Natural Groundwater Quality and Human-Induced Changes

Indicator #7100

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin.

Purpose

- To measure groundwater quality as determined by the natural chemistry of the bedrock and overburden deposits, as well as any changes in quality due to anthropogenic activities; and
- To address groundwater quality impairments, whether they are natural or human induced in order to ensure a safe and clean supply of groundwater for human consumption and ecosystem functioning.

Ecosystem Objective

The ecosystem objective for this indicator is to ensure that groundwater quality remains at or approaches natural conditions.

State of the Ecosystem

Background

Natural groundwater quality issues and human induced changes in groundwater quality both have the potential to affect our ability to use groundwater safely. Some constituents found naturally in groundwater renders some groundwater reserves inappropriate for certain uses. Growing urban populations, along with historical and present industrial and agricultural activity, have caused significant harm to groundwater quality, thereby obstructing the use of the resource and damaging the environment. Understanding natural groundwater quality provides a baseline from which to compare, while monitoring anthropogenic changes can allow identification of temporal trends and assess any improvements or further degradation in quality.

Natural Groundwater Quality

The Grand River watershed can generally be divided into three distinct geological areas; the northern till plain, the central region of moraines with complex sequences of glacial, glaciofluvial and glaciolacustrine deposits, and the southern clay plain. These surficial overburden deposits are underlain by fractured carbonate rock (predominantly dolostone). The groundwater resources of the watershed include regional-scale unconfined and confined overburden and bedrock aquifers as well as discontinuous local-scale deposits which contain sufficient groundwater to meet smaller users needs. In some areas of the watershed (e.g. Whitemans Creek basin) the presence of high permeability sands at ground surface and or a high water table leads to unconfined aquifers which are highly susceptible to degradation from surface contaminant sources.

The natural quality of groundwater in the watershed for the most part is very good. The groundwater chemistry in both the overburden and bedrock aquifers is generally high in dissolved inorganic constituents (predominantly calcium, magnesium, sodium, chloride and sulphate). Measurements of total dissolved solids (TDS) suggest relatively "hard" water throughout the watershed. For example, City of Guelph production wells yield water with hardness measured from 249 mg/l to 579 mg/l, which far exceeds the aesthetic Ontario Drinking Water Objective of 80 mg/l to 100 mg/l. Elevated concentrations of trace metals (iron and manganese) have also been identified as ambient quality issues with the groundwater resource.

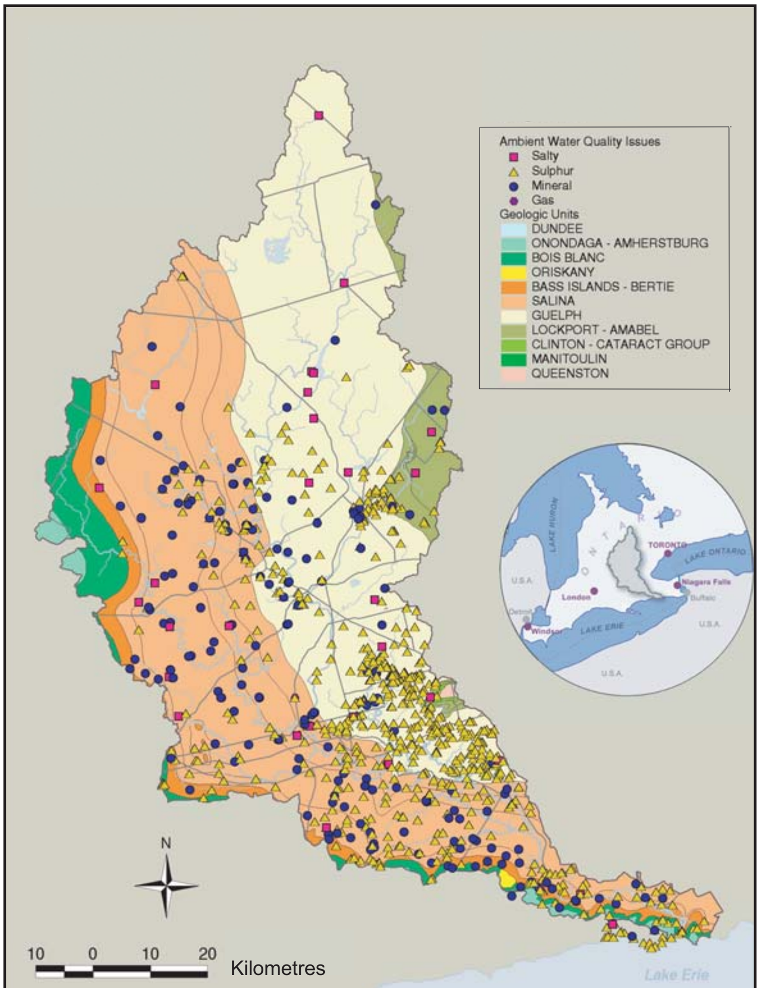

Figure 1. Bedrock wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

Figures 1 and 2 illustrate water quality problems observed in bedrock and overburden wells, respectively. These figures are based on a qualitative assessment of well water at the time of drilling as noted on the Ontario Ministry of Environment's water well record form. The majority of these wells were installed for domestic or livestock uses. Overall, between 1940 and 2000, less than 1% (approximately 1131 wells) of all the wells drilled in the watershed reported having a water quality problem. Of the wells exhibiting a natural groundwater problem about 90% were bedrock wells while the other 10% were completed in the overburden. The most frequently noted quality problem associated with bedrock wells was high sulphur content (76% of bedrock wells with quality problems). This is not surprising, as sulphur is easy to detect due to its distinctive and objectionable odour. Generally, three bedrock formations commonly intersected within the watershed contain most of the sulphur wells: the Guelph Formation, the Salina Formation, and the Onondaga-Amherstburg Formation. The Salina Formation forms the shallow bedrock under the west side of the watershed while the Guelph underlies the east side of the watershed.

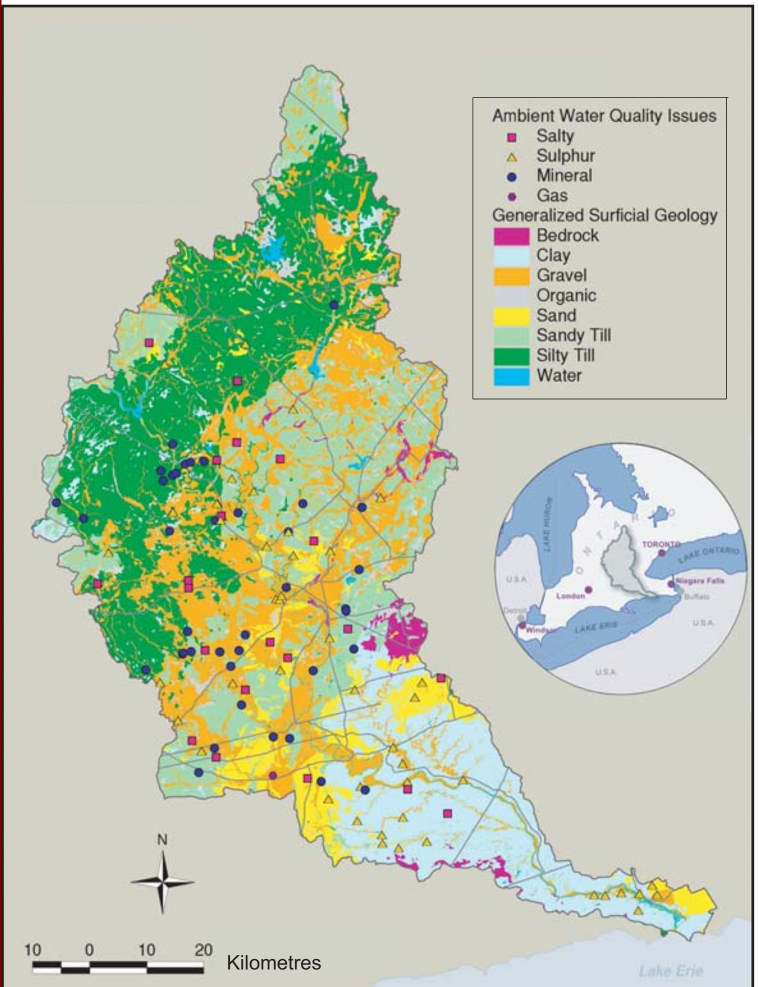

Figure 2. Overburden wells with natural quality issues in the Grand River watershed.
Source: Grand River Conservation Authority

Additional quality concerns noted in the water well records include high mineral content and salt. About 20% of the reported quality concerns in bedrock wells were high mineral content while 4% reported salty water. Similar concerns were noted in overburden wells where reported problems were sulphur (42%), mineral (34%), and salt (23%).

