap, it is important to emphasize that direct withdrawals of groundwater may divert water that would normally discharge into the Great Lakes system.

Aquifer beds can range from gravels and sands to bedrock; however, unconsolidated materials with high porosity (pore space that may hold fluid) and permeability (the ability to allow fluids to pass through) make up the most productive groundwater reservoirs. Within the Great Lakes - St. Lawrence River region, much of this unconsolidated material was deposited at or near the land surface as a result of large-scale glacial ice advances and retreats. These deposits are as much as 1,200 feet thick in parts of Michigan and are several hundred feet thick in buried bedrock valleys in Illinois, Indiana, Ohio, Wisconsin and New York. The deposits are thin or nonexistent in areas where bedrock that was not easily eroded by glacial ice is exposed at land surface. (Grannemann, et al, 2000)

Most glacial deposits are composed of mixtures of sand and gravel and silt and clay. Sand and gravel deposits are the most productive aquifers because they have greater permeability and effective porosity than do the finer grained deposits. Some areas with silt and clay at the surface (till or glacial lake deposits) contain more permeable deposits at depth and are able to yield moderate to large amounts of water to wells. In general, however, these silt and clay deposits are not aquifers. (Grannemann, et al, 2000)

Bedrock aquifers are generally widespread throughout the region and are more continuous than the aquifers in glacial deposits (Figure B-1). Some bedrock aquifers in the region extend far beyond the watershed boundaries. The relationship between groundwater in these aquifers and water in the Great Lakes is complicated because groundwater divides and watershed boundaries may not coincide. Carbonate rocks (limestone and dolomite) are the most common bedrock aquifers in the region. The most extensive carbonate aquifer in the region consists of a series of limestones and dolomites that underlie a large part of the upper Midwest. Sandstone aquifers are the next most common bedrock aquifer. An extensive sandstone aquifer underlies much of the northern Midwest and even extends under Lake Michigan. In general, shale, igneous and metamorphic bedrock have limited water-yielding capacity, and they are not considered regional aquifers. (Grannemann, et al, 2000)

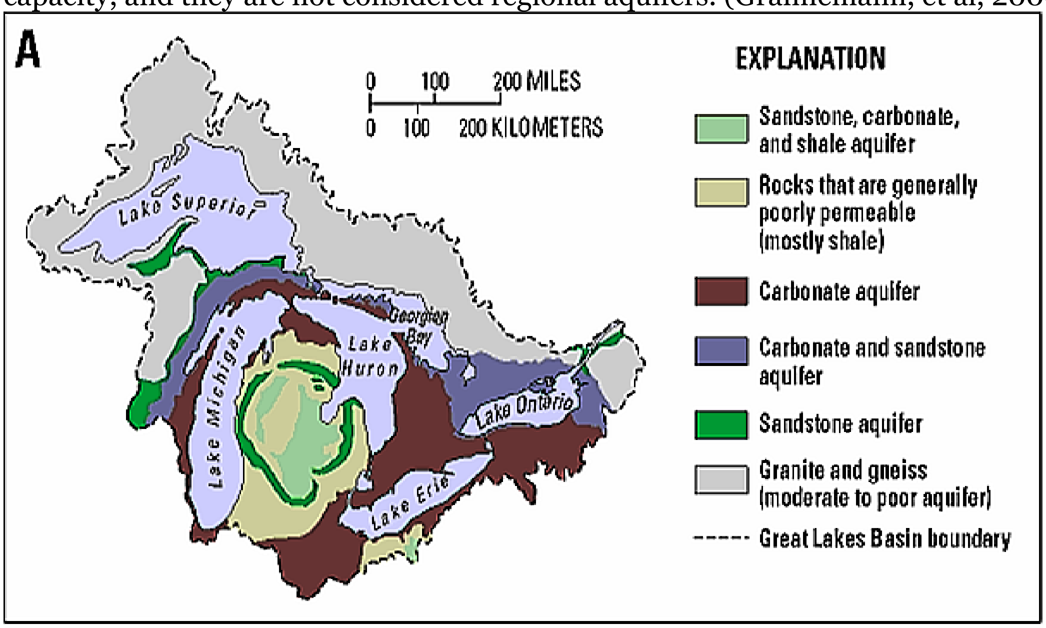

Figure B-1: Bedrock aquifers of the Great Lakes - St. Lawrence River basin (modified from Great Lakes Commission, 1975)

Groundwater is replenished by rainfall and recharge from rivers and lakes. When rain falls or snow melts, some of the water evaporates, some is absorbed by the roots of plants, some flows overland and collects in surface waters, and some infiltrates into the pores or cracks of the soil and rocks. Between the land surface and the aquifer is a zone that hydrologists call the unsaturated zone; that is, the pores contain some air and are not completely filled with water. After a significant rain, this zone may be almost saturated; after a long dry spell, it may be almost dry. (U.S. Geological Survey, 1999, Ground Water)

After the water requirements for the plants and soil are satisfied, excess water will infiltrate downward into the saturated zone, the level in which the pores of the soil or rock are completely filled with water. The boundary between the two zones is termed the groundwater table, usually shortened to “water table”. It is this water which moves through the soils or rock to discharge into surface waters, springs, or is withdrawn from wells. Most areas, unless composed of solid rock or covered by development, allow a certain percentage of total precipitation to reach the water table. However, in some areas more precipitation will infiltrate than in others. (U.S. Geological Survey, 1999, Ground Water; Washington State Department of Ecology, 1986)

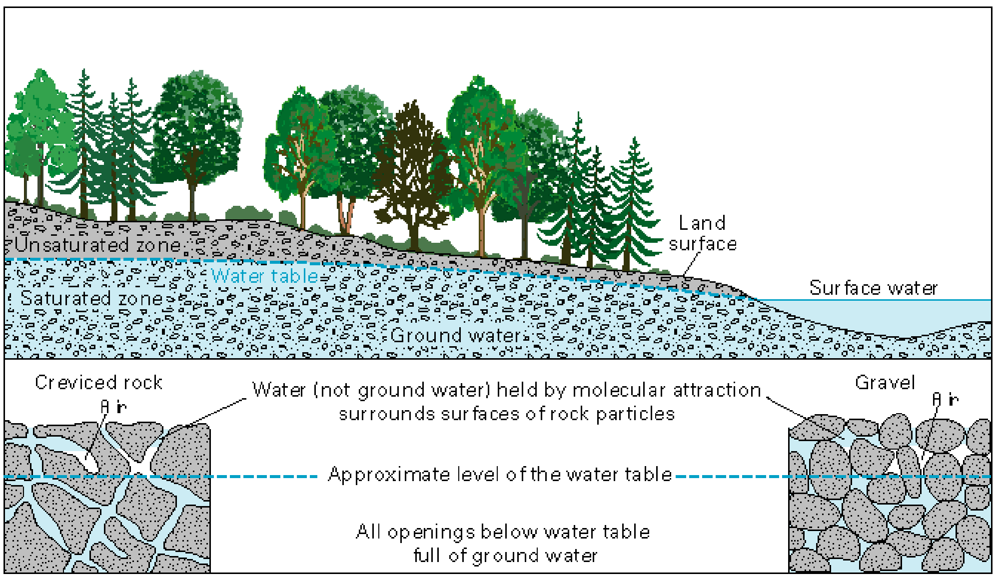

Figure B-2: How groundwater occurs in rocks. (U.S. Geological Survey)

The natural refilling of aquifers at depth is a slow process because groundwater moves slowly through the unsaturated zone and the aquifer. It has been estimated that aquifers that lie in areas of slight precipitation may take centuries to refill. In contrast, a shallow aquifer in an area of substantial precipitation may be replenished almost immediately. Therefore, the rate of recharge (the process by which groundwater is replenished) and recharge area (the area where water from precipitation is transmitted downward toward an aquifer) are important considerations. (U.S. Geological Survey, 1999, Ground Water; Washington State Department of Ecology, 1986)

The rate of water infiltration depends on vegetation cover, slope, soil composition, depth to the water table, the presence or absence of confining units and other factors. A confining unit is a bed of relatively impermeable materials through which water cannot flow or flows very slowly. In locations where permeable aquifers, typically sandstones (which are found in the Great Lakes - St. Lawrence River basin), are bounded above and below by beds of low permeability, a confined aquifer exists. Such impermeable beds above a confined aquifer prevent rainwater from infiltrating downward into the aquifer. Instead, the confined aquifer is recharged by precipitation over an area where water can travel down the aquifer (Figure

C-3). Depending on the location of the recharge area, this could result in precipitation from hundreds of miles away, or even outside the basin, infiltrating into the confined aquifer. Therefore, it is extremely important to know where these recharge areas occur in order to prevent them from being covered over by pavement or other impervious materials. Without the potential for infiltration, recharge cannot occur, and continued pumping of water from the aquifer will result in a depletion of the resource. (Press and Siever, 1998)

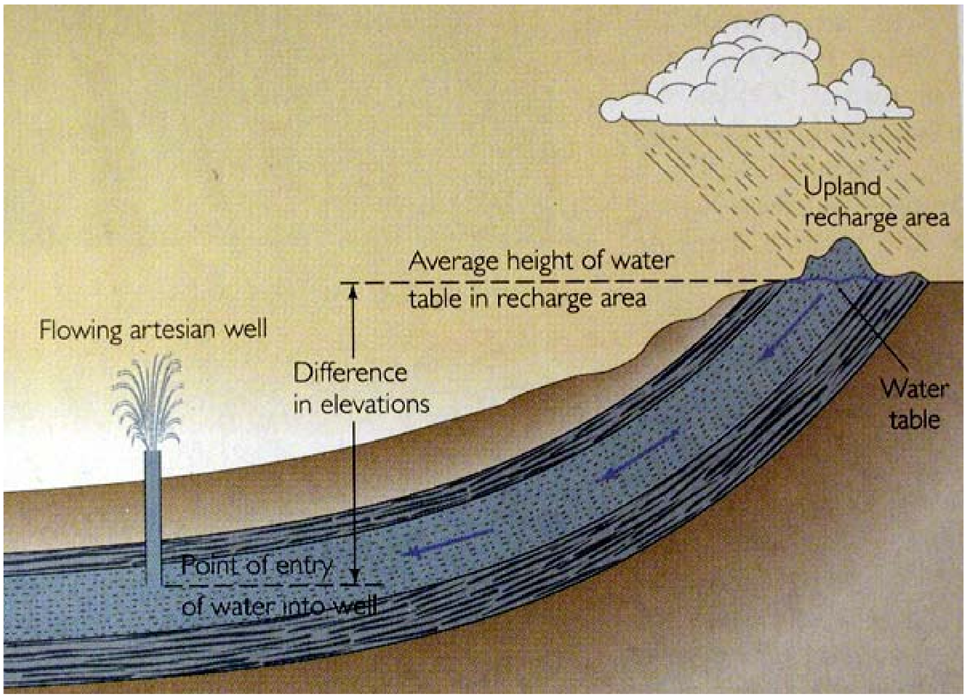

Figure B-3: Upland recharge area for a confined aquifer. (Press and Siever, 1998)

Discharge areas are the opposite of recharge areas. They are the locations at which the water table intersects with the land surface or a stream or lake. Where this occurs, groundwater leaves the aquifer and flows to the surface in the form of springs or seeps. Under the force of gravity, groundwater flows from high areas to low areas. Consequently, high areas such as hills or plateaus are typically where aquifers are recharged and low areas such as river valleys are where they discharge. (Washington State Department of Ecology, 1986)

In the Great Lakes - St. Lawrence River basin, the groundwater system is recharged mainly by the infiltration of precipitation. As a result, withdrawal of groundwater at rates greater than the recharge rate causes water levels in aquifers to decline and the amount of flow into surface waters to decrease. If the amount of decline is sufficient, water may be drawn from streams or lakes into the groundwater system, thus reducing the amount of their waters directly discharging to the Great Lakes (Figure B-4 B). This illustrates a key link between the balance of ground and surface waters within the Great Lakes - St. Lawrence River basin (International Joint Commission, 2000).

This balance between discharge and recharge is strongly affected by the rate at which water moves in the ground. Most groundwater moves slowly, a fact of nature that maintains supply of groundwater. If groundwater were to move as rapidly as rivers, aquifers would rapidly run dry after a period of time without rain, just as many small streams run dry. (Press and Siever, 1998)

Groundwater extraction, especially in areas of growing population, can result in the lowering of the level of groundwater when water extraction exceeds the rate at which the aquifer can recharge. As water in sediments is removed, the sediments undergo additional compaction and this loss of volume is reflected in the lowering of the surface. Potential impacts of the ground deformation include damage to buildings, roads and underground pipes. The price tag for flooding and structural damage associated with subsidence exceeded $125M per year nationally as of the early 1990s (National Research Council, 1991). Although a few experiments have attempted to reverse subsidence by pumping water back into the groundwater system, they have not been successful since most compacted materials do not expand easily to their former state. Therefore, in areas where land subsidence has occurred, the best solution to stem further subsidence has been to restrict overpumping of the groundwater. (Press and Siever, 1998)

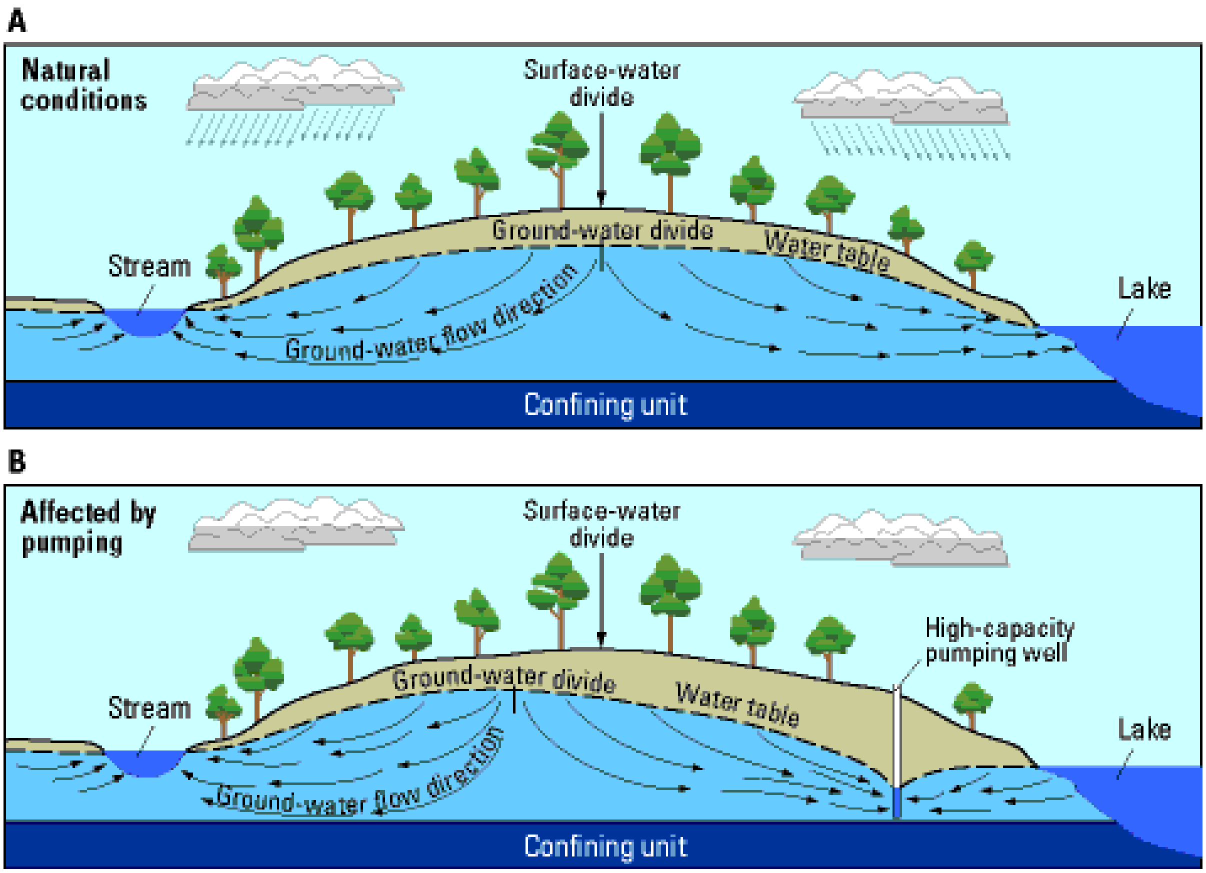

Figure B-4: Generalized groundwater flow (A) under natural conditions and (B) affected by pumping. In figure B, water flows from the lake into the groundwater system when affected by high-capacity pumping. (U.S. Geological Survey)

Another important concept to understand is the groundwater basin. A groundwater basin may be defined as a hydrogeologic unit containing one large aquifer or several connected and interrelated aquifers. Groundwater basins may have boundaries that are considerably different from the boundaries of surface water basins to which they discharge. In fact, there may be several groundwater basins layered at different depths, and each of these groundwater basins may have a boundary that does not coincide with the boundary of the surface water basin under which it is found. For example, the aquifers that act as sources of groundwater for the land within the Great Lakes - St. Lawrence River basin extend beyond the boundaries of the surface water basin (Figure B-1).

A groundwater basin may be separated from adjacent basins by geologic boundaries such as a topographic high, an impermeable body of rock, or by hydrologic boundaries such as a large body of surface water or a groundwater divide. A groundwater divide is represented by the position of the water table from which groundwater moves away in both directions. Groundwater divides generally coincide with a surface feature (topographic high), but may be influenced by hydraulic stresses including pumping from wells and varying rates of recharge on either side of the divide (Figure B-4 A and B).

Existing Data Collection and Monitoring Programs

As described above, the quantity of groundwater that can be withdrawn from a groundwater basin varies depending on the characteristics of the water-bearing rocks and sediments. Therefore, to understand the groundwater system for the Great Lakes - St. Lawrence River basin, it is imperative to understand the soils and bedrock found within and adjacent to the basin. The following sections provide a brief summary of current and ongoing soil survey digitizing efforts by various agencies and organizations within the Great Lakes - St. Lawrence River basin.

Soils Mapping – United States

National Cooperative Soil Survey Program

The National Cooperative Soil Survey Program (NCSS) is a partnership led by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), made up of federal, regional, state and local agencies and institutions. This partnership works together to cooperatively investigate, inventory, document, classify and interpret soils and to disseminate, publish and promote the use of information about the soils of the United States and its trust territories. The activities of the NCSS are carried out on national, regional and state levels. For example, individual state and regional offices of the NRCS are responsible for the implementation of the soils mapping in the form of countywide soil surveys.

Soil surveys provide a scientific inventory of soil resources that includes maps showing the locations and extent of soils, data about the physical and chemical properties of those soils and information derived from those data about potentialities and problems of use on each kind of soil. This information is in adequate detail to meet the needs of farmers, agricultural technicians, community planners, engineers and scientists in planning and transferring the findings of research and experience to specific land areas (U.S. Department of Agriculture, 2003, National Cooperative Soil Survey).

National Soil Information System

The National Soil Information System (NASIS) is the core component of the NRCS effort and is designed to manage and maintain soil data from collection to dissemination. NASIS maintains the hierarchical structure of soil survey data, through the use of table-oriented editors, but allows for new flexibility in creating and maintaining soil survey data. The state offices of the NRCS are responsible for the development and distribution of a state subset of the NASIS data.

Soil Survey Geographic Database

The focus of the NRCS is shifting from producing static printed soil survey reports to providing a dynamic resource of soils information for a wide range of needs. The current effort is to digitize original soil survey maps using national standards to create a Soil Survey Geographic (SSURGO) database. The map extent for a SSURGO data set is a soil survey area, which may consist of a county, multiple counties, or parts of multiple counties. A

SSURGO data set consists of map data, attribute data and metadata. SSURGO digitized maps are the most detailed level of soil mapping done by the NRCS. Mapping scales generally range from 1:12,000 (one inch on the map equals 1,000 feet on the ground) to 1:63,360 (one inch on the map equals 1 mile on the ground). This level of mapping is designed for use by landowners, townships and county natural resource planning and management. Table B-2 (in Findings section) shows the status of each Great Lakes state's SSURGO digitizing effort. Digitization of existing soil surveys for the entire country is estimated to be completed by 2007, dependent upon sustained funding at the current level. (U.S. Department of Agriculture, 2001, Soil Survey Geographic Data Base)

State Soil Geographic Database
Maps for the State Soil Geographic (STATSGO) database are made by generalizing the detailed soil survey data for each county at a mapping scale of 1:250,000 (one inch on the map equals approximately 4 miles on the ground). This level of mapping can be used for broad planning and management uses covering state, regional and multi-state areas. Existing STATSGO maps are now being digitized for incorporation into a national database except in cases where revisions are necessary before digitization. This digitization effort is separate from the SSURGO digitizing effort. (U.S. Department of Agriculture, 2001, State Soil Geographic Data Base)

State-Level Soil Mapping Efforts
As stated previously, the NRCS soil survey digitizing effort is a partnership made up of federal, regional, state and local agencies and institutions. In some instances, individual state departments of natural resources, agriculture and transportation, soil and water conservation districts, counties and other federal agencies such as the U.S. Forest Service, have worked cooperatively to provide reliable digital soil information for the states.

For example, Ohio's Statewide Digital Soils Information Project is part of the NRCS nationwide initiative to develop and digitize statewide soil information. This project was conceived as a joint venture by the Ohio Department of Natural Resources (DNR), NRCS and the Ohio State University's School of Natural Resources and has been cost-shared by multiple federal, state and local agencies and academic institutions in order to provide statewide soil survey information for use in three-dimensional Geographic Information System (GIS) format by 2006 (Ohio Department of Natural Resources, 2002). Other states such as Minnesota, in conjunction with the NRCS and various academic institutions, have compiled data and information sets based on soil and landform characteristics in the form of state soil atlases. This type of information may be useful for regional decisionmaking or other cartographic purposes.

Soils Mapping – Canada

Canadian Soil Information System
Since 1972, the Canadian Soil Information System (CanSIS) has supported the research activities of Agriculture and Agri-Food Canada (AAFC) and Natural Resources Canada by building the National Soil Database (NSDB). The NSDB is a set of computer readable files, which contain soil, landscape and climatic data for all of Canada. It serves as the national archive for land resources information that was collected by federal and provincial field surveys, or created by land data analysis projects. The NSDB includes GIS coverages at a variety of scales and the characteristics of each named soil series. (Agriculture and Agri-Food Canada, 2000, Canadian Soil Information System AND Agriculture and Agri-Food Canada, 2003, National Soil Database)

The principal types of NSDB data holdings include the following:

- Soil Map of Canada/Land Potential Database
  The Land Potential Data Base (LPDB) is a computerized information base, containing data about soil, climate, physiography, land use, modeled constraint free (potential) crop yields, actual crop yields and soil degradation for all regions of Canada. These data are referenced to map polygons of the Soils of Canada map, at a scale of 1:5,000,000. The LPDB is a comprehensive national source of information on the land resources of Canada.

- Agroecological Resource Areas
  The Agroecological Resource Area (ARA) maps were developed to provide biophysically homogenous units at a scale of 1:2,000,000 and includes climatic, economic, crop, soil and landscape data. These ARAs represent areas of generally similar agricultural potential and are based on ecoclimatic zonation, landform and soil characteristics.

- Soil Landscapes of Canada
  The Canadian Land Resources Network has created a series of GIS coverages that show the major characteristics of soil and land for the whole country. Soil Landscapes of Canada (SLCs) are based on existing soil survey maps and have been recompiled at a scale of 1:1,000,000. Information is organized according to a uniform national set of soil and landscape criteria based on permanent natural attributes. The full array of attributes that describe a distinct type of soil and its associated landscape, such as surface form, slope, water table depth, permafrost and lakes, is called a soil landscape. SLCs were originally conceived as a standardized database consisting of major attributes important to plant growth, land management and soil degradation. These data have since turned out to be a useful framework to support other databases, including Environment Canada's Ecological Land Classification System.

- Canada Land Inventory
  The Canada Land Inventory (CLI) is a comprehensive multi-disciplinary land inventory of rural Canada, covering over 2.5 million square kilometers of land and water. Over 1,000 mapsheets at the 1:250,000 scale were created during the 1960s, 70s and early 80s, showing the land capability for agriculture, forestry, wildlife, recreation and wildlife. Although the information is old, and better information is available for some areas as part of more recent soil surveys, the interpretations are still largely valid, and many jurisdictions still use them for land use planning purposes.

- Plan Detailed Soil Surveys
  Soil surveys have been published for most of the agricultural areas and many surrounding areas across Canada. Data from these surveys comprise the most detailed soil inventory information in the NSDB. The scale of the soil surveys vary from 1:20,000 to 1:250,000 as does the data content and availability of digital data.

Soils Ontario Program
The Ontario Ministry of Agriculture and Food (OMAF, formerly the Ontario Ministry of Agriculture, Food, and Rural Affairs) and AAFC, in cooperation with the Ministry of Natural Resources, have begun compiling a high quality, detailed, geospatial soils database in a seamless format. This database consolidates the existing digital soil mapping that exists

individually on a county basis in a seamless standardized product. The project coverage generally encompasses the area of the province south of the Canadian Shield. (Ontario Ministry of Agriculture and Food, 2003, Soils Ontario)

A list of additional soil programs and sources of data may be found in the Inventory tables located at the end of this appendix.

Geologic Mapping – United States

Over the last 1-2 million years, continental ice sheets repeatedly advanced and retreated over the Great Lakes - St. Lawrence River region leaving behind mud, clay, sand and gravel in deposits typically thicker than 100 feet. A three-dimensional knowledge of the characteristics, distribution and thickness of these deposits is required to address a wide range of current management and planning issues, including the quality, quantity, distribution and accessibility of surface and groundwater. Therefore, to improve our understanding of the importance of groundwater flow in unconsolidated and bedrock aquifers in the Great Lakes watershed, new geologic maps that show the extent, thickness and boundaries of these bedrock and glacial drift formations are needed. (Berg, et al, 1999)

Central Great Lakes Geologic Mapping Coalition

In 1999, the state geological surveys of Illinois, Indiana, Michigan and Ohio joined with the USGS (under the Earth Surface Dynamics Program) to form the Central Great Lakes Geologic Mapping Coalition. The Coalition is working to map the unconsolidated glacial materials within the four participating states from the surface down to the upper level of the bedrock unit in reduced-scale, three-dimensional digital form. This type of mapping varies from traditional two-dimensional geologic mapping in that it is now possible to view the vertical layering of materials.