Human Induced Changes to Groundwater Quality

Changes to the quality of groundwater from anthropogenic activities associated with urban sprawl, agriculture and industrial operations have been noted throughout the watershed. Urban areas within the Grand River watershed have been experiencing considerable growth over the past few decades. The groundwater quality issues associated with human activity in the watershed include: chloride, industrial chemicals (e.g. trichloroethylene (TCE)), and agricultural impacts (nitrate, bacteria, and pesticides). These contaminants vary in their extent from very local impact (e.g. bacteria) to widespread impact (e.g. chloride). Industrial contaminants tend to be point sources, which generally require very little concentration to impact significant groundwater resources.

Chloride

Increasing chloride concentrations in groundwater have been observed in most municipal wells in the urban portions of the watershed. This increase has been attributed to winter deicing of roads with sodium chloride (salt). Detailed studies carried out by the Regional Municipality of Waterloo have illustrated the impact of road salting associated with increased urban development to groundwater captured by two municipal well fields. Figure 3 shows the temporal changes in chloride concentration for the two well fields investigated in this study. Wells A, B, and C, are from the first well field while wells D and E are from the second well field. In 1967 land use within the capture zone of the first field was 51% rural and 49% urban, while in the second well field capture zone the land use was 94% rural and 6% urban. By 1998, the area within the first well field capture zone had been completely converted to urban land while in the second well field capture zone 60% of the land remained rural.

Although wells from both well fields show increased chloride levels, wells A, B, and C in the heavily urbanized capture zone show a greater increase in chloride concentrations than do wells D and E in the predominantly rural capture zone. For example, well B showed a change in chloride concentration from 16.8 mg/l in 1960, to 260 mg/l in 1996, where as well D showed a change from 3 mg/l in 1966, to 60 mg/l in 1996. This indicates that chloride levels in groundwater can be linked to urban growth and its associated land uses (i.e. denser road network). The Ontario Drinking Water Objective for chloride had been

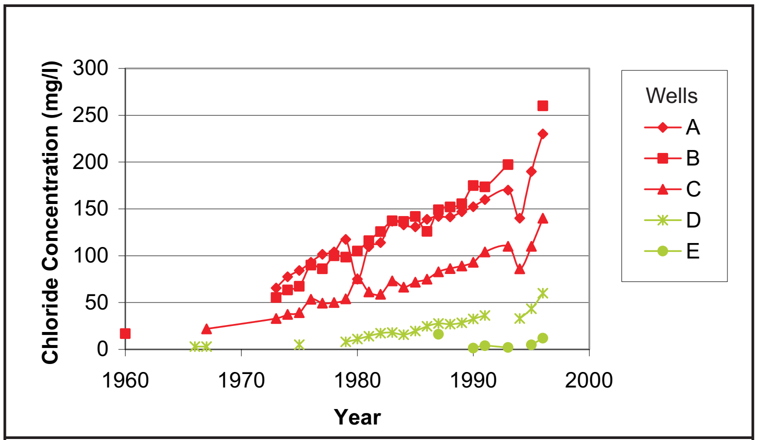

Figure 3. Chloride levels in selected groundwater wells in the Regional Municipality of Waterloo. Red indicates wells from one area/well field. Green indicates wells from a different area/well field.
Source: Stanley Consulting, 1998

established at 250 mg/l, although this guideline is predominantly for aesthetic reasons, the issue of increasing chloride levels should be addressed.

Industrial Contaminants
Groundwater resources in both the overburden and bedrock deposits within the Grand River watershed have been impacted by contamination of aqueous and non-aqueous contaminants which have entered the groundwater as a result of industrial spills or discharges, landfill leachates, leaky storage containers, and poor disposal practices. A significant number of these chemicals are volatile organic compounds (VOCs). Contamination by VOCs such as TCE, have impacted municipal groundwater supplies in several communities in the watershed. For example, by the year 1998, five of the City of Guelph's 24 wells were taken out of service due to low-level VOC contamination. These wells have a combined capacity of 10,000 to 12,000 m^3/day and represent about 15% of the City's permitted water-taking capacity. As a second example, contamination of both a shallow aquifer and a deeper municipal aquifer with a variety of industrial chemicals (including toluene, chlorobenzene, 2,4-D, 2,4,5-T) emanating from a chemical plant in the Region of Waterloo led to the removal of municipal wells from the water system in the town of Elmira.

Agricultural and Rural Impacts
Groundwater quality in agricultural areas is affected by activities such as pesticide application, fertilizer and manure applications on fields, storage and disposal of animal wastes and the improper disposal and spills of chemicals. The groundwater contaminants from these activities can be divided into three main groups: nitrate, bacteria and pesticides. For example, the application of excessive quantities of nutrients to agricultural land may impact the quality of the groundwater. Excess nitrogen applied to the soil to sustain crop production is converted to nitrate with infiltrating water and hence transported to the water table. Seventy-six percent of the total land area in the Grand River watershed is used for agricultural purposes and thus potential and historical contamination of the groundwater due to these activities is a concern.

Land use and nitrate levels measured in surface water from two sub-watersheds, the Eramosa River and Whitemans Creek, are

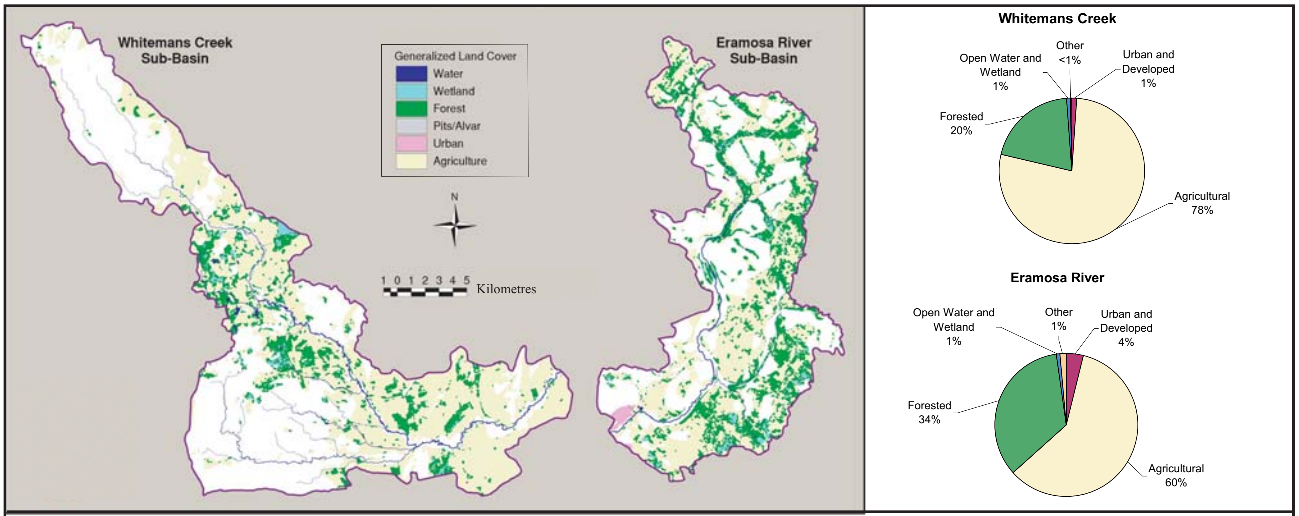

Figure 4. Land cover on moraine systems and areas that facilitate high to very high groundwater recharge of the Whitemans Creek and Eramosa River sub-watersheds: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

used to illustrate the effects of agricultural activities on groundwater quality and the quality of surface water.

In the Whitemans Creek sub-watershed, approximately 78% of the land classified as groundwater recharge area is covered with agricultural uses, and only 20% is forested. In the Eramosa sub-watershed about 60% of the significant recharge land is used for agricultural purposes with approximately 34% of the land being covered with forest (Figure 4). Both of these tributary streams are considered predominantly groundwater-fed streams, meaning that the majority of flow within them is received directly from groundwater discharge.

Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003 are shown in Figure 5. Average annual concentration of nitrate measured in Whitemans Creek between 1997 and 2003 were 2.5 to 8 times higher than those measured in the Eramosa River. The higher nitrate levels measured in Whitemans Creek illustrate the linkage between increased agricultural activity and groundwater contamination and its impact on surface water quality. In addition to the agricultural practices in the Whitemans Creek sub-watershed, the observed nitrate concentrations may also be linked to rural communities with a high density of septic systems that leach nutrients to the subsurface.

Manure spreading on fields, runoff from waste disposal sites, and septic systems may all provide a source of bacteria to groundwater. Bacterial contamination in wells in agricultural areas is common, however, this is often due to poor well construction allowing surface water to enter the well and not indicative of widespread aquifer contamination. Shallow wells are particularly vulnerable to bacterial contamination.

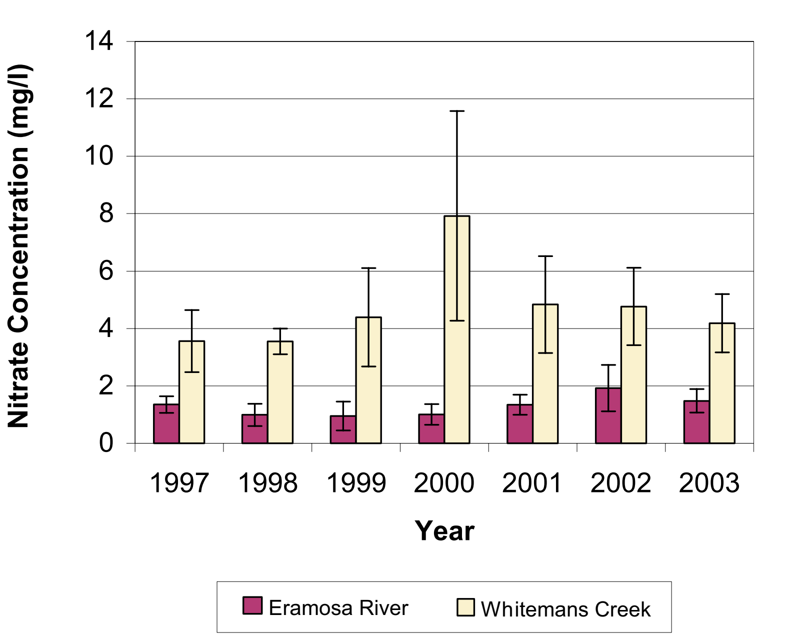

Figure 5. Average annual concentrations of nitrate measured in the Eramosa River and Whitemans Creek from 1997 to 2003. (Also shown on the bar graphs is the standard error of measurement)
Source: Ontario Provincial Water Quality Monitoring Network, 2003.

Pressures

The population within the Grand River watershed is expected to increase by over 300,000 people in the next 20 years. The urban sprawl and industrial development associated with this population growth, if not managed appropriately, will increase the chance for contamination of groundwater resources. Intensification of agriculture will lead to increased potential for pollution caused by nutrients, pathogens and pesticides to enter the groundwater supply and eventually surface water resources. While largely unknown at this time, the effects of climate change may lead to decreased groundwater resources, which may concentrate existing contaminant sources.

Management Implications

Protecting groundwater resources generally requires multi-faceted strategies including regulation, land use planning, water resources management, voluntary adoption of best management practices and public education. Programs to reduce the amount of road salt used for deicing will lead to reductions in chloride contamination in groundwater. For example, the Regional of Waterloo (the largest urban community in the watershed) in cooperation with road maintenance departments has been able to decrease the amount of road salt applied to Regional roads by 27% in just one winter season.

Acknowledgments

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Alan Sawyer's position was partially funded through a grant from Environment Canada's Science Horizons internship program. The assistance of Samuel Bellamy of the Grand River Conservation Authority, as well as Harvey Shear, Nancy Stadler-Salt and Andrew Piggott of Environment Canada is gratefully acknowledged.

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Authors' Commentary
While there is a large quantity of groundwater quality data available for the various aquifers in the watershed, this data has not been consolidated and evaluated in a comprehensive or systematic way. Work is needed to bring together this data and incorporate ongoing groundwater monitoring programs. An assessment of the groundwater quality across Ontario is currently being undertaken through sampling and analysis of groundwater from the provincial groundwater-monitoring network (PGMN) wells (includes monitoring stations in the Grand River watershed). Numerous watershed municipalities also have had ongoing monitoring programs, which examine the quality of groundwater as a source of drinking water in place for a number of years. Integrating this data along with data contained in various site investigations will allow for a more comprehensive picture of groundwater quality in the watershed.

Last Updated
State of the Great Lakes 2005

Groundwater and Land: Use and Intensity

Indicator #7101

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin.

Purpose

- To measure water use and intensity and land use and intensity;
- To infer the potential impact of land and water use on the quantity and quality of groundwater resources as well as evaluate groundwater supply and demand; and
- To track the main influences on groundwater quantity and quality such as land and water use to ensure sustainable high quality groundwater supplies.

Ecosystem Objective

The ecosystem objective for this indicator is to ensure that land and water use does not negatively impact groundwater supplies/resources.

State of the Ecosystem

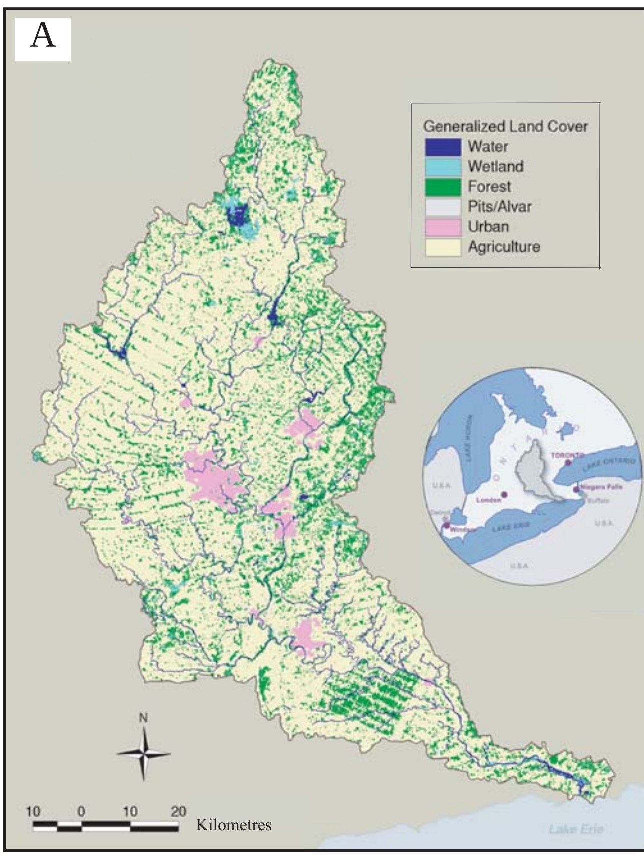
Background

Land use and intensity has the potential to affect both groundwater quality and quantity. Similarly, water use and intensity (i.e. demand) can impact the sustainability of groundwater supplies. In addition, groundwater use and intensity can impact streams and creeks, which depend on groundwater for base flows to sustain aquatic plant and animal communities.