Field observations and logs of water wells, satellite imagery, aerial photographs, engineering and test borings are used to construct the Coalition's three-dimensional maps. Since this type of geologic data can be difficult and expensive to obtain, the Coalition has collaborated and cost-shared on data collection efforts with private consultants, state geological surveys and academic institutions. This data is then stored in a database that allows a wide range of users to manipulate maps to analyze specific layers in support of critical decisionmaking with regard to natural resources. For instance, a hydrologist might use a layer of the subsurface map that depicts the shape of an aquifer in order to help manage and conserve the groundwater resource. (Central Great Lakes Geologic Mapping Coalition, 1999 and 2000)

Since its inception in 1999, the Central Great Lakes Geologic Mapping Coalition has received modest funding, which has enabled several smaller pilot mapping projects and other program development and educational activities to occur throughout the four participating states. Within the Great Lakes surface water basin, specific mapping projects have included quadrangles in Allen County, Indiana; the lower Huron River basin in Ohio; and Berrien County, Michigan. A fourth project, the Antioch quadrangle in Lake County, Illinois, is located just outside the surface water basin but within an aquifer directly affected by Great Lakes surface watersheds.. While somewhat costly to produce due to the reduced-scale and detailed format, it has been estimated that this type of geologic mapping is worth 25 to 39 times the cost of making the map. (Central Great Lakes Geologic Mapping Coalition, 1999 and 2000)

National Cooperative Geologic Mapping Program

The National Geologic Mapping Act of 1992 established the National Cooperative Geologic Mapping Program (NCGMP) to implement and coordinate an expanded geologic mapping effort by the USGS, the state geological surveys and academia. The primary goal of the program is to collect, process, analyze, translate and disseminate earth-science information through geologic maps. Over the last decade, technological advances in computing and spatial data analysis have enabled the program to provide geologic map data in digital formats that can be used by the public at all levels to assist in analysis and decisionmaking. The NCGMP has three primary components: STATEMAP, a matching-funds grants program with state geological surveys; FEDMAP, which funds federal mapping projects; and EDMAP, a geologic mapping education matching-funds program with academic institutions. (U.S. Geological Survey, 2001, National Cooperative Geologic Mapping Program)

- State Geological Mapping Program

  The STATEMAP program is an important component of the NCGMP because it assists states in the development of stacked-unit, three-dimensional mapping of the state's surficial and bedrock geology. This type of high quality, large-scale mapping shows the materials in the vertical sequence from the surface down to the bedrock, which is crucial information needed to assess movement of groundwater and for determining the locations and potential of aquifers. The STATEMAP program is a cooperative program, leveraging federal dollars with state funds at a 1:1 match. Funding is competitive nationwide and is awarded based on the quality of the proposal and the state's ability to match the federal funds. This allows states to have more freedom in the design and execution of the mapping project. Typically, most maps are created at a scale of 1:24,000, but may be 1:100,000. A list of the STATEMAP projects within the Great Lakes - St. Lawrence River basin since the program's inception in 1993 is available in Table B-1. (U.S. Geological Survey, 2001, National Cooperative Geologic Mapping Program)

- Federal Geologic Mapping Program

  The FEDMAP component of the NCGMP provides federal funding to the USGS for geologic mapping activities throughout the country and also provides a national perspective to the geologic mapping effort. Within the Great Lakes - St. Lawrence River region, FEDMAP-funded NCGMP efforts have assisted the Central Great Lakes Geologic Mapping Coalition in providing critical geologic map information on the three-dimensional distribution and characteristics of the glacial deposits.

- Geologic Mapping Education Program

  The EDMAP component of the NCGMP is designed to train student mappers and is unique among research grant programs in its emphasis on the development of geologic mapping skills and production of new geologic maps. Proposals are submitted by graduate students or upper level undergraduate students, along with a faculty supervisor, to request support for mapping projects. These projects require the creation of a new geologic map at a scale of 1:24,000 or larger that covers a 7.5-minute quadrangle or part of a quadrangle. Projects are funded on a year-by-year basis and all federal funds must be matched 1:1 by the academic institutions.

Table B-1: STATEMAP-Funded Projects within the Great Lakes - St. Lawrence River basin

State	Federal Fiscal Year	Quadrangles Mapped	Federal Dollars	State Dollars	Total Project Dollars
Illinois	1993-2002	No STATEMAP-Funded Projects in the Basin			
Indiana	1993	Chicago 30x60-min Quad (Phase 1) – Glacial Terrain Map (1:100,000 & 1:24,000)	$24,426	$64,160	$88,586
	1994	Chicago 30x60-min Quad (Phase 2) – Glacial Terrain Map (1:100,000 & 1:24,000)	$57,938	$79,418	$137,356
	1995	Dyer, Crown Point and Saint John – Glacial Terrain Map (1:24,000)	$35,000	$53,203	$88,203
	1996	Shipshewana, Topeka, Middlebury, Millersburg, and Sturgis – Glacial Terrain Map (1:24,000) Digital Conversion of Maps/Report of Allen County	$51,446 $12,290	$51,673 $13,191	$103,119 $25,481
	1997	Mongo and Wolcottville Quads – Glacial Terrain Maps (1:24,000)	$44,827	$45,101	$89,928
	1998	Middlebury, Millersburg, Bristol, Goshen, Stroh, Orland and Bronson South Qquads – Glacial Terrain Maps (1:24,000)	$56,045	$57,008	$113,053
	1999	Michiana Corridor – Geological Mapping (1:24,000)	$62,950	$63,052	$126,002
	2000	Michiana Corridor – New Mapping (1:24,000)	$63,775	$64,502	$128,277
Michigan	1995	St. Joseph Co. (Yr 1) – Surficial Geology (1:24,000)	$15,000	$15,088	$30,088
	1996	St. Joseph Co. (Yr 2) – Surficial Geology (1:24,000) Kent Co. (Yr 1) – Surficial Geology (1:24,000)	$51,826 $25,420	$51,940 $25,420	$103,766 $50,840
	1997	St. Joseph Co. (Yr 3) – Surficial Geology (1:24,000)	$45,386	$45,494	$90,880
	1998	Kent Co. (Yr 2) – Surficial Geology (1:24,000) Van Buren Co. (Yr 1) – Surficial Geology (1:24,000)	$40,000 $21,000	$45,864 $21,962	$85,864 $42,962
	1999	Kent Co. (Yr 3) – Surficial Geology (1:24,000) Van Buren Co. (Yr 2) – Surficial Geology (1:24,000)	$52,837 $40,575	$54,842 $40,580	$107,679 $81,155
	2000	Van Buren Co. (Yr 3) – Surficial Geology (1:24,000) Genesee Co. (Yr 1) – Surficial Geology (1:24,000)	$42,507 $49,128	$42,503 $49,128	$85,010 $98,256
	2001	Van Buren Co. (Yr 4) – Surficial Geology (1:24,000) Genesee Co. (Yr 2) – Surficial Geology (1:24,000)	$46,183 $31,080	$46,765 $31,217	$92,948 $62,297
	2002	Genesee Co. (Yr 3) – Surficial Geology (1:24,000) Allegan Co. (Yr 1) – Surficial Geology (1:24,000)	$33,875 $41,125	$34,207 $41,227	$68,082 $82,352
State	**Federal Fiscal Year**	**Quadrangles Mapped**	**Federal Dollars**	**State Dollars**	**Total Project Dollars**

Minnesota	2001	Lakewood – Surficial & Bedrock Geology (1:24,000) Babbitt NE – Bedrock Geology (1:24,000) Knife River – Bedrock Geology (1:24,000) French River – Surficial & Bedrock Geology 1:24,000)	$25,750 $40,000 $12,875 $25,750	$25,750 $40,000 $12,875 $25,750	$51,500 $80,000 $25,750 $51,500
	2002	Knife River – Surficial Geology (1:24,000) Two Harbors – Surficial & Bedrock Geology (1:24,000)	$17,834 $35,667	$17,833 $35,667	$35,667 $71,334
New York	1993	White Plains – Surficial & Bedrock Geology	$9,000	$11,052	$20,052
	1994	South Onondaga – Surficial & Bedrock Geology	$20,000	$29,759	$49,759
	1996	Otisco Valley, Tully – Surficial & Bedrock Geology Mt. Kisco – Bedrock Geology (1/3)	$63,663	$67,014	$130,677
	1997	Marcellus, Jamesville – Surficial & Bedrock Geology Mt. Kisco (1/3), Angellica – Bedrock Geology	$85,162	$93,939	$179,101
	1998	Mt. Kisco (1/3) – Bedrock Geology	$10,149	$16,489	$26,638
	1999	Skaneateles – Surficial & Bedrock Geology Ashford Hollow, Monroe – Bedrock Geology	$66,848	$83,989	$150,837
	2000	Spafford – Surficial & Bedrock Geology West Valley, Sloatsburg – Bedrock Geology	$79,283	$81,739	$161,022
	2001	Digitize South Onondaga, Tully, Otisco Valley - bedrock & surficial, Marcellus – Bedrock Geology	$14,000	$15,190	$29,190
	2002	Oran – Surficial & Bedrock Geology Delavan, Sloatsburg – Bedrock Geology	$70,000	$72,849	$142,849
Ohio	1993	Northwestern Ohio, 90 7.5-min Quads – Bedrock Geology (1:24,000)	$40,035	$87,111	$127,146
	1994	North-Central Ohio, 47 7.5-min Quads – Bedrock Geology (1:24,000)	$29,375	$83,530	$112,905
	1995	Northeastern Ohio, 62 7.5-min Quads – Bedrock Geology (1:24,000)	$20,000	$49,955	$69,955
	1996	Digitization of Bedrock-Geology and Bedrock-Topography Maps for North-Central Ohio	$13,156	$13,156	$26,312
	1998	Lorain & Put-in-Bay 30x60-min Quads (incl. 36 7.5-min Quads) – Surficial Geology (1:100,000)	$84,815	$84,815	$169,630
	1999	Cleveland South 30x60-min Quads (incl. 30 7.5-min Quads) – Surficial Geology (1:100,000)	$103,802	$103,803	$207,605
	2000	Canton & East Liverpool 30x60-min Quads (incl. 2 7.5-min Quads) - Surficial Geology (1:100,000)	$4,162	$4,162	$8,324
Pennsylvania	1993-2003	No STATEMAP-Funded Projects in the Basin			
Wisconsin	1996	Manitowoc Co. (Yr 1) – Quaternary Geology (1:100,000)	$47,502	$48,130	$95,632
	1997	Manitowoc Co. (Yr 2) – Quaternary Geology (1:100,000) Kewaunee Co. (Yr 1) – Quaternary Geology (1:100,000)	$48,604 $28,086	$48,621 $29,428	$97,225 $57,514

	1998	Kewaunee Co. (Yr 2) – Quaternary Geology (1:100,000) Walworth, Racine and Kenosha Co. – Paleozoic Geology (1:100,000)	$31,253 $51,877	$32,815 $52,889	$64,068 $104,766
	1999	Milwaukee and Waukesha Co. – Paleozoic Geology (1:100,000) Door Co. (Yr 1) – Quaternary Geology (1:100,000)	$59,574 $54,445	$65,360 $56,199	$124,934 $110,644
	2000	Ozaukee Co. – Paleozoic Geology (1:100,000) Door Co. (Yr 2) – Quaternary Geology (1:100,000)	$32,581 $46,848	$30,352 $53,554	$62,933 $100,402
	2001	Washington Co. – Paleozoic Geology (1:100,000) Door Co. (Yr 3) – Quaternary Geology (1:100,000) Fox River Lowland (Yr 1) – Quaternary Geology (1:100,000) Digital Compilation of Existing Maps in Vilas, Florence, Forest and Langlade Counties	$32,480 $30,029 $91,467 $13,255	$32,740 $31,974 $91,482 $13,788	$65,220 $62,003 $182,949 $27,043
	2002	Fox River Lowland (Yr 2) – Quaternary Geology (1:100,000) Fond du Lac Co. (Yr 1) – Paleozoic Geology (1:100,000)	$97,000 $35,000	$97,000 $35,000	$194,000 $70,000

(State Geological Surveys and U.S. Geological Survey)

National Geologic Map Database
As part of the NCGMP, a National Geologic Map Database is being created as a national archive containing geologic maps and related databases. Geologic maps, derivative maps and related information serve as a vital role in supporting public and private decision-making, general education and advances in scientific research. This database will eventually include all geologic mapping being done by the states, the USGS and other professional associations and allow for viewing and manipulation of the data. (U.S. Geological Survey, 2001, National Cooperative Geologic Mapping Program)

State-Level Geologic Mapping Efforts
At the state level, individual state geological surveys and departments of natural resources are working to map the surficial and bedrock geology of each state. These mapping activities may range in scale. However, where possible, states are utilizing the most efficient field approaches, modern mapping technologies and digital analysis to provide up-to date, detailed geological information. As data is gathered and organized, databases are being developed that can be used directly or as the basis for map products.

In addition, many of the Great Lakes states have completed three-dimensional aquifer visualization mapping and groundwater flow modeling. Pertinent data from these studies have been gathered and organized to develop computerized datasets and models that can be used by managers and regulators to visualize the distribution of shallow aquifers and flow of groundwater in various portions of the region. For example, the State of Ohio's Statewide Aquifer Mapping Project, which began in March 1997 and ended in March 2000, worked to delineate aquifer boundaries, quantify yields, develop a standardized naming system and define aquifer thickness for all of the significant aquifers in the state.

Prior to the initiation of this project, the State of Ohio did not have a statewide aquifer map for unconsolidated (glacial) or bedrock aquifers and had no formal identification system for aquifer boundaries, types, or names. Partial funding for the project was provided by a grant obtained from the U.S. Environmental Protection Agency (USEPA) under Section 319 of the Clean Water Act. (Ohio Department of Natural Resources, 2003, Statewide Aquifer Mapping Project)

Geologic Mapping – Canada

Geological Survey of Canada – GeoServ
The Geological Survey of Canada (GSC) is part of the Earth Sciences Sector of Natural Resources Canada and is Canada's premier agency for geoscientific information and research. One of the mandates of the GSC is to provide geoscience information on the Canadian landmass required for sustainable development of Canada's resources and protection of the environment, to identify geohazards, to monitor global changes and provide standard surficial geology maps of the country. Developed by the Terrain Sciences Division of the GSC, GeoServ provides access to geoscience data in the form of dynamic maps and databases, which can be explored on the Internet. (Natural Resources Canada, 2002, Geological Survey of Canada)

Ontario Geological Survey – Mapping the Geologic Framework of Ontario
At the provincial level, the Ontario Geological Survey (OGS) is part of the Mines and Mineral Division of the Ontario Ministry of Northern Development and Mines. One of OGS Sedimentary Geoscience Section’s main tasks is to conduct systematic mapping of the surficial and glacial deposits of the province at a scale of 1:50,000. These detailed maps have been digitized and are now available for wider use. (Ontario Ministry of Northern Development and Mines, 2003)

In order to develop the regional-scale hydrogeological understanding necessary for planning urban development while protecting groundwater resources, the GSC and the OGS will be working together to study the geological framework of southern Ontario over the next ten years. This study is based on previous efforts to develop regional three-dimensional mapping methods for the Oak Ridges Moraine, which includes most of the Greater Toronto Area. The Oak Ridges Moraine study should have broad application in the Great Lakes - St. Lawrence River basin.