Land use and intensity

The Grand River watershed can generally be divided into three distinct geological areas; the northern till plain, central moraines with complex sequences of glacial, glaciofluvial and glaciolacustrine deposits, and the southern clay plain. These surficial overburden deposits are underlain by fractured carbonate rock (predominantly dolostone). The groundwater resources of the watershed include regional-scale unconfined and confined overburden and bedrock aquifers as well as discontinuous local-scale deposits which contain sufficient groundwater to meet smaller users' needs. In some areas of the watershed (e.g. Whiteman's Creek basin) the presence of high permeability sands at ground surface and/or a high water table leads to unconfined aquifers which are highly susceptible to contamination from surface contaminant sources.

Agricultural and rural land uses predominate in the Grand River watershed. Approximately 76% of the watershed land area is used for agriculture (Figure 1). Urban development covers about



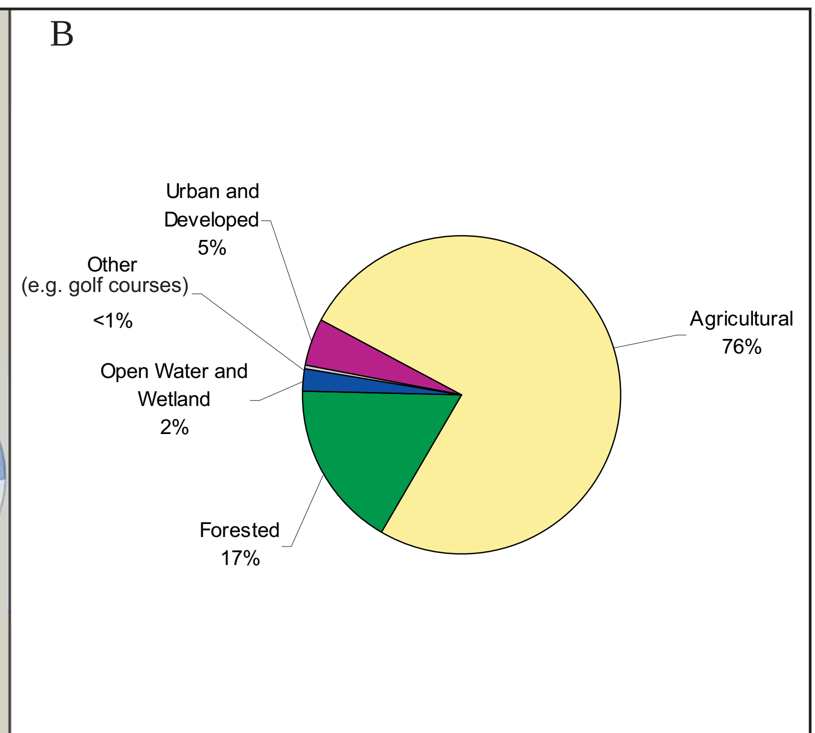


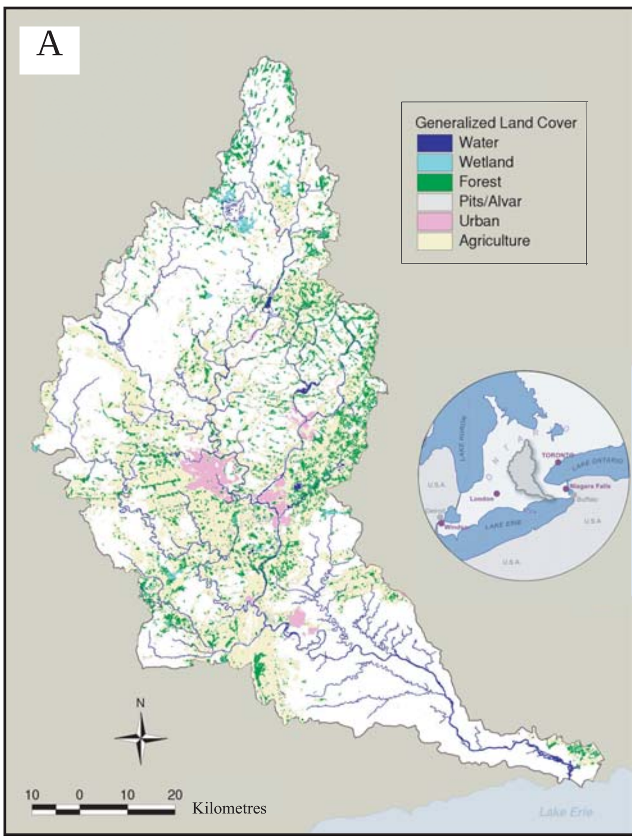
Figure 1. Land cover in the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use.
Source: Grand River Conservation Authority

5% of the watershed area while forests cover about 17%. The largest urban centres, including Kitchener, Waterloo, Cambridge and Guelph, are located in the central portion of the watershed and are situated on or in close proximity to many of the complex moraine systems that stretch across the watershed (Figure 1). The moraines and associated glacial outwash area in the watershed form a complex system of sand and gravel layers separated by less permeable till layers. Together with the sand plain in the southwest portion of the watershed these units provide significant groundwater resources. The majority of the groundwater recharge in the watershed is concentrated in a land area that covers approximately 38% of the watershed. Figure 2 illustrates the land cover associated with those areas that have high recharge potential.

Land use on these moraines and significant recharge areas can have major influence on both groundwater quantity and quality (Figure 2). Intensive cropping practices with repeated manure and fertilizer applications have the potential to impact groundwater quality while urban development can interrupt groundwater recharge and impact groundwater quantity. About 67% of the significant recharge areas are in agricultural production while 23% and 8% of the recharge areas are covered with forests and urban development respectively. Since the moraine systems and recharge areas in the Grand River watershed provide important ecological, sociological and economical services to the watershed, they are important watershed features that must be maintained to ensure sustainable groundwater supplies.

Land use directly influences the ability of precipitation to recharge shallow aquifers. Urban development such as the paving of roads and building of structures intercepts precipitation and facilitates the movement of water off the land in surface runoff, which subsequently reduces groundwater recharge of shallow aquifers. A significant portion (62%) of the urban area in the Grand River watershed tends to be concentrated in the highly sensitive groundwater recharge areas (Figure 3). Development is continuing in these sensitive areas. For example, of the total kilometres of new roads built between 2000 and 2004 in the Region of Waterloo, about half of them were situated in the more sensitive areas.

Land uses that protect groundwater recharge such as some agricultural land use and forested areas need to be protected to ensure groundwater recharge. About 34% and 51% of the watershed's agricultural and forested land cover is located in the significant recharge areas. Strategic development is needed to protect these recharge areas to protect groundwater recharging function in the watershed.



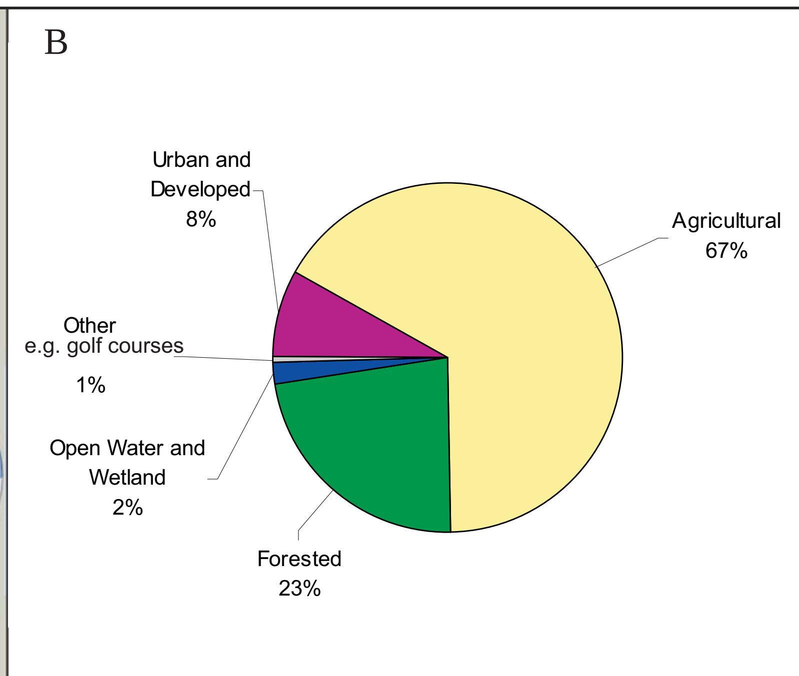


Figure 2. Land cover on moraine systems and areas that facilitate high or very high groundwater recharge of the Grand River watershed: (a) Spatial distribution and (b) Percent distribution of classified land use. Source: Grand River Conservation Authority

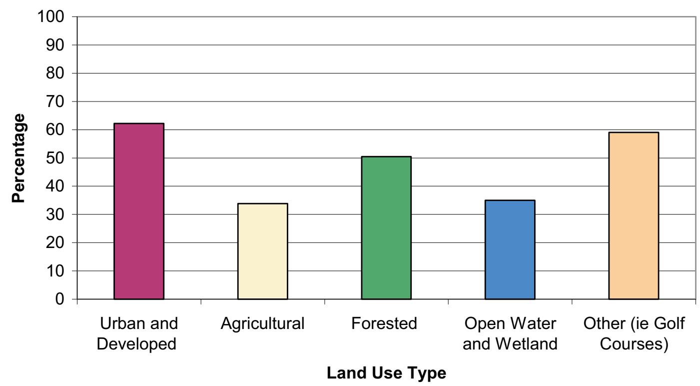


Figure 3. Percentage of land use type in significant recharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

Groundwater use and intensity

Groundwater in the Grand River watershed is used for a range of activities including domestic, municipal, public, agricultural, and industrial/commercial supplies. It is estimated that approximately 80% of the 875,000 watershed residents use groundwater as their primary source of potable water.

Between 1940 and 2003, over 37,000 wells were constructed in the Grand River watershed. Approximately 79% of these wells (or 29,683 wells) are, or were, used for domestic water supplies (Figure 4). However, this represents only 3% of the total annual groundwater takings in the watershed (Figure 5). The largest users of groundwater in the watershed are municipalities (30%) who use the water to provide potable water to their residents. Industries, commercial developments, aggregate washing, dewatering and remediation also withdraw significant amounts of groundwater (43%, combined). Aquaculture is a significant user of groundwater at approximately 13% of the total annual groundwater takings in the watershed.

Even though total annual groundwater withdrawals identify municipal takings as the most significant use of groundwater, seasonal demands in selected areas can be significant. Irrigation becomes the second largest use of water in July in the Grand River watershed. Approximately 60% of all irrigation is done with groundwater. Therefore, this seasonal demand can have a significant impact on local groundwater fed streams and the aquatic life that inhabits them. Although the irrigated land in the Grand River watershed is less than 1% of the total land area, increasing trends in irrigation (Figure 6) places added stress on these local groundwater-dependant ecosystems.

Climatic factors and population growth can also impact the demand for groundwater resources. The number of new wells drilled since 1980 grew steadily until 1989 (Figure 7). The number of new wells drilled peaked between 1987 and 1989, which coincides with a period of lower flow in the river. The average annual river flows illustrated in Figure 7 represents conditions where average, below average and above average streamflow were measured. The 1987-1989 period had below average streamflow suggesting it was dryer than normal and that watershed residents were searching for new groundwater supplies. The same occurrence is illustrated again in 1998-1999. The cumulative impact of both climate effects and increased population growth (Figure 8) likely contributes to greater demand for groundwater supplies.

Pressures

Urbanization and associated development on sensitive watershed landscapes that facilitate groundwater recharge is a significant threat to groundwater resources in the Grand River watershed. Eliminating this important watershed function will directly

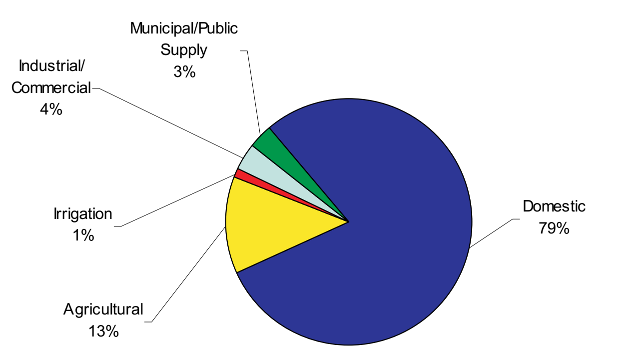


Figure 4. Distribution of groundwater wells by primary use in the Grand River watershed.
Source: Ontario Ministry of the Environment Water Well Database, 2003

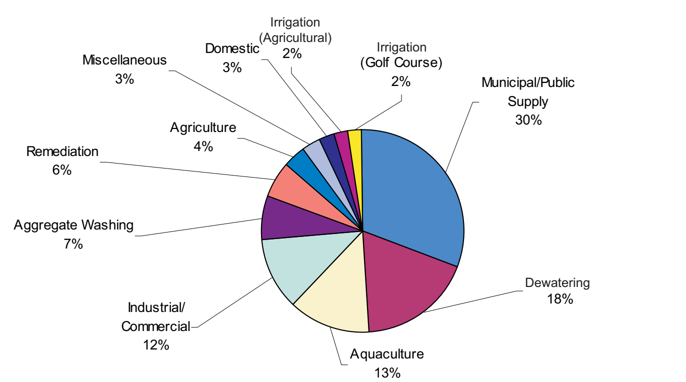


Figure 5. Percentage of total annual groundwater takings in the Grand River watershed from designated uses.
Source: Modified from Bellamy and Boyd, 2004

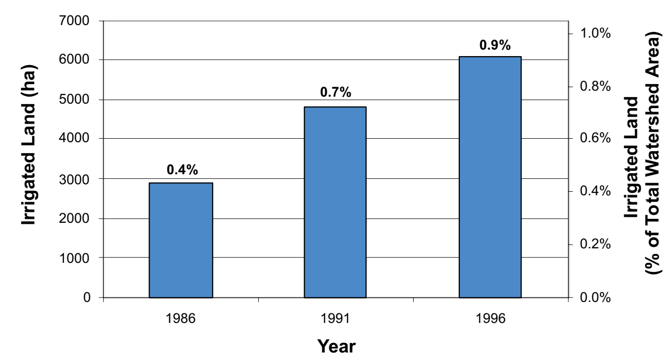


Figure 6. Changes in amount of irrigated land in the Grand River watershed (percentage of total watershed area irrigated). Source: Statistics Canada data for 1986, 1991, and 1996