Northern Ontario Engineering Geology Terrain Studies
The OGS and Canada Centre for Remote Sensing have undertaken a project to develop a methodology for engineering geology terrain analysis using Digital Elevation Models (DEMs) and remotely sensed imagery for areas within the north central Ontario. Four main components of the terrain are considered: material, landform, relief and regional drainage conditions; this follows the existing format of Northern Ontario Engineering Geology Terrain Studies (NOEGTS) maps (Gartner, et al, 1981).

NOEGTS maps (1:100,000 scale) provide useful information concerning the landscape for forest management, mineral exploration and civil engineering undertakings and are currently undergoing digitization for wider use. Over the past few years, methods for creating or predicting landform, topography (relief) and drainage condition components of the NOEGTS legend have also been developed (Barnett and Singhroy 2000). A list of additional sources of geologic data may be found in the Inventory tables located at the end of this appendix.

Groundwater Data Collection Programs and Observation Networks – United States

The foundation of any good groundwater analysis, including those analyses whose objective is to propose and evaluate alternative management strategies, is the availability of high-quality data. Thus, a key starting point for assuring a sustainable future for any groundwater system is the development of a comprehensive hydrogeologic database over time (Alley, et al, 1999).

As the primary Federal science agency for water-resource information, the USGS monitors the quantity and quality of water in the nation's rivers and aquifers, assesses the sources and fate of contaminants in aquatic systems, develops tools to improve the application of hydrologic information and ensures that its information and tools are available to all potential users. The following sections provide a brief summary of current and ongoing groundwater-related monitoring and data collection efforts by various agencies and organizations within the Great Lakes - St. Lawrence River basin.

Regional Aquifer-System Analysis Program

The Regional Aquifer-System Analysis (RASA) Program of the USGS was initiated in 1978 and was completed in 1995. The purpose of this program was to define the regional hydrogeology and establish a framework of background information on geology, hydrology and geochemistry of the nation's important aquifer systems. Twenty-five of the nation's major aquifer systems were studied under this program. Four of these RASA study units incorporated parts of the Great Lakes - St. Lawrence River basin, including the Michigan basin, Midwestern Basins and Arches, Northern Midwest and Northeast Glacial Aquifers RASA study units. However, most of the RASA assessments are now 10 to 20 years old, and groundwater issues have increased in scope as competing demands on the resource have grown.

Starting in 1988, the program devoted part of its resources to compilation of a National Groundwater Atlas that presets a comprehensive summary of the nation's major groundwater resources. The atlas, which is designed in a graphical format supported by descriptive text, serves as a basic reference for the location, geography, geology and hydrologic characteristics of the major aquifers in the nation. (Sun, et al, 1997) Beginning in fiscal year 2004, the USGS will be working to update several of the RASA models; however, it has not yet been decided which proposals for these updates will be funded or whether any of these updates will be for models that occur within the Great Lakes - St. Lawrence River basin.

Ground-Water Resources Program

The Ground-Water Resources Program was created to replace the RASA Program and encompasses regional studies of groundwater systems, multidisciplinary studies of critical groundwater issues, access to groundwater data and research and methods development. The program provides unbiased scientific information and many of the tools that are used by federal, state and local management and regulatory agencies to make important decisions about the nation's groundwater resources.

Based on a National Research Council report in November 2000, titled "Investigating Groundwater Systems on Regional and National Scales," the following scientific issues have been identified as high priority for the Ground-Water Resources Program:

- Support for Aquifer Management Support for Aquifer Management Decisions – Innovations in artificial recharge, water reuse and conjunctive use of groundwater and surface-water resources are leading to new challenges for USGS scientists to provide the data analyses and predictive tools to support sound aquifer management decisions.

- Natural Groundwater Recharge – Improved knowledge of recharge processes, development and testing of new recharge estimation techniques and methods to scale up specific site-recharge estimates to regional values are needed.

- Groundwater Flow in Shallow Aquifers – Shallow aquifers are particularly vulnerable to contamination from human activities and sensitive to droughts and climate change.

- Groundwater and Surface Water Interaction – It is recognized that nearly all surface-water features (streams, lakes, reservoirs, wetlands and estuaries) interact with groundwater. A fundamental understanding of these interactions is needed to evaluate their effects on water availability and the environment and to support watershed planning and management.

- Groundwater in Karst and Fractured-Rock Aquifers – New methods are needed to help understand groundwater flow in karst and fractured-bedrock aquifers, which are the principal aquifers in many parts of the nation. Many groundwater issues are amplified in fractured-rock aquifers because responses to pumping stresses and contamination can be more rapid than in aquifers where water flows through material such as sand and gravel.

- Improved Hydrogeologic Frameworks – More maps that accurately show the geology in three-dimensions, as well as improved conceptual and statistical models of the geologic framework of aquifers, are needed to adequately assess groundwater resources and determine the effects of groundwater withdrawals.

Evaluation of the issues listed above will require new methods of collecting and analyzing groundwater data. Government agencies, institutions and private companies around the world use models developed by the USGS for simulating groundwater flow and contamination. As computer technology improves and new issues emerge, improvements are needed to better integrate models with advanced GIS and hydrogeologic data bases. Development of new field techniques also continues to be a high priority of the program. These techniques include geophysical methods for groundwater studies and groundwater age-dating methods to determine aquifer properties and understand the interaction of groundwater and surface water.

Comprehensive, long-term data bases are needed to support management of the nation's resources for groundwater. Data-related priorities for the Ground-Water Resources Program include 1) improved water-level monitoring of major aquifers, 2) greater access to groundwater data through the Internet, and 3) development of systems for storage and presentation of the three-dimensional extent of aquifers and their hydrologic characteristics. (U.S. Geological Survey, 2001, Ground-Water Resources Program)

Within the Great Lakes - St. Lawrence River basin, the Ground-Water Resources Program is currently funding two projects: a groundwater flow model of the St. Joseph River watershed in Michigan and a Western Lake Erie multidisciplinary project to estimate groundwater discharge to Western Lake Erie.

Cooperative Water Program
For more than 100 years, the Cooperative (Coop) Water Program has been a highly successful cost-sharing partnership between the USGS and water-resource agencies at the state, local and tribal levels. Most work in the Coop Program is directed toward potential and emerging long-term problems, such as water supply, waste disposal, groundwater quality, effects of agricultural chemicals, floods, droughts and environmental protection. The Coop Program also combines the utilization of USGS offices within states with the much larger national infrastructure of the USGS. This infrastructure includes the National Water Quality Laboratory, the National Water Information System, the National Research Program (which provides new methods and consultation on difficult scientific issues), instrumentation testing facilities and a national system of quality assurance.

Most of the USGS data-collection stations serve multiple purposes and many are funded, wholly or in part, through cooperative agreements. In FY 2002, more than 1,400 state, regional, local and municipal agencies and tribes participated in the Coop Program. Normally, these stations, though funded by various organizations, are operated as part of an integrated network rather than as stand-alone entities. This arrangement also assures that data collection in remote areas does not become so expensive that these stations must be dropped from the network. Based on USGS data-collection activities in 2002, there are approximately 146 groundwater observation wells with the capability of monitoring groundwater levels located within or adjacent to the Great Lakes - St. Lawrence River basin (Figure B-5).

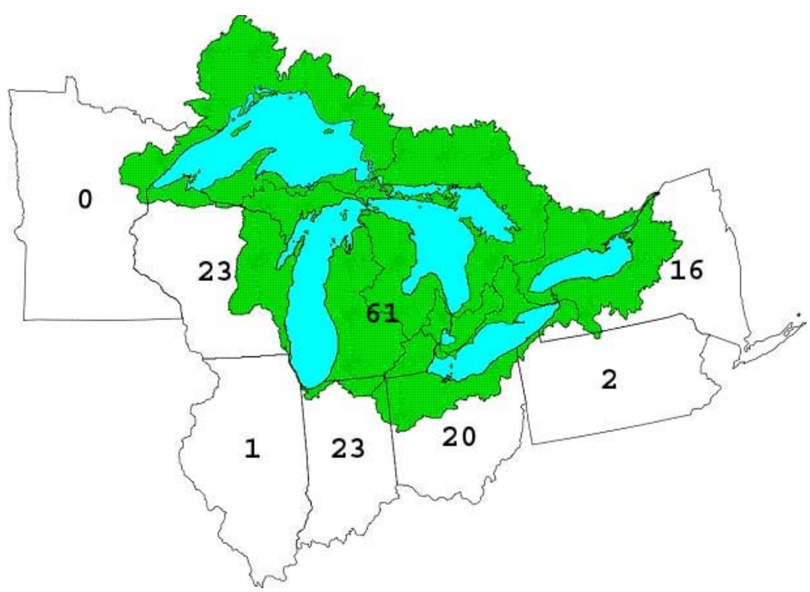

Figure B-5: Number of U.S. Geological Survey groundwater observation wells within or adjacent to the Great Lakes - St. Lawrence River basin for which water levels are monitored. (U.S. Geological Survey)

The hydrologic-data networks constitute the foundation for watershed and aquifer management and for many other USGS programs. Present and future USGS initiatives will require access to a comprehensive, uniform and accurate foundation of surface water, groundwater, water quality and water use data of national scope. Emphasis will be placed on biological monitoring to assess conditions that affect human health and aquatic health. Enhancement of the hydrologic data networks; improved accessibility and presentation of available information, such as an increase in the availability of real-time data for surface water and groundwater and presenting regional summaries of current conditions and coordination of program activities with those of other agencies continue to be high-priority activities. (U.S. Geological Survey, 2002, Cooperative Water Program)

Ground Water Climate Response Network
The USGS maintains a network of wells to monitor the effects of droughts and other climate variability on groundwater levels. The network consists of a national network of about 150 wells monitored as part of the Ground-Water Resources Program, supplemented by wells in some states monitored as part of the Cooperative Water Program. (U.S. Geological Survey, 2003, Ground Water Climate Response Network)

National Water-Quality Assessment Program
Since 1991, USGS scientists with the National Water-Quality Assessment (NAWQA) program have been collecting and analyzing data and information in more than 50 major river basins and aquifers across the nation. The goal is to develop long-term consistent and comparable information on streams, groundwater and aquatic ecosystems to support sound management and policy decisions. Of the 50 NAWQA study units nationwide, three of these are located at least partially within the boundaries of the Great Lakes - St. Lawrence River basin. These include the Upper Illinois River Basin, Lake Erie-Lake St. Clair Drainages and Western Lake Michigan Drainages study units. Data from these studies are available through the NAWQA Data Warehouse. (U.S. Geological Survey, 2001, The National Water-Quality Assessment Program)

Ground-Water Site-Inventory System
The USGS investigates the occurrence, quantity, quality, distribution and movement of surface and underground waters and disseminates the data to the public, state and local governments, public and private utilities and other federal agencies involved with managing our water resources via the National Water Information Systems website. The Ground-Water Site-Inventory (GWSI) System contains and provides access to inventory information about sites at stream reaches, wells, test holes, springs, tunnels, drains, lakes, reservoirs, ponds, excavations and water-use facilities. The system also provides for entering new sites within the local database. Data files contain well-construction, groundwater level, groundwater well or spring discharge, hydrogeologic characteristics, observation well report header, aquifer hydraulic, state groundwater use and miscellaneous data. (U.S. Geological Survey, 1998, National Water Information System)

State-Level Groundwater Data Collection Programs and Observation Networks
Other state-level groundwater data collection programs and observation networks include efforts by state departments of natural resources and geological surveys. For example, the Groundwater Section of the Indiana DNR is working to evaluate the groundwater resources of Indiana and disseminate the results through maps and reports. Typical projects include monitoring and analyzing pumping tests, preparing computer models of aquifers, evaluating effects of high capacity wells on local domestic wells, evaluating effects of lakebed and shoreline alterations of public freshwater lakes and preparing maps and text for reports on the state's ground water resources. The Groundwater Section also maintains a paper and digital database of records of water wells received from water well drillers. Water well

information and other geologic information is used to answer requests for data and provide ground water availability estimates.

Another example of a state-level program is the Minnesota DNR's Groundwater Technical Analysis Program. This program is responsible for conducting studies of groundwater availability and groundwater supply. Products and services from the program include: groundwater education, groundwater availability assessment, groundwater supply studies, well interference investigations, aquifer tests and pumping tests, groundwater modeling, groundwater mining, groundwater-surface water investigations, pollution confinement pump-outs, well sealing and environmental review and project evaluations. (Minnesota Department of Natural Resources, 2003, Groundwater Technical Analysis Program)

The Ohio DNR Division of Water's Water Resources Section is responsible for collecting, researching, interpreting and disseminating hydrologic and groundwater resource information for the State of Ohio through their Groundwater Level Monitoring Program. An important component of this program is to characterize Ohio's groundwater resources through monitoring and evaluating long-term trends in groundwater level fluctuations throughout the state's various aquifer systems. Beginning in 1938, with one groundwater well, the extent of the observation well network peaked during the early 1970s with 145 wells representing 83 of Ohio's 88 counties equipped with continuous recorders. At present, the network numbers 100 wells, representing 51 counties. Approximately 23 of these wells are located within the Great Lakes - St. Lawrence River basin. The groundwater level monitoring program is a cooperative effort between Ohio and the USGS. (Ohio Department of Natural Resources, 2003, Groundwater Level Monitoring in Ohio)

A program to seal unused wells on state-owned land is being implemented by the Minnesota DNR through their Well Sealing Program. Abandoned wells that are open on the surface can allow surface runoff and any contaminant contained in that runoff to enter groundwater supplies and completely bypass the natural filtration capacity of the soil. Deep abandoned wells that have cracked and damaged casings can allow contaminants to reach groundwater supplies that would normally be protected by a clay or other permeability layer.