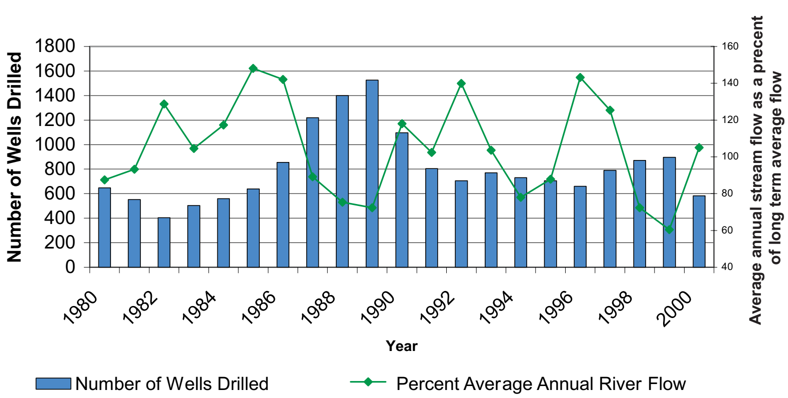


Figure 7. Number of new wells drilled each year (bars). Annual average stream flow (as a percentage on long term average) in the Grand River watershed illustrating below average, and average climatic conditions (green line).
Source: Ontario Ministry of the Environment Water Well Database, 2003

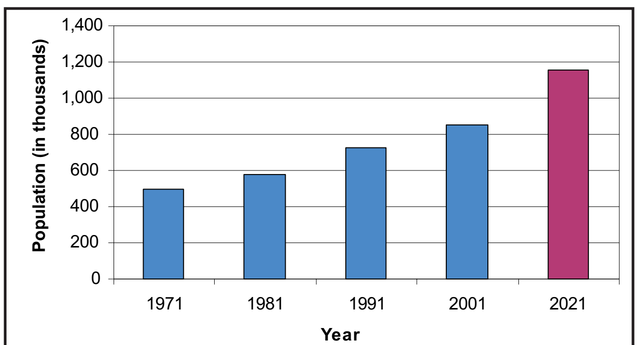


Figure 8. Estimated population in the Grand River watershed including future projections (burgundy bar).
Source: Dorfman, 1997 and Grand River Conservation Authority, 2003

impact the quantity of groundwater supplies for watershed residents. Therefore, it is essential that municipalities and watershed residents protect the moraine systems and significant recharge areas to ensure future groundwater supplies.

Population growth with continued urban development and agricultural intensification are the biggest threats to groundwater supplies in the Grand River watershed. It is estimated that the population of the watershed will increase by approximately 300,000 people in the next 20 years (Figure 8). The biggest single users of groundwater are municipalities for municipal drinking water supplies, although industrial users, including aggregate and dewatering operations, use a significant amount of groundwater. Municipalities, watershed residents and industries will need to increase their efforts in water conservation as well as continue to seek out new or alternate supplies.

Climate influence on groundwater resources in the Grand River watershed cannot be underestimated. It is evident that during times with below average precipitation, there is increased demand for groundwater resources for both the natural environment and human uses. In addition, climate change will likely redistribute precipitation patterns throughout the year, which will likely impact groundwater resources in the watershed.

Management Implications

Land use and development has a direct effect on groundwater quantity and quality. Therefore, land use planning must consider watershed functions such as groundwater recharge when directing future growth. Municipal growth strategies should direct growth and development away from sensitive watershed landscapes such as those areas that facilitate groundwater recharge. Efforts in recent years have focussed on delineating wellhead protection zones, assessing the threats and understanding the regional hydrogeology. Through the planning process, municipalities such as the Region of Waterloo, City of Guelph and the County of Wellington have recognized the importance of protecting recharge to maintain groundwater resources and have been taking steps to protect this watershed function. These initiatives include limiting the amount of impervious cover in sensitive areas and capturing precipitation with rooftop collection systems. By permitting development that facilitates groundwater recharge or redirecting development to landscapes that are not as sensitive, important watershed functions can be protected to ensure future groundwater supplies.

Water conservation measures should be actively promoted and adopted in all sectors of society. Urban communities must actively reduce consumption while rural communities require management plans to strategically irrigate using high efficiency methods and appropriate timing.

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Authors' Commentary

Understanding the impact of water use on the groundwater resources in the watershed will require understanding the availability of water to allow sustainable human use while still maintaining healthy ecosystems. Assessing groundwater availability and use at appropriate scales is an important aspect of water balance calculations in the watershed. In other words, assessing water and land use at the larger watershed scale masks more local issues such as the impact of extensive irrigation.

Consistent and improved monitoring and data collection are required to accurately estimate groundwater demand as well as determine long-term trends in land use. For example, linking groundwater permits to actual well log identification numbers will assist with understanding the spatial distribution of groundwater takings. Furthermore, groundwater permit holders should be required to report actual water use as opposed to permitted use. This will help estimate actual water use and therefore the true impact on the groundwater system.

Last Updated

State of the Great Lakes 2005

Base Flow Due to Groundwater Discharge
Indicator #7102

Overall Assessment

Status:	**Mixed**
Trend:	**Deteriorating**
Primary Factors Determining Status and Trend	**It is estimated that human activities have detrimentally impacted groundwater discharge on at least a local scale in some areas of the Great Lakes basin and that discharge is not significantly impaired in other areas.**

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed
Trend: Undetermined

Lake Michigan

Status: Not Assessed
Trend: Undetermined

Lake Huron

Status: Not Assessed
Trend: Undetermined

Lake Erie

Status: Not Assessed
Trend: Undetermined

Lake Ontario

Status: Not Assessed
Trend: Undetermined

Purpose

•To measure the contribution of base flow due to groundwater discharge to total stream flow; and
•To detect the impacts of anthropogenic factors on the quantity of the groundwater resource.

Ecosystem Objective

Base flow due to the discharge of groundwater to the rivers and inland lakes and wetlands of the Great Lakes basin is a significant and often major component of stream flow, particularly during low flow periods. Base flow frequently satisfies flow, level, and temperature requirements for aquatic species and habitat. Water supplies and the capacity of surface water to assimilate wastewater discharge are also dependent on base flow. Base flow due to groundwater discharge is therefore critical to the maintenance of water quantity and quality and the integrity of aquatic species and habitat.

State of the Ecosystem

Background

A significant portion of precipitation over the inland portion of the Great Lakes basin returns to the atmosphere by evapo-transpiration. Water that does not return to the atmosphere either flows across the ground surface or infiltrates into the subsurface and recharges groundwater. Some of this water is subsequently removed by consumptive uses such as irrigation and water bottling. Water that flows across the ground surface discharges into surface water features (rivers, lakes, and wetlands) and then flows toward and eventually into the Great Lakes. The component of stream flow due to runoff from the ground surface is rapidly varying and transient, and results in the peak discharges of a stream.

Water that infiltrates into the subsurface and recharges groundwater also results in flow toward the Great Lakes. Most recharged groundwater flows at relatively shallow depths at local scales and discharges into adjacent surface water features. However, groundwater also flows at greater depths at regional scales and discharges either directly into the Great Lakes or into distant surface water features. The quantities of groundwater flowing at these greater depths can be significant locally but are generally believed to be modest relative to the quantities flowing at shallower depths. Groundwater discharge to surface water features in response to precipitation is greatly delayed relative to surface runoff. The stream flow resulting from groundwater discharge is, therefore, more uniform.

Base flow is the less variable and more persistent component of total stream flow. In the Great Lakes region, groundwater discharge is often the dominant component of base flow; however, various human and natural factors also contribute to base flow. Flow regulation, the storage and delayed release of water using dams and reservoirs, creates a stream flow signature that is similar to that of groundwater discharge. Lakes and wetlands also moderate stream flow, transforming rapidly varying surface runoff into more slowly varying flow that approximates the dynamics of groundwater discharge. It is important to note that these varying sources of base flow affect surface water quality, particularly with regard to temperature. All groundwater discharge contributes to base flow but not all base flow is the result of groundwater discharge.