The 1989 Minnesota Ground Water Act requires the DNR to inventory wells on state land and to prepare a plan to seal all unused wells on state land. In 1994, the Minnesota Legislature began allocating funds to locate and seal these unused wells (Minnesota Department of Natural Resources, 2003, Well Sealing Program). Similar abandoned well-sealing projects are also occurring in other Great Lakes states within the basin.

Groundwater Data Collection Programs and Observation Networks – Canada
Groundwater is vital to the Canadian economy and ecosystems. Groundwater supplies water to 30 percent of Canadians, and that number is growing. There are, however, major gaps in our understanding of this resource. While it is known that Canada's surface water represents 20 percent of the world's useable freshwater, the amount of groundwater is unknown. More needs to be known about the number, size, characteristics and dynamics of Canada's main aquifers.

Earth Sciences Sector Groundwater Program
The Natural Resources Canada Earth Sciences Sector (ESS) Groundwater Program focuses on determining the extent of the most strategic groundwater resources with emphasis on the synthesis of existing data and on the determination of resource characteristics of aquifers with critical dependencies for human use, agriculture and/or industry. The program's goal

is to enable water management agencies and well owners to make decisions that will result in a reliable groundwater supply through the provision of a national groundwater database and through supporting tools such as maps, publications and models. (Natural Resources Canada, 2003, Earth Sciences Sector)

Outputs from this program will include:

- Completion of current regional groundwater projects to the accepted Canadian Framework for Collaboration on Groundwater standards
- Maps of natural quality of the groundwater of regional aquifers
- Establishment of national database on groundwater including data on groundwater quantity and quality

National Water Research Institute
In the Great Lakes - St. Lawrence River basin, the National Water Research Institute (NWRI) is generating the first regional-scale description of groundwater conditions that will give water managers and conservation authorities the tools needed to protect groundwater resources in land and water use planning. (National Water Research Institute, 2003)

Provincial Groundwater Monitoring Program
In 1995, a review of existing groundwater monitoring programs within Ontario's Ministry of Environment (MOE) was undertaken by the Environmental Monitoring and Reporting Branch and concluded that most groundwater monitoring in Ontario is being conducted as part of site specific assessments. The review also determined that a network of monitoring wells existed in Ontario between 1946 and 1979. These monitoring wells were used to measure the fluctuations of groundwater levels for detailed hydrogeologic studies as well as for assessing the impacts of water supply withdrawals and the resolution of interference complaints. This review affirmed the need for a comprehensive groundwater database for Ontario to characterize the location, quality and sustainable yield of the resource and describe where, how and why changes occur.

In April 2000, the Ontario Cabinet approved $6 million to develop a groundwater monitoring network strategically distributed throughout the province. The objectives of this program were to install approximately 400 electronic monitors to measure water levels in wells across Ontario, establish a provincial groundwater information database, complete hydrogeologic mapping to support the selection of monitoring sites and undertake chemical analysis of water samples.

Currently, 300 of the wells are operating and 100 wells will be installed over the next year. These wells allow for observations 24-hours per day related to water levels and approximately 50 water quality parameters of interest. The design of the groundwater monitoring network is tailored to fit regional hydrogeologic and land use conditions, current and future water demands and the specific needs of various users. The information network is based on a cooperative partnership among federal and provincial agencies, conservation authorities, municipalities, industry, academia and the general public. (Ontario Ministry of the Environment, 2001)

A list of groundwater observation networks and other sources of data may be found in the Inventory tables located at the end of this appendix.

Water Drainage and Infiltration Studies – United States

Much of the agricultural lands in the Great Lakes - St. Lawrence River basin require the installation of tile drains to make them arable and to keep them from flooding. These tiles remove water from the land and work to lower the local water table. From a hydrologic standpoint, the presence of heavily-tiled areas results in less groundwater recharge and more movement of water directly into surface water bodies such as streams and rivers. This short-circuiting of the hydrologic system also leads to flashier overland flows and an increased flow in streams and rivers during storms. During times of drought, a lack of recharge to the groundwater system could have an impact on replenishing the water quantity in the Great Lakes, as there would be less subsurface flow from groundwater sources. The following sections provide a brief summary of current and ongoing drain tile studies and mapping efforts by various agencies and organizations within the Great Lakes - St. Lawrence River basin.

National Water Quality Assessment Program

The USGS NAWQA Program is currently working to create a mass budget for the water in Sugar Creek Basin in Indiana. This is part of a national study with similar studies being conducted in irrigated regions of Washington, California and Nebraska and humid areas in Maryland/Delaware. Researchers have been monitoring flow and collecting water samples from the primary hydrologic compartments (rain, tile drains, overland flow, streams, vadose zone and groundwater) to determine the flow paths and water quality in each hydrologic compartment. This type of data is important to understand how pesticides and nutrients move through the water source, which is also an important consideration when evaluating water withdrawals and use proposals.

In addition to the sampling of various hydrologic compartments, USGS researchers have been working with researchers at the University of Illinois at Urbana-Champaign to map drainage paths and tile fields within the basin using aerial infrared photography techniques. Aerial infrared photographs of the study area were taken after the crops were harvested from the fields and shortly after a rain to avoid significant crop residue that may block the view of the drainage pathways and tiles. Soil (hydric/non-hydric soils) and elevation coverages are then overlain on the infrared photographs to help delineate tile drains. One of the problems with the study to date is that the digitized SSURGO data for the Sugar Creek Basin has not been completed. Once completed, this data should help in the delineation of the tiles. Researchers have found that tiles are not always visible using infrared photography in fields where conservation tillage has been utilized. Methods using ground-penetrating radar are now being pursued to develop baseline techniques for viewing tiles with this type of technology.

Natural Resources Conservation Service and Soil and Water Conservation Districts

NRCS state offices and Soil and Water Conservation Districts keep records of new tiles installed by farmers, especially in cases where farmers are receiving financial or technical assistance from the these agencies. However, records are not well kept for the significant number of farmers who install tiles on their own.

University Research

Richard Cooke with the Department of Agricultural Engineering, University of Illinois at Urbana-Champaign and his team have been working on drain tile mapping procedures in areas where there are few records of the actual locations of drainage systems. Specifically, Cooke's team is using color infrared (CIR) aerial photographs and GIS analysis for mapping tile lines in Vermilion County, Illinois.

The drain tile mapping procedure is based on the fact that soil over efficiently draining tile line dries faster than the soil at other locations in the field and has higher reflectance in the infrared region of the radiation spectrum. CIR aerial photographs are taken in spring, a few days after a heavy rain storm, converted to digital format and subjected to edge enhancement to heighten the sharpness of the images. A GIS package is then used to overlay soil data, hydrological parameters, topography and vegetation cover. The combination of these map layers makes it possible to identify the layout of functional tile drainage systems. However, careful timing for obtaining the aerial photographs is required or else crop residue may block the view of the drainage pathways and tiles. The method appears to be a promising and cost effective tool as compared to conventional tile probe methods; however, additional research is needed. Cooke and his team are now pursuing ground-penetrating radar (GPR) to detect tiles in areas where their location is known to help improve the accuracy of the procedure. (Verma and Cooke, 1996)

Barry Allred with the Soil Drainage Research Unit at Ohio State University is using GPR to detect tile drains. Even though this method has proven to be more difficult in clay soils, Dr. Allred has been effective in applying these techniques. Typically, the electrical conductivity of the soil is greater where large amounts of clay are present. In these environments, the GPR can be effectively used at shallow depths (Allred, et al, 2002, 2003).

Water Drainage and Infiltration Studies – Canada

Constructed Drains Project

The OMAF is working to create a spatial database of drains that can easily be updated and integrated with watercourse data from other agencies. Enhanced drainage data will allow users to make more knowledgeable observations and decisions about current drainage conditions, future drainage plans and environmental conditions. The constructed drain data can also be used for the construction of DEMs and the delineation of watershed boundaries. (Ontario Ministry of Agriculture and Food, 2003, Constructed Drains Project)

Tile Drainage Project

Licensed agricultural tile drainage contractors create plans for numerous agricultural tile drainage systems and install thousands of feet of agricultural drainage tile each year. As a requirement of their license, each contractor must report to the OMAF the location of the area that has been tiled. The information collected each year is submitted as a small hand sketch of the drained area. As time permits, the sketched area has been re-mapped onto Mylar so that white prints showing areas of tile drainage can be produced on demand.

The objective of the Tile Drainage Project is to apply Global Positioning System (GPS) and GIS technology to support the standardized collection of drainage information from the drainage contractors. (Ontario Ministry of Agriculture and Food, 2003, Tile Drainage Project)

Northern Ontario Engineering Geology Terrain Studies

The OGS and Canada Centre for Remote Sensing have undertaken a project to develop a methodology for engineering geology terrain analysis using DEMs and remotely sensed imagery for remote areas within north central Ontario. Four main components of the terrain are considered: material, landform, relief and regional drainage conditions; this follows the existing format of Northern Ontario Engineering Geology Terrain Studies (NOEGTS) maps (Gartner, et al, 1981). NOEGTS maps (1:100,000 scale) provide useful information concerning the landscape for forest management, mineral exploration and civil engineering undertakings. Over the past few years, methods for creating or predicting landform, topography (relief) and drainage condition components of the NOEGTS legend have also been developed (Barnett and Singhroy 2000).

A list of infiltration, recharge, drainage programs or studies and other sources of data may be found in the Inventory tables located at the end of this appendix.

Groundwater Extraction and Consumptive Use Evaluation Programs – United States

When water is diverted or extracted from the Great Lakes - St. Lawrence River basin's groundwater system for other uses, this either temporarily or permanently removes water that may otherwise flow, or discharge into the basin's lakes or streams. This most commonly occurs through the pumping of groundwater from an aquifer and may or may not be returned back to the groundwater source, depending on the use of the water. Consumptive use, as defined by the Great Lakes Regional Water Use Database is "that portion of water withdrawn or withheld from the Great Lakes - St. Lawrence River basin and assumed to be lost or otherwise not returned to the Great Lakes - St. Lawrence River basin due to evapotranspiration, incorporation into products, or other processes."[1] In this situation, water that has been evaporated may be returned to the land in the form of precipitation. The following section provides a brief summary of current and ongoing efforts by the USGS to monitor groundwater extraction and use within the Great Lakes - St. Lawrence River basin. A detailed discussion of water extraction and consumptive use issues for the basin can be found in Appendix F.

National Water Use Information Program

The USGS National Water Use Information Program (NWUIP) is a cooperative program with state and local governments designed to collect, store, analyze and disseminate water-use information, both nationally and locally, to a wide variety of government agencies and private organizations. Every five years, data at the state and hydrologic region level are compiled into a national water use data system and are published in a national circular. With the implementation of the NWUIP in 1978, the USGS began to establish the framework to study the demand side of the water supply and demand equation. (U.S. Geological Survey, 2003, The National Water-Use Information Program)

Groundwater Flow Modeling Programs – United States

During the past several decades, computer simulation models for analyzing flow and solute transport in groundwater and surface water systems have played an increasing role in the evaluation of strategic approaches to groundwater development and management (Alley, et al, 1999).

Many of the same federal and state agencies and organizations that participate in groundwater monitoring and data collection programs also support various groundwater flow modeling programs within the Great Lakes - St. Lawrence River basin. The USGS is the primary federal agency in this effort. Government agencies, institutions and private companies around the world use models developed by the USGS for simulating groundwater flow and contamination. Most state departments of natural resources or geological surveys also support groundwater modeling programs. A detailed discussion of these programs can be found under the previous section entitled "Groundwater Data Collection Programs and Observation Networks – United States."

[1] All the Great Lakes states and provinces use this definition, except Minnesota, which defines consumptive use as any water, not returned to its source (i.e., all groundwater). The U.S. Geological Survey (USGS) and the IJC use similar, but slightly different consumptive use definitions.

Groundwater Flow Modeling Programs – Canada

As is similar with the United States, many of the same federal and provincial agencies and organizations within Canada that support groundwater monitoring and data collection programs also support various groundwater flow modeling programs within the Great Lakes - St. Lawrence River basin. A more detailed discussion of these programs can be found under the previous section entitled "Groundwater Data Collection Programs and Observation Networks – Canada."

A list of groundwater flow models and other sources of data may be found in the Inventory tables located at the end of this appendix.

Findings

Mapping the Great Lakes - St. Lawrence River Basin's Groundwater System

Groundwater is a strategic natural resource, vital to all inhabitants of the Great Lakes - St. Lawrence River region who rely on it for their daily needs. To manage the Great Lakes - St. Lawrence River basin's groundwater resources in a sustainable way, there is a need for regional knowledge of the groundwater system. Improving this regional knowledge requires a multidisciplinary approach that advances the geological understanding of the basin. (Sharpe, et al, 2002)

Digitized soil maps at a detailed scale are needed to create the first layer of the three-dimensional geologic mapping of the Great Lakes - St. Lawrence River basin groundwater system. The NRCS has been leading the effort to digitize the nation's published soil surveys to meet the established SSURGO standards. At this time, approximately 12 of the 209 counties (or six percent) that are located within or adjacent to the Great Lakes - St. Lawrence River basin do not have published soil surveys. SSURGO digitizing cannot proceed for these counties until soil surveys have been completed. The status of the Great Lakes states' digitizing efforts is shown in Table B-2.

Table B-2: SSURGO Soil Survey Digitizing Status For Counties Within or Adjacent to the Great Lakes - St. Lawrence River basin

State	Total Counties	SSURGO Certified (digital format)	Digitizing Completed (not yet certified)	Digitizing In Progress	No Digital Data Available	Unmapped Counties (no soil survey)
Illinois	2	0	0	1	1	0
Indiana	13	2	0	3	8	0
Michigan	83	45	12	23	0	3
Minnesota	7	0	0	1	3	3
New York	29	11	0	15	1	2
Ohio	35	12	0	22	1	0
Pennsylvania	3	0	2	1	0	0
Wisconsin	37	28	1	2	2	4
Total	**209**	**98** (47%)	**15** (7%)	**68** (32%)	**16** (8%)	**12** (6%)

Data current as of October 1, 2003.

During the 2003 federal fiscal year, the NRCS SSURGO effort to digitize existing soil surveys was funded at $12.5 million nationwide. Dependent upon sustained funding at this level, it is estimated that this nationwide effort may be completed by 2007. Due to the importance of digitized soils information in the management of the region's groundwater resources, additional funding provided to the NRCS would allow for the creation of new soil surveys in counties which have not been mapped to date. Extensive fieldwork is often required to compile the necessary data to complete a soil survey which, depending on the size of the area to be mapped and the nature of the soils, can be quite costly. In addition, some of the existing soil surveys may contain older data, which require additional updates before digitization can be completed. Thus, additional funding is also needed to revise and digitize the soil surveys for approximately 16 counties, which contain older data.

For the Canadian portion of the basin, AAFC and Natural Resources Canada are responsible for the Canadian Soil Information System and for setting the standards for Canada's soil mapping at the federal level. From a provincial standpoint, approximately 80 percent of Canada's published soil surveys in Ontario have already been digitized and are in the process of being updated to meet the Canadian Soil Information System Standard. However, there is a distinct need to bring together these data at a standardized scale and standard to provide a uniform output across mapping boundaries. A framework to work towards this goal for southwestern Ontario's maps has already been established, but due to a lack of funding, the effort has been focused on only the most intensive agricultural areas of southwestern Ontario. Currently, this effort is funded both federally and provincially.

Finding 1: Soil surveys within and adjacent to the Great Lakes - St. Lawrence River basin need to be completed and stored in a digital form. Completion of this work is within normal mission responsibilities assigned to the Natural Resources Conservation Service (NRCS).

In response to this finding, the following task has been determined:

Task 1: The Natural Resources Conservation Service (NRCS) needs to complete all soil survey maps within and immediately adjacent to the Great Lakes – St. Lawrence River basin in a consistent manner and encode them in digital form.

Improving Our Understanding of Basin-Wide Groundwater Storage and Flow
Data related to the flow and storage properties of groundwater through aquifers is critical for evaluating water withdrawals and diversions from the basin. As discussed previously, geology – whether in the form of bedrock or as unconsolidated material that was deposited at or near the land surface – establishes the framework for aquifers. However, aquifers are not mapped consistently or accurately throughout the basin. While some aquifer maps have been created from groundwater observations, many older aquifer maps are based on the surficial geology and topography of an area. Consequently, the accuracy of these maps at depth is questionable because the boundaries of aquifers may not coincide with land and water surface features.

To improve our understanding of the quantity and quality implications of groundwater in the basin, new geologic maps that show the extent, thickness and boundaries of unconsolidated and bedrock aquifers are needed (Grannemann, et al, 2000). Because much of the region's geology lies unexposed below the surface in complex layers of glacial drift much of it must be interpreted from limited amounts of information. Therefore, being able to integrate the different kinds of information – such as that contained in aerial photographs, well records, core samples, geophysical logs and seismic readings – provides a more complete view of the subsurface and improves the accuracy and usability of the map products.

Digital three-dimensional geological mapping of the groundwater system will help to guide groundwater investigations and to provide better definition of the pathways by which groundwater enters into the basin; whereas, traditional two-dimensional glacial geologic maps do not provide sufficient data for making informed decisions. However, approximately 79 percent of the land area within Great Lakes - St. Lawrence River basin has not yet been mapped with these newer technologies as outlined in Table B-3.

Table B-3: Geological Mapping for 7.5-minute Quadrangles Within or Adjacent to the Great Lakes - St. Lawrence River basin

State	Total 7.5-minute Quadrangles	Mapped 7.5-minute Quadrangles	Unmapped 7.5-minute Quadrangles	STATEMAP-Funded Projects Occurring Within State	Coalition Projects Occurring Within State
Illinois	12	0	12		
Indiana	119	60	59	×	×
Michigan	1292	100	1192	×	×
Minnesota	163	6	157	×	
New York	481	14	467	×	
Ohio	229	68	161	×	×
Pennsylvania	24	0	24		
Wisconsin	442	342	100	×	
Total	**2762**	**590** (21%)	**2172** (79%)		

Data current as of October 1, 2003. Quadrangles mapped through various programs and funding sources. (State Geological Surveys)

The Central Great Lakes Geologic Mapping Coalition, which consists of a collaborative partnership among the state geological surveys of Illinois, Indiana, Michigan and Ohio and the USGS, focuses on producing products such as detailed, digital, three-dimensional geologic models of the region's surface and subsurface layers, to enable the user to support critical decisionmaking with regard to natural resources. However, the third dimension of glacial deposits cannot be mapped by conventional geological methods; expensive drilling and geophysical techniques must be used. The compilation of such detailed maps is a detailed and time-consuming process (Berg, et al, 1999).

As a collaborative effort, the Coalition can combine and utilize the expertise and resources from five geological surveys to answer key scientific questions, such as the origin, nature, distribution and resource potential of the glacial deposits that cover the Great Lakes states. Due to the extensive data collection needed to create such detailed three-dimensional maps, the Coalition has also formed cooperative partnerships with academic institutions and other private entities to assist in the collection of data. As the data is collected, a second and equally important component of the Coalition's work is to develop a database that will allow users to manipulate the data and will enable decisionmakers, planners, educators, engineers and consultants to evaluate the complex resource management issues within the region.

Since its creation five years ago, the Coalition has received only $2 million (four annual appropriations of approximately $500,000 each) of the requested $20 million in federal funding. This funding has been divided among the four state geological surveys and the USGS and has allowed Coalition partners to move ahead slowly with four smaller pilot studies in the region.

Three of the pilot mapping projects occurred within the Great Lakes surface water basin, with the fourth project occurring just outside of the surface water basin but within the groundwater basin. The location of this fourth project is in an area of very rapid growth that is also dependent entirely upon groundwater as a source of drinking water. This area is indicative of the many suburban communities that are located just outside of the Great Lakes surface watershed, but are still dependent on the basin's groundwater supply for household water needs. The need for up-to-date, detailed geological information is especially critical in these rapidly expanding areas.

In order for the Coalition to make significant progress and to meet their initial goal of producing more than 500 three-dimensional geologic maps in digital format, additional funding beyond the current annual funding level of $500,000 would be required. Additional funding will allow for intensive fieldwork to begin on a greater scale and will aid in the development of three-dimensional analysis and information-delivery systems. Data obtained from this effort can be utilized in the development of the basin-wide groundwater flow model and would also improve estimates of groundwater contributions to the water balance. Once funding levels have been increased, the role of the Coalition should be expanded to include the other four Great Lakes states (Wisconsin, Minnesota, Pennsylvania and New York) to provide complete coverage of the United States' portion of the Great Lakes groundwater basin.

Due to a limited amount of funding for the Coalition over the last five years, the National Cooperative Geologic Mapping Program's STATEMAP program has proven to be critical for obtaining high quality geologic mapping for the Great Lakes - St. Lawrence River region. Through the STATEMAP program, state geologic surveys may compete nationally for funding for bedrock and surficial geologic mapping projects and funds are awarded based on the quality of the proposal. The STATEMAP program is a federal/state cost-share agreement that requires states to match federal funds with a 1:1 match. Consequently, due to the cost-share arrangement of the program, states have more flexibility in determining the scope and location of their mapping projects and to determine their own mapping priorities.

Table B-4: National Cooperative Geologic Mapping Program Funding

Program	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**	**1996**	**1995**	**1994**	1993
STATEMAP	7.6	7.83	7.86	4.5	4.54	4.44	4.38	4.38	1.34	1.84	1.34
FEDMAP	17.8	17.72	17.8	14.88	17.56	17.28	17.07	17.07	20.63	21.17	20.64
EDMAP	0.6	0.63	0.59	0.4	0.45	0.44	0.44	0.44	0	0	0
Total	26	26.18	26.25	19.78	22.55	22.16	21.89	21.89	21.97	23.01	21.98
Authorized	50	43	37	30	28	26	NA	55.5	48.5	42.8	37.5

Figures listed in millions. (U.S. Geological Survey)

During the 2003 federal fiscal year, the STATEMAP program was funded at $7.6 million nationally. Over the last ten years, approximately 4 to 6 percent of that funding has been awarded for projects within the Great Lakes - St. Lawrence River basin on an annual basis (Tables B-4 and B-5). Continued and/or increased funding for these programs is essential.

A recent survey of the participating states found that states would have the ability to match increased STATEMAP funds up to $16-18 million; however, beyond a level of approximately

$10 million, personnel limitations would become a limiting factor over the states' ability to match the federal funds. Therefore, increased funding for the STATEMAP program could be reasonably matched by participating states. While increases in funding for the STATEMAP program on a national level will not be directly realized in the Great Lakes - St. Lawrence River basin, it will strengthen the program as a whole and raise awareness for the importance of geologic mapping programs. Table B-1 lists examples of projects within the Great Lakes - St. Lawrence River region funded by the STATEMAP program since inception in 1993.

Table B-5: Approximate STATEMAP PROGRAM Funding in the Great Lakes - St. Lawrence River basin

Federal Fiscal Year	Federal Funds Contributed Basinwide	State Funds Contributed Basinwide	Total Project Funds Basinwide	Percent of Total Federal Programmatic Funding (Nationwide)
1993	$73,461	$162,323	$235,784	5.48%
1994	$107,313	$192,707	$300,020	5.83%
1995	$70,000	$118,246	$188,246	5.22%
1996	$265,303	$270,524	$535,827	6.05%
1997	$252,065	$262,583	$514,648	5.75%
1998	$295,139	$311,842	$606,981	6.64%
1999	$441,031	$467,825	$908,856	9.71%
2000	$318,284	$325,940	$644,224	7.07%
2001	$362,869	$367,531	$730,400	4.61%
2002	$330,501	$333,783	$664,284	4.22%

(State Geological Surveys and U.S. Geological Survey)

Through various federal and provincial efforts, much of southern Ontario's surficial geology has been mapped and digitized in three-dimensions, but at a greater scale and with less detail than the mapping currently underway within the United States. Future partnerships could be created across the international boundary to ensure the continuity of data across these mapping boundaries and for the entire Great Lakes groundwater basin.

Finding 2: High resolution, digital, three-dimensional geologic maps for the Great Lakes - St. Lawrence River region are needed to define aquifer system characteristics. This activity is within the normal mission responsibilities assigned to the U.S. Geological Survey and frequently involves state collaboration.

In response to this finding, the following task has been determined:

Task 2: High resolution, digital, three-dimensional geologic maps need to be produced by the U.S. Geological Survey (USGS) and collaborating state agencies to define the aquifer systems in the Great Lakes - St. Lawrence River region.

The Importance of Basin-Wide Groundwater Data
Groundwater, in general, is not well understood in the Great Lakes - St. Lawrence River basin. This was reflected recently by the IJC report entitled "Protection of the Waters of the Great Lakes" and also by the USGS report entitled, "The Importance of Ground Water in the Great Lakes Region" (Grannemann, et al, 2000). Both reports clearly draw attention to how little information exists within the basin on water quality and quantity, while also illustrating the large role that groundwater plays in Great Lakes.

According to the USGS report, the effects of groundwater withdrawals have been quantified at only a few locations, groundwater recharge rates can only be estimated and represent the approximate range of recharge to the water table in the entire Great Lakes - St. Lawrence River basin, and more work needs to be done to define and quantify the interactions between regional groundwater flow and groundwater discharge to the Great Lakes. Therefore, it is widely concluded that a comprehensive study for the entire watershed is needed to more completely determine the significance of groundwater in the hydrologic balance of the Great Lakes and to define aquifer characteristics and monitor groundwater changes within the Great Lakes groundwater basin.

Findings 3-7 (Groundwater Modeling): Groundwater flow characteristics need to be defined, and changes in groundwater movement need to be monitored for the Great Lakes - St. Lawrence River region. This activity is within the normal mission responsibilities assigned to the U.S. Geological Survey.

In response to this finding, the following tasks have been determined:

Tasks 3-7 (Groundwater Modeling): The USGS, in association with collaborating state agencies, needs to define groundwater flow characteristics and monitor changes over time that impact the Great Lakes - St. Lawrence River region.

Expanding the Network of Groundwater Observation Wells
Due to the slow movement of groundwater, the effects of surface activities on groundwater flow and quality can take years to manifest themselves (Grannemann, et al, 2000). Therefore, to better understand the role of groundwater in the overall water balance of the Great Lakes - St. Lawrence River basin and to observe the effects of water withdrawals and/or diversions from the basin, it is important to first observe the groundwater system in its natural state. This information can be analyzed for trends or variances related to particular stresses on the groundwater system.

A change in the water level of any well is a measure of a change in storage in the groundwater reservoir near the open interval of the well. Thus, a rising water level in a well represents an increase in storage and a declining water level represents a decrease in storage in the groundwater reservoir. (Alley, et al, 1999)

To fully observe the Great Lakes groundwater system, a uniform network of groundwater observation wells and water level gauges must be established across the groundwater basin. The USGS maintains a network of wells to monitor groundwater parameters nationwide. This network is supplemented by wells in some states which are monitored as part of the USGS Ground-Water Resources Program.

Based on USGS data-collection activities in 2002, there are approximately 146 groundwater observation wells with the capability of monitoring groundwater levels located within or adjacent to the Great Lakes - St. Lawrence River basin (Figure B-5). These wells and gauges are either funded in full or through cost-share arrangements with the USGS. However, some portions of the basin contain a greater concentration of groundwater wells and gauges than do others, resulting in an inequality among the density of observations throughout the basin.

Separate from the USGS network of observation wells, some areas of the basin contain state, county, local, or privately funded wells that have been installed by these entities to study a specific problem. These wells typically serve the purpose of obtaining data for site-specific assessments and are vulnerable to reductions in funding based on cost-share arrangements or changes in priorities related to those particular sites (e.g. once the site-specific study has been completed, the well may be abandoned). As such, this non-systematic network of observation wells makes the continuity of data vulnerable.