Status of Base Flow

Base flow is frequently determined using a mathematical process known as hydrograph separation. This process uses stream flow monitoring information as input and partitions the observed flow into rapidly and slowly varying components, surface runoff and base flow, respectively. The stream flow data that are used in these analyses are collected across the Great Lakes basin using networks of stream flow gauges that are operated by the United States Geological Survey (USGS) and Environment Canada. Neff *et al*. (2005) summarize the calculation and interpretation of base flow for 3,936 gauges in Ontario and the Great Lakes states using six methods of hydrograph separation and length-of-record stream flow monitoring information for the periods ending on December 31, 2000 and September 30, 2001, respectively. The results reported by Neff *et al*. (2005) are the basis for the majority of this report. Results corresponding to the UKIH method of hydrograph separation (Piggott *et al*. 2005) are referenced throughout this report in order to maintain consistency with the previous report for this indicator; however, results calculated using the five other methods are considered to be equally probable outcomes. Figure 1 illustrates the daily stream flow monitoring information and the results of hydrograph separation for the Nith River at New Hamburg, Ontario for January 1 to December 31, 1993. The rapidly varying response of stream flow to precipitation and snow melt are in contrast to the more slowly varying base flow.

Application of hydrograph separation to daily stream flow monitoring information results in lengthy time series of output. Various measures are used to summarize this output; for example, base flow index is a simple, physical measure of the contribution of base flow to stream flow that is appropriate for use in regional scale studies. Base flow index is defined as the average rate of base flow relative to the average rate of total stream flow, is unitless, and varies from zero to one where increasing values indicate an increasing contribution of base flow to stream flow. The value of base flow index for the data shown in Figure 1 is 0.28, which implies that 28% of the observed flow is estimated to be base flow. Neff *et al.* (2005) used a selection of 960 gauges in Ontario and the Great Lakes states to interpret base flow. Figure 2 indicates the distribution of the values of base flow index calculated for the selection of gauges relative to the gauged and ungauged portions of the Great Lakes basin. The variability of base flow within the basin is apparent; however, further processing of the information is required to differentiate the component of base flow that is due to groundwater discharge and the component that is due to delayed flow through lakes and wetlands upstream of the gauges. An approach to the differentiation of base flow calculated using hydrograph separation into these two components is summarized in the following paragraphs of this report. Variations in the density of the stream flow gauges and discontinuities in the coverage of monitoring are also apparent in Figure 2 and may have significant implications relative to the interpretation of base flow.

The values of base flow index calculated for the selection of gauges using hydrograph separation are plotted relative to the extents of surface water upstream of each of the gauges in Figure 3 where the extents of surface water are defined as the area of lakes and wetlands upstream of the gauges relative to the total area upstream of the gauges. While there is considerable scatter among the values, the expected tendency for larger values of base flow index to be associated with larger extents of surface water is confirmed. Neff *et al.* (2005) modeled base flow index as a function of surficial geology and the spatial extent of surface water. Surficial geology is assumed to be responsible for differences in groundwater discharge and is classified into coarse and fine textured sediments, till, shallow bedrock, and organic deposits.

The modeling process estimates a value of base flow index for each of the geological classifications, calculates the weighted averages of these values for each of the gauges based on the extents of the classifications upstream of the gauges, and then modifies the weighted averages as a function of the extent of surface water upstream of the gauges. A non-linear regression algorithm was used to determine the values of base flow index for the geological classifications and the parameter in the surface water modifier that correspond to the best match between the values of base flow index calculated using hydrograph separation and the values predicted using the model. The process was repeated for each of the six methods of hydrograph separation.

Extrapolation of base flow index from gauged to ungauged watersheds was performed using the results of the modeling process. The ungauged watersheds consist of 67 tertiary watersheds in Ontario and 102 eight-digit hydrologic unit code or HUC watersheds in the Great Lakes states. The extents of surface water for the ungauged watersheds are shown in Figure 4 where the ranges of values used in the legend match those used to average the values of base flow index shown in

Figure 3. A component of base flow due to delayed flow through lakes and wetlands appears to be likely over extensive portions of the Great Lakes basin. The distribution of the classifications of geology is shown in Figure 5. Organic and fine textured sediments are not differentiated in this rendering of the classifications because both classifications have estimated values of base flow index due to groundwater discharge in the range of 0.0 to 0.1; however, organic deposits are of very limited extent and represent, on average, less than 2% of the area of the ungauged watersheds. The spatial variation of base flow index shown in Figure 5 resembles the variation shown in Figure 2. However, it is important to note that the information shown in Figure 2 includes the influence of delayed flow through lakes and wetlands upstream of the gauges while this influence has been removed, or at least reduced, in the information shown in Figure 5.

Figure 6 indicates the values of the geological component of base flow index for the ungauged watersheds obtained by calculating the weighted averages of the values for the geological classifications that occur in the watersheds. This map therefore represents an estimate of the length-of-record contribution of base flow due to groundwater discharge to total stream flow that is consistent and seamless across the Great Lakes basin. The pie charts indicate the range of values of the geological component of base flow index for the six methods of hydrograph separation averaged over the sub-basins of the Great Lakes. Averaging the six values for each of the sub-basins yields contributions of base flow due to groundwater discharge of approximately 60% for Lakes Huron, Michigan, and Superior and 50% for Lakes Erie and Ontario. It is important to note that there is frequently greater variability of this contribution within the sub-basins than among the sub-basins as the result of variability of geology that is more uniformly averaged at the scale of the sub-basins.

Mapping the geological component of base flow index, which is assumed to be due to groundwater discharge, across the Great Lakes basin in a consistent and seamless manner is an important accomplishment in the development of this indicator. Additional information is, however, required to determine the extent to which human activities have impaired groundwater discharge. There are various alternatives for the generation of this information. For example, the values of base flow index calculated for the selection of stream flow gauges using hydrograph separation can be compared to the corresponding modeled values. If a calculated value is less than a modeled value, and if the difference is not related to the limitations of the modeling process, then base flow is less than expected based on physiographic factors and it is possible that discharge has been impacted by human activities. Similarly, if a calculated value is greater than a modeled value, then it possible that the increased base flow is the result of human activities such as flow regulation and wastewater discharge. Time series of base flow can also be used to assess these impacts. The previous report for this indicator illustrated the detection of temporal change in base flow using data for watersheds with approximately natural stream flow and with extensive flow regulation and urbanization; however, no attempt has yet been made to systematically assess change at the scale of the Great Lakes basin. Change in base flow over time may be subtle and difficult to quantify (e.g., variations in the relation of base flow to climate) and may be continuous (e.g., a uniform increase in base flow due to aging water supply infrastructure and increasing conveyance losses) or discrete (e.g., an abrupt reduction in base flow due to a new consumptive water use). Change may also be the result of cumulative impacts due to a range of historical and ongoing human activities, and may be more pronounced and readily detected at local scales than at the scales that are typical of continuous stream flow monitoring.

Figure 7 is an alternative view of the data for the Grand River at Galt, Ontario that was previously used to illustrate the impact of flow regulation on base flow. The cumulative depth of base flow calculated annually as the total volume of flow at the location of the gauge during each year divided by the area that is upstream of the gauge, is plotted relative to cumulative total flow. Base flow index is, by definition, the slope of the accumulation of base flow relative to the accumulation of total flow. The change in slope and increase in base flow index from a value of 0.45 prior to the construction of the reservoirs that are located upstream of the gauge to 0.57 following the construction of the reservoirs clearly indicates the impact of active flow regulation to mitigate low and high flow conditions. Calculating and interpreting diagnostic plots such as Figure 7 for hundreds to thousands of stream flow gauges in the Great Lakes basin will be a large and time consuming, but perhaps ultimately necessary, task.