Historically, the USGS and alternatively-funded network of wells has been greatly expanded from what exists today. It is estimated that this historical network of wells may have contained hundreds of wells within the Great Lakes groundwater basin. However, over time many of these wells have been abandoned, with some being sealed to prevent contamination from entering the groundwater source. To ensure the adequate placement of groundwater observation wells and gauges in all regions of the basin it is, therefore, necessary to reinstate some of these underutilized wells to expand the current network of wells. Because many states have well-sealing programs as a mechanism of pollution prevention, this effort to identify and reinstate abandoned wells will require timely action to prevent key wells from being sealed.

In portions of the groundwater basin where underutilized or dormant wells do not exist or have already been sealed, it will be necessary to install new wells for groundwater observations. The strategic placement of wells and gauges in sensitive watersheds and headwater areas (the source and upper part of a river or stream), which require continuous observation of natural groundwater properties and variances, is key for this type of broad analysis and will help to illustrate where current data gaps may exist. Consequently, all new and reinstated wells should be equipped with continuous recorders to obtain real-time data for analysis throughout the Great Lakes groundwater basin. The data obtained from this network of wells can then be compared with climate and aquifer data across the basin, as well as to other data showing groundwater responding to specific stresses. (Climate and overland meteorological data and observation networks are discussed in greater detail in Appendix E.)

The estimated cost to maintain such a network and to collect and archive the necessary data would be approximately $3,200 per well, per year. The installation of new wells may require approximately $10,000 per well, but may vary depending on the type and depth of the well and the local geology. Based on this assessment of current data needs within the Great Lakes - St. Lawrence River basin, it is estimated that to create an optimal network of groundwater observation wells, at least 400 reinstated wells and 100 new wells, with secure sources of funding for maintenance and data collection, are needed across the basin.

A similar effort, Ontario's Provincial Groundwater Monitoring Network, may be considered as a model for developing a network of observation wells for the United States. Ontario's network includes 400 groundwater wells (both shallow and deep) in watersheds province-wide. These wells allow for observations (one per hour, 24-hours a day) related to water levels across Ontario and also provide water quality samples with testing for more than 50 parameters. Three hundred of the wells are already in place and the remaining 100 will be completed over the next year. These data will be made available to the public via a provincial groundwater information database supported by a cooperative partnership among various federal, provincial, public and private entities.

Finding 3: The existing network of groundwater observation wells for the Great Lakes - St. Lawrence River region is inadequate to support water withdrawal decisionmaking. The existing network needs to be expanded and maintained. The USGS, in cooperation with various state agencies, has been assigned the mission responsibility to address this need.

In response to this finding, the following task has been determined:

Task 3: The USGS needs to develop, maintain and expand the network of groundwater observation wells within and immediately adjacent to the Great Lake-St. Lawrence River basin.

The Infiltration, Recharge and Drainage of Water into the Groundwater System

In many areas of the Great Lakes - St. Lawrence River basin, intense development has been one factor leading to the depletion of aquifers. Surface changes resulting from development can significantly divert water to surface water bodies such as streams and lakes, decreasing the amount of recharge to the groundwater system. Heavily-tiled agricultural areas also increase the rate and quantity of overland flow of water and reduce the ability of precipitation to infiltrate downward through the soils to recharge the aquifers.

To observe the impacts of development and agricultural tile drains on the natural infiltration and flow of water into the groundwater system, it is important to be able to identify existing drainage tile fields and to have consistent and reliable maps of impervious surfaces throughout the region. Therefore, precipitation runoff surveys are needed to calculate recharge values based on daily data. Estimates are also needed of the effects of land-use changes and population growth on groundwater availability and quality.

NRCS state offices and soil and water conservation districts currently keep records of any new tiling being done by farmers that receive financial or technical help in agricultural areas of the basin. However, it is much more difficult to identify areas where drainage tiles may have been installed before these records were kept by various organizations or by farmers who install the tiles on their own. Researchers at several academic institutions throughout the region are attempting to improve upon current measures for identifying and mapping drainage tiles through the use of remote sensing and electromagnetic mapping applications. These methods appear to be promising and cost effective tools as compared to conventional tile probe methods; however, additional research is needed.

As a requirement of their license, Canadian agricultural tile drainage contractors in Ontario are required to report to the Ministry of Agriculture and Food the location of areas where tiles are being installed. However, this information has only been collected since 1986 and there are some large gaps in the data. As a result, the OMAF is also currently working to map tiles with infrared photography, but have experienced similar frustrations with these methods due to crop residue or tillage practice issues.

Finding 4: Groundwater infiltration, recharge, and drainage characteristics for the Great Lakes - St. Lawrence River region are ill-defined. This area of research is within the assigned mission responsibilities of the USGS.

As a result of this finding, the following task has been determined:

Task 4: The USGS needs to define the infiltration, recharge and drainage characteristics of the Great Lakes - St. Lawrence River basin that affect water supplies within the region.

Removing Groundwater from the System

Humans have the capacity to change the natural groundwater flow system by withdrawing groundwater for use (Alley, et al, 1999). When water is diverted or extracted from the Great Lakes - St. Lawrence River basin's groundwater system for other uses, this effectively removes water that may otherwise flow, or discharge into the basin's lakes or streams. (Alley, et al, 1999).

The term water use refers to all instream and offstream uses of water for human purposes from any water source. Instream use is a water use that takes place without water being withdrawn from surface or groundwater. Offstream use is use of water that is diverted from surface water sources or withdrawn from groundwater sources (a withdrawal in either case) and is conveyed to the place of use. This water is either lost to the system (consumptive use) or returned to surface or groundwater bodies (return flow), possibly with losses in transit (conveyance loss). Between withdrawal and return, the water may be delivered (to a public supplier, a water user, or a wastewater treatment plant) and released one or more times. (National Research Council, 2002)

Depending on the type of aquifer from which the groundwater is removed, the groundwater source may be depleted if the rate of removal exceeds the rate of recharge by infiltration of water through the soil to the aquifer. Consequently, as water use requirements increase, the need for more detailed and reliable water use and extraction information is essential.

Additional discussion on the findings associated with the extraction of water from the Great Lakes system can be found in Appendix F.

Task 5: Groundwater modeling requires accurate estimates of extraction rates from aquifers which provide water supply to the Great Lakes - St. Lawrence River system.

As a result of this finding, the following task has been determined:

Task 5: The USGS, in cooperation with regional and state agencies, needs to conduct focused research aimed at improving accounting of groundwater extraction rates from the Great Lakes - St. Lawrence River basin.

The Consumptive Use of Groundwater

The consumptive use of water occurs when water is withdrawn from a ground or surface source and is not directly returned. Consumptively used water doesn't disappear forever; it is released into the atmosphere through evapotranspiration. But it can be reused only when it returns to the earth as precipitation. Based on whether this precipitation is returned to the land within the physical boundaries of the Great Lakes groundwater basin and the rate of recharge of the aquifer, the consumptive use of the region's groundwater can play a major role in the overall groundwater balance.

To aid in the evaluation of the basin's groundwater system, the consumptive uses for specific areas must be known. Although some quantitative information is available on consumptive use, in many cases the figures are based on broad estimates and do not reliably reflect the true level and extent of consumptive use (International Joint Commission, 2000). In order to increase the accuracy of such data, it will be necessary to observe consumptive uses in the field by obtaining measurements of water withdrawal and return. This may involve testing in various locations, environments, climate zones, soils, etc., to be able to represent the entire basin for a basin-wide model. Detailed studies focusing on major metropolitan areas may also be needed where rapid development has occurred.

Additional discussion on the findings associated with the consumptive of water from the Great Lakes system can be found in Appendix F.

Finding 6: Groundwater modeling requires accurate estimates of consumptive uses of Great Lakes - St. Lawrence River groundwater resources. Current estimates lack scientific rigor and consistency.

In response to this finding, the following task has been determined:

Task 6: The USGS, in cooperation with regional and state agencies, needs to conduct focused research on improving consumptive use estimates of Great Lakes - St. Lawrence River groundwater resources.

Modeling the Great Lakes - St. Lawrence River Basin Groundwater Flow

According to the USGS report entitled "The Importance of Groundwater in the Great Lakes Region" (Grannemann, et al, 2000), all of the major groundwater issues in the Great Lakes - St. Lawrence River region can be tied to the quantity of groundwater, the interaction of groundwater and surface water, changes in groundwater quality as development expands and the ecosystem health in relation to quantity and quality of water. Consequently, the evaluation of most groundwater development is extremely complex; for example, it may comprise many wells pumping from an aquifer at varying pumping rates and at different locations within the groundwater-flow system. Computer models commonly are needed to evaluate the time scale and time-varying response of surface water bodies to such complex patterns of groundwater development (Alley, et al, 1999). Improved groundwater flow definition and simulation of the entire Great Lakes groundwater basin is needed which, in turn, requires more reliable water data for management of the many aquifers that serve as important local or regional sources of water.

Groundwater models are tools used to predict what might happen if given changes to the groundwater regime are permitted. First, an attempt is made to mimic the present conditions. This generally requires the input of a wide range of hydrologic, hydraulic and physical data. Once that is reliably done, then different scenarios can be investigated. One might try to determine how much water can be pumped in a given hydrogeologic setting without affecting a groundwater-fed resource. If there are several ways to design the project, all could be modeled, and the one with the least predicted impact could be chosen. This further illustrates the need to collect quality data within the Great Lakes system.

Finding 7: Comprehensive modeling of groundwater characteristics within and adjacent to the Great Lakes - St. Lawrence River basin is needed to support scientifically defensible decisions on water withdrawal.

In response to this finding, the following task has been determined:

Task 7: The USGS, in cooperation with regional agencies and academic institutions, needs to develop comprehensive modeling procedures that can be used to assess impacts of groundwater withdrawals within and adjacent to the Great Lakes - St. Lawrence River basin.

Emerging Issues

This analysis of groundwater and mapping activities throughout the Great Lakes - St. Lawrence River basin has highlighted similar ongoing efforts by various U.S. and Canadian agencies. Consequently, in order to achieve a basin-wide view of the groundwater system, cooperative partnerships are needed to increase scientific coordination between the two countries and among federal, state and provincial agencies.

Another major issue within the basin relates to conjunctive use management. Conjunctive use management is the integrated management of ground and surface water resources. Studies to quantify the role of ground and surface water interflow are needed to show the linkage between streamflow and groundwater withdrawals. (Conjunctive and other water use accounting considerations are discussed in greater detail in Appendix F.)

Implementation Strategies– Geology and Groundwater

Tasks for improving the information base related to the groundwater and other physical systems within the Great Lakes - St. Lawrence River basin are presented in this section. These tasks are defined within a comprehensive framework of enhancing the U.S. federal role in creating and maintaining an information base to support science-based decisions on water withdrawals and diversions from the Great Lakes - St. Lawrence River basin. Each finding is defined at different options of implementation under the USACE plan formulation approach. This approach, in a broad sense, is being used to develop systematic strategic plans that Congress could consider for supporting the states' Great Lakes Charter Annex decisionmaking process.

Five implementation options are presented, each as a separate integrated approach. This, however, is not an exclusive list and does not represent an "all or nothing" approach. Individual elements from one option could be pulled out and funded separately, making an important contribution to Great Lakes - St. Lawrence River basin information base. Even modest increases in funding over the "Without Plan" option can enhance decisionmaking. Water resources managers should examine each particular integrated plan option as well as individual findings to discern where important progress can be made.

Described below are five implementation strategies considered:

- **Without Plan Strategy** – Describes the status of the activity as it currently exists. Without change, this current status may actually decline, representing negative impacts. If negative impacts are expected, they are highlighted wherever possible.

- **Minimum Investment Strategy** – Describes the least costly measures needed to insure minimum functionality of the decision support system. Not all system components of an implementation plan are included in this option.

- **Selective Implementation Strategy** – Describes an integrated system comprised of prioritized components. Few components are fully funded, but no essential components are excluded.

- **Enhanced Implementation Strategy** – Describes an integrated system that includes all essential components at funding levels which enhance information accuracies and decision support system functionalities.

- **Full Implementation Strategy** – Describes an integrated system that fully implements all of the listed activities. Technical staff and financial resources are not restricted. Information accuracies and completeness approaches state-of-the science.

Due to the interdependent nature of many issues described in the appendices, some information may be repeated in total or in part elsewhere in another appendix. The interdependence of information is noted explicitly in the appendices wherever appropriate.

A dollar value has been estimated for the four potential strategies that require additional investment over a 10-year implementation schedule. Monetary value is based on the best available information through extensive research and review by project collaborators and is presented in 2004 U.S. dollars. Further information is provided in Appendix K – Cost Estimation, including an analysis of the uncertainty associated with these estimates.

Comparisons of costs at various implementation levels provide a useful measure of investment versus return. It is important to remember that the primary objective of all investments is to reduce uncertainties associated with decisionmaking. Since the hydrogeology and meteorology of the Great Lakes – St. Lawrence River system is highly complex, reductions in uncertainty are sought for each task outlined for the integrated information system.

The definition of the individual tasks outlined in this report has sought to eliminate "double-counting" as much as possible. Costs for the various tasks also explicitly address any interdependencies that occur under a particular implementation strategy. Cost estimates for each task under each implementation strategy also reflect anticipated economies of scale.

Risk and Uncertainty

Risk and uncertainty are inherent aspects of all facets of an integrated information system for water management of the Great Lakes – St. Lawrence River system. Risk can be viewed relative to human and aquatic health, to real property, to the ability to attain profit from a commercial venture, or to relative benefits that can be attained at given investment levels.

The integrated information system described within this report, once improved above current conditions, has a very low likelihood of adverse risk to human health, life or personal property. It is simply a monitoring, modeling and predictive system that does not include significant physical structures or construction. The converse does apply however; continued financial stressors on the monitoring system can cause atrophy of monitoring abilities which could, in turn, mask physical, chemical and biologic change to natural streamflow throughout the system.

Risk is also factored in throughout this report related to the prospective reward or benefit attained at increasing levels of investment. Each task in the integrated information system is evaluated in terms of cost effectiveness, whenever practical. This discussion is addressed in detail in the Main Report, although each appendix includes detailed information on the risk/return for each task under each implementation strategy.