Improving the spatial resolution of the current estimates of base flow due to groundwater discharge would be beneficial in some settings. For example, localized groundwater discharge has important implications in terms of aquatic habitat and it is unlikely that this discharge can be predicted using the current regional estimates of base flow. The extrapolation of base flow information from gauged to ungauged watersheds described by Neff *et al*. (2005) is based on a classification and therefore reduced resolution representation of the Quaternary geology of the basin. Figure 8 compares this classification to the full resolution of the available 1:1,000,000 scale (Ontario Geological Survey 1997) and 1:50,000 scale (Ontario Geological Survey 2003) mapping of the geology of the gauged portion of the Grand River watershed in southern Ontario. Interpretation of base flow in terms of these more detailed descriptions of geology, where feasible relative to the network of stream flow gauges, may result in an improved estimate of the spatial distribution of groundwater discharge for input into functions such as aquatic habitat management.

Estimation of base flow using low flow observations, single “spot” measurements of stream flow under assumed base flow conditions, is another means of improving the spatial resolution of the current prediction of groundwater discharge. Figure 9 illustrates a series of low flow observations performed within the watershed of Duffins Creek above Pickering, Ontario where the observations are standardized using continuous monitoring information and the drainage areas for the observations following the procedure described by Gebert *et al*. (in press) and then classified into quantile groupings of high, intermediate, and low values. The standardized values of low flow illustrate the spatially variable pattern of groundwater discharge that results from the interaction between surficial geology, the complex three-dimensional hydrostratigraphy, topography, and surface water features. Areas of potentially high groundwater discharge may have particularly important implications in terms of aquatic habitat for cold water fish species such as Brook Trout.

Finally, reconciling estimates of base flow generated using differing methods of hydrograph separation, perhaps by interpreting the information in a relative rather than absolute manner, will improve the certainty and therefore performance of base flow as an indicator of groundwater discharge. It may also be possible to assess the source of this uncertainty using chemical and isotopic data in combination with the methods of hydrograph separation if adequate data is available at the scale of the gauged watersheds. Figure 10 compares the values of base flow index calculated for the selection of 960 stream flow gauges in Ontario and the Great Lake states using the PART (Rutledge 1998) and UKIH methods of hydrograph separation. The majority of the values calculated using the PART method are greater than the values calculated using the UKIH method and there is considerable scatter in the differences among the two methods. The average of the differences between the two sets of values is 0.15 and is significant when measured relative to the differences in the estimates of base flow index for the sub-basins of the Great Lakes, which is on the order of 0.1.

Pressures

The discharge of groundwater to surface water features is the end-point of the process of groundwater recharge, flow, and discharge. Human activities impact groundwater discharge by modifying the components of this process where the time scale, and to some extent the severity, of these impacts is a function of hydrogeological factors and the proximity of surface water features. Increasing the extent of impervious surfaces during residential and commercial development and installation of drainage to increase agricultural productivity are examples of activities that may reduce groundwater recharge and ultimately groundwater discharge. Withdrawals of groundwater as a water supply and during dewatering (pumping groundwater to lower the water table during construction, mining, etc.) remove groundwater from the flow regime and may also reduce groundwater discharge. Groundwater discharge may be impacted by activities such as the channelization of water courses that restrict the motion of groundwater across the groundwater and surface water interface. Human activities also have the capacity to intentionally, or unintentionally, increase groundwater discharge. Induced storm water infiltration, conveyance losses within municipal water and wastewater systems, and closure of local water supplies derived from groundwater are examples of factors that may increase groundwater discharge. Climate variability and change may compound the implications of human activities relative to groundwater recharge, flow, and discharge.

Management Implications

Groundwater has important societal and ecological functions across the Great Lakes basin. Groundwater is typically a high quality water supply that is used by a significant portion of the population, particularly in rural areas where it is often the only available source of water. Groundwater discharge to rivers, lakes, and wetlands is also critical to aquatic species and habitat and to in-stream water quantity and quality. These functions are concurrent and occasionally conflicting. Pressures such as urban development and water use, in combination with the potential for climate impacts and further contamination of the resource, may increase the frequency and severity of these conflicts. In the absence of systematic accounting of groundwater supplies, use, and dependencies; it is the ecological function of groundwater that is most likely to be compromised.

Managing the water quality of the Great Lakes requires an understanding of water quantity and quality within the inland portion of the basin, and this understanding requires recognition of the relative contributions of surface runoff and groundwater discharge to stream flow. The results described in this report indicate the significant contribution of groundwater discharge to flow within the tributaries of the Great Lakes. The extent of this contribution has tangible management implications. There is considerable variability in groundwater recharge, flow, and discharge that must be reflected in the land and water management practices that are applied across the basin. The dynamics of groundwater flow and transport are different than those of surface water flow.

Groundwater discharge responds more slowly to climate and maintains stream flow during periods of reduced water availability; however, this capacity is known to be both variable and finite. Contaminants that are transported by groundwater may be in contact with geologic materials for years, decades, and perhaps even centuries or millennia. As a result, there may be considerable opportunity for attenuation of contamination prior to discharge. However, the lengthy residence times of groundwater flow also limit opportunities for the removal of contaminants, in general, and non-point source contaminants, in particular.

Comments from the author(s)
The indicated status and trend are estimates that the authors consider to be a broadly held opinion of water resource specialists within the Great Lakes basin. Further research and analysis is required to confirm these estimates and to determine conditions on a lake by lake basis.

Acknowledgments
Authors: Andrew Piggott, Environment Canada;
Brian Neff, U.S. Geological Survey; and
Marc Hinton, Geological Survey of Canada.
Contributors: Lori Fuller, U.S. Geological Survey and
Jim Nicholas, U.S. Geological Survey.

Base flow information cited in the report is a product of Groundwater and the Great Lakes: A Co-ordinated Bi-national Basin-wide Assessment in Support of Annex 2001 Decision Making, which was supported by the Great Lakes Protection Fund.

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List of Figures

Figure 10. Comparison of the values of base flow index calculated using the PART method of hydrograph separation to the values calculated using the UKIH method.
Source: Environment Canada and the U.S. Geological Survey

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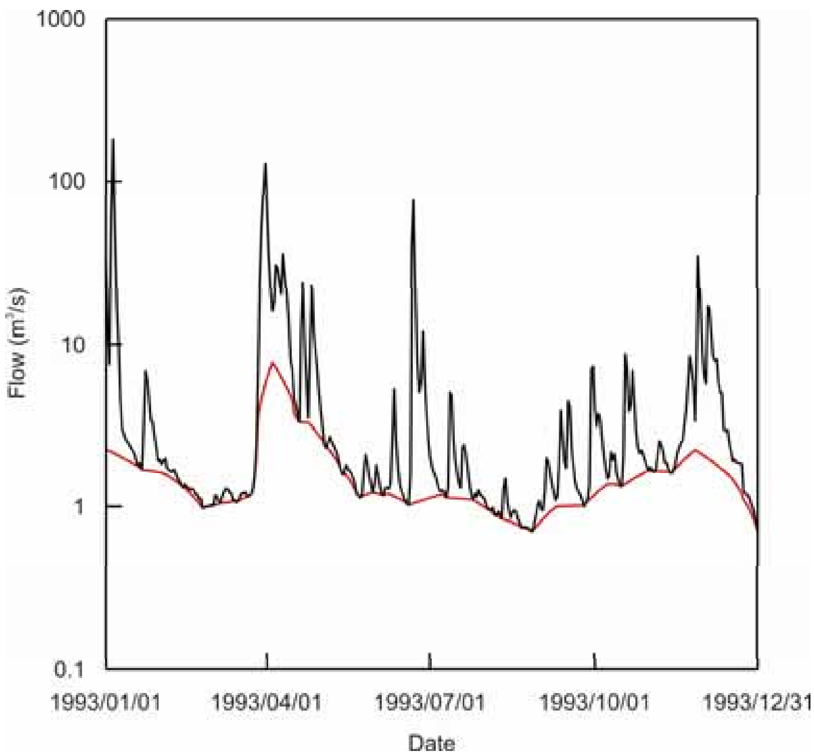