Uncertainty is pervasive throughout the design, implementation and operation of any integrated water management system. At the current level of investment in groundwater, surface water and open lake monitoring and modeling, cumulative withdrawals from headwater systems can not be detected, measured or adequately estimated. Hence, the uncertainty of cumulative hydrologic effects is extremely large under the Without Plan and Minimum Investment Strategies . Even under the Full Implementation strategy, uncertainty will continue to exist, albeit at a much lower level. This uncertainty would be accompanied, however, with an accurate error budget including almost all hydrologic and biologic factors, which currently does not exist.

The analytical functions of the integrated information system will generally have reduced uncertainties as funding increases from one implementation strategy to the next. In addition, these uncertainties can be computed with greater confidence as more investment is made in the monitoring frame and computer modeling. The legal defensibility of permitting water withdrawal improves as uncertainty is reduced, in part or in total.

Integrated Information System Tasks

Tasks 1-7 described in this appendix present an integrated approach towards collecting and managing information on the groundwater and geology of the Great Lakes – St. Lawrence River system. It is important to see these tasks as "building blocks" for the integrated information system. Improvements under any specific task will provide incremental benefit, but the sum of the parts provides the greatest opportunity for reducing uncertainties under each implementation strategy. These tasks are repeated below.

Task 1: The Natural Resources Conservation Service (NRCS) needs to complete all soil survey maps within the Great Lakes – St. Lawrence River basin in a consistent manner and to encode them in digital form.

Task 2: High resolution, digital, three-dimensional geologic maps need to be produced by the U.S. Geological Survey (USGS) and collaborating state agencies to define the aquifer systems in the Great Lakes - St. Lawrence River region.

Tasks 3-7 (Groundwater Modeling): The USGS, in association with collaborating state agencies, need to define groundwater flow characteristics and monitor changes over time that impact the Great Lakes - St. Lawrence River region.

Task 3: The USGS, in association with collaborating state agencies, needs to develop, maintain and expand the network of groundwater observation wells within and immediately adjacent to the Great Lake-St. Lawrence River basin.

Task 4: The USGS needs to define the infiltration, recharge and drainage characteristics of the Great Lakes - St. Lawrence River basin that affect water supplies within the region.

Task 5: The USGS, in cooperation with regional and state agencies, needs to conduct focused research aimed at improving accounting of groundwater extraction rates from the Great Lakes - St. Lawrence River basin.

Task 6: The USGS, in cooperation with regional and state agencies, needs to conduct focused research on improving consumptive use estimates of Great Lakes - St. Lawrence River groundwater resources.

Task 7: The USGS, in cooperation with regional agencies and academic institutions, needs to develop comprehensive modeling procedures that can be used to assess impacts of groundwater withdrawals within and adjacent to the Great Lakes - St. Lawrence River basin.

Implementation Mechanisms and Costs

The proposed approaches/mechanisms for implementing the tasks and associated costs are provided below for each of the five implementation strategies s considered. The U.S. federal agency which has the assigned mission responsibility for implementing these activities is identified, whenever clear. If potential overlap occurs between U.S. federal agencies in mission responsibilities, one is proposed over the other based on perceived technical or administrative competencies to complete the necessary work within budget and schedule.

Task 1: The Natural Resources Conservation Service (NRCS) needs to complete all soil survey maps within and immediately adjacent to the Great Lakes - St. Lawrence River basin in a consistent manner and encode them in digital form.

Without Plan Strategy (1) – Digitizing of existing soil surveys under the Soil Survey Geographic (SSURGO) program is expected to be completed for the entire country by 2007, dependent upon continued level funding for the effort ($12.5 M per year).

Minimum Investment Strategy(1) – No additional investment is considered under this strategy as it assumes continued funding for the NRCS through 2007 to complete its digitization of existing soil surveys.

Selective Implementation Strategy(1) – Provide funding to the NRCS to fully fund the creation of soil surveys for the 12 remaining unsurveyed counties and revisions to 3 obsolete county surveys within the Great Lakes - St. Lawrence River basin at a cost of $38 M over a compressed 3-year schedule. This strategy assumes continued level funding for the NRCS to complete digitization of existing soil surveys.

Enhanced Implementation Strategy (1) – Provide funding to the NRCS to fully fund the creation of soil surveys for the 12 remaining unsurveyed counties and revisions to 8 obsolete county surveys within the Great Lakes - St. Lawrence River basin at a cost of $53 M over a compressed 3-year schedule. This strategy assumes continued level funding for the NRCS to complete digitization of existing soil surveys.

Full Implementation Strategy (1) – Provide funding to the NRCS to fully fund the creation of soil surveys for the 12 remaining unsurveyed counties and revisions to 16 county obsolete surveys within the Great Lakes - St. Lawrence River basin at a cost of $ 80M over 3 years. This strategy assumes continued level funding for the NRCS to complete digitization of existing soil surveys.

Task 2: High resolution, digital, three-dimensional geologic maps need to be produced by the USGS and collaborating state agencies to define the aquifer systems in the Great Lakes - St. Lawrence River region.

Without Plan Strategy(2) – Maintain current funding commitment to the USGS Central Great Lakes Geologic Mapping Coalition ($500 K per year) for the continuation of pilot projects in the four participating states of Indiana, Illinois, Ohio, and Michigan. Continue current federal funding allocations for federal/state cost-share support for the STATEMAP component of the USGS National Cooperative Geologic Mapping Program at a cost of $7.6 M per year.

Minimum Investment Strategy (2) **-** No additional investment considered.

Selective Implementation Strategy (2) – Provide funding to the USGS Central Great Lakes Geologic Mapping Coalition and STATEMAP Program to complete the mapping of approximately 500 quads (or about 20 percent) of priority sites at a cost of $120 M over 10 years. This level of funding would allow for the completion of additional discrete projects throughout the basin.

Enhanced Implementation Strategy (2) – Expand focus of the USGS Central Great Lakes Geologic Mapping Coalition to include all 8 Great Lakes states. Provide funding to the Coalition and STATEMAP Program at a level of $320 M over the next 10 years to conduct geological mapping and related studies of approximately 1300 quads (or about 60 percent) of priority sites across the Great Lakes - St. Lawrence River basin.

Full Implementation Strategy(2) – Expand focus of the USGS Central Great Lakes Geologic Mapping Coalition to include all 8 Great Lakes states. Provide funding to the Coalition and STATEMAP Program to work jointly in completing all geologic mapping for all remaining quads (approximately 2200) within or adjacent to the Great Lakes - St. Lawrence River basin at a cost of $560 M over next 10 years. **

Footnotes (2)
** Funding levels beyond these specified amounts would be impractical due to personnel limitations. However, additional funding may be required beyond the scope of 10 years to complete the task.

Task 3-7 (Groundwater Modeling): The USGS, in association with collaborating state agencies, need to define groundwater flow characteristics and monitor changes over time that impact the Great Lakes - St. Lawrence River region.

Task 3: The USGS needs to develop, maintain and expand the network of groundwater observation wells within and immediately adjacent to the Great Lake-St. Lawrence River basin.

Without Plan Strategy(3) – A non-systematic network currently exists with a variety of funding sources and objectives, resulting in unequal concentrations of groundwater wells within the U.S. Great Lakes groundwater basin. The number of wells within the current network will likely decrease due to constraints associated with maintenance funding.

Minimum Investment Strategy(3) – Provide additional funding to the USGS to maintain the existing network of groundwater wells within the U.S. Great Lakes groundwater basin. This additional funding should be used to replace cost-share funding arrangements on existing wells that are vulnerable to current and future cost-share funding reductions. Full federal funding is required to protect the continuity of the wells and long-term data collection at a cost of $750 K over 5 years, and operation and maintenance costs thereafter.

Selective Implementation Strategy (3) – Provide funding to the USGS to restore and maintain 100 underutilized groundwater observation wells throughout the U.S. Great Lakes groundwater basin at a cost of $3.2 M over 10 years, and operation and maintenance costs thereafter.

Enhanced Implementation Strategy (3) – Provide funding to the USGS to restore and maintain 300 underutilized groundwater observation wells throughout the U.S. Great Lakes groundwater basin at a cost of $10 M over 10 years, and operation and maintenance costs thereafter.

Full Implementation Strategy (3) – Provide funding to the USGS to restore and maintain 400 underutilized groundwater observation wells and install and maintain 175 new wells where needed at a cost of $20 M over 10 years, and operation and maintenance costs thereafter.

Task 4: The USGS needs to define the infiltration, recharge and drainage characteristics of the Great Lakes - St. Lawrence River basin that affect water supplies within the region.

Without Plan Strategy (4) – Estimates of impervious surfaces are coarse and lack consistency. Infiltration, recharge and drainage characteristics may exist in some key areas, but are not comprehensive.

Minimum Investment Strategy (4) – The USGS would conduct a pilot study on infiltration and recharge rates for all land cover types in at least one high priority watershed within Great Lakes - St. Lawrence River basin at a cost of $1 M over 3 years.

Selective Implementation Strategy (4) – The USGS would conduct a pilot study for all land cover types in at least one high priority watershed within Great Lakes - St. Lawrence River basin at a cost of $1 M over 3 years.

Enhanced Implementation Strategy (4) – The USGS would conduct studies for all land cover types in at least one high priority watersheds in each Great Lakes state at a cost of $2 M over 3 years.

Full Implementation Strategy (4) – The USGS would develop a comprehensive, detailed model of infiltration rates for all land cover types for all U.S. watersheds at a cost of $5 M over 5 years.

Task 5: The USGS, in cooperation with regional and state agencies, needs to conduct focused research aimed at improving accounting of groundwater extraction rates from the Great Lakes - St. Lawrence River basin.

Without Plan Strategy (5) – Groundwater withdrawals are estimated or calculated based upon pumping capacity and/or estimation techniques for selected water use sectors. Accounting is inconsistent from state to state. Future approaches are not likely to change without significant collaboration.

Minimum Investment Strategy (5) – This strategy calls for an increase in funding to the USGS to advance the National Water Use Information Program (NWUIP) and continue federal/state cost-share support for program at a cost of $2 M over 10 years, and continue thereafter. The focus of the program would be expanded to emphasize groundwater, especially the need to increase accuracy and consistency of groundwater withdrawal data and increasing the ability to meter, measure, or improve calculation methods.

Selective Implementation Strategy (5) – Increase funding for the USGS NWUIP and continue federal/state cost-share support for program at a cost of $5 M over 10 years, and continue thereafter. Expand focus of the program to emphasize groundwater, especially the need to increase accuracy and consistency of groundwater withdrawal data and increasing the ability to meter, measure, or improve calculation methods.

Enhanced Implementation Strategy (5) – Increase funding for the USGS NWUIP and continue federal/state cost-share support for the program. Establish or expand state programmatic authority to require direct measurement of groundwater withdrawals for all categories of use. Ensure adequate funding to carry out the program at the state and national levels. Costs are estimated at $10 M over 10 years, and continue thereafter.

Full Implementation Strategy (5) – Require states to implement direct measurements of groundwater withdrawals for all categories of use. Federal funding to support this mandate could be as high as $50 M over 10 years, and continue thereafter.

Task 6: The USGS, in cooperation with regional and state agencies, needs to conduct focused research on improving consumptive use estimates of Great Lakes - St. Lawrence River groundwater resources.

Without Plan Strategy (6) – Without significant new collaboration, coefficients will need to be used to estimate consumption; these estimates will continue to be inconsistent and unreliable.

Minimum Investment Strategy (6) – Under this strategy, the USGS would assess consumptive use data needs, compile available sources of consumptive use data, and assess quality of that data at a cost of $100 K for 1 year.

Selective Implementation Strategy (6) – Under this strategy, the USGS would assess consumptive use data needs, compile available sources of consumptive use data, and assess quality of that data at a cost of $100 K for 1 year.

Enhanced Implementation Strategy (6) – Under this strategy, the USGS in cooperation with appropriate regional and state agencies would develop consumptive groundwater use estimates by categories or facility types specific to the Great Lakes by conducting pilot studies that directly measure groundwater consumptive uses at a cost of $500 K over 2 years.

Full Implementation Strategy (6) – Under this strategy, Congress would require the Great Lakes states to implement direct measurements of groundwater consumptive uses and would provide pass-through funding to establish and maintain necessary infrastructure. Federal funding to support this mandate could be as high as $10 M over 10 years, and continue thereafter.

Task 7: The USGS, in cooperation with regional agencies and academic institutions, needs to develop comprehensive modeling procedures that can be used to assess impacts of groundwater withdrawals within and adjacent to the Great Lakes - St. Lawrence River basin.

Without Plan Strategy (7) – Some modeling will be developed for individual watersheds or subwatersheds by various entities based upon need. These efforts will continue to be inconsistent.

Minimum Investment Strategy (7) – Under this strategy, the USGS would develop a prototype groundwater model for at least one or more pilot watersheds at a cost of $500 K over 2 years.

Selective Implementation Strategy (7) – Under this strategy, the USGS would develop a prototype groundwater model for at least one or more pilot watersheds at a cost of $500 K over 2 years.

Enhanced Implementation Strategy (7) – Contingent upon substantial information availability based upon completion of prior tasks, the USGS in cooperation with regional entities would complete comprehensive groundwater models for up to 20 pilot U.S. Great Lakes watersheds at a cost of $10 M over 10 years.

Full Implementation Strategy (7) – Contingent upon substantial information availability based upon completion of prior tasks, the USGS in cooperation with regional entities would complete comprehensive groundwater models for all U.S. Great Lakes watersheds at a cost of $35M over 10 years.

Total Costs Over 10 Years

Without **Plan Strategy** (TOTAL) – $0 M

Minimum Investment Strategy TOTAL) – $4.35 M

Selective Implementation Strategy (TOTAL) – $167.8 M

Enhanced Implementation Strategy (TOTAL) – $405.5 M

Full Implementation Strategy (TOTAL) – $760.0 M

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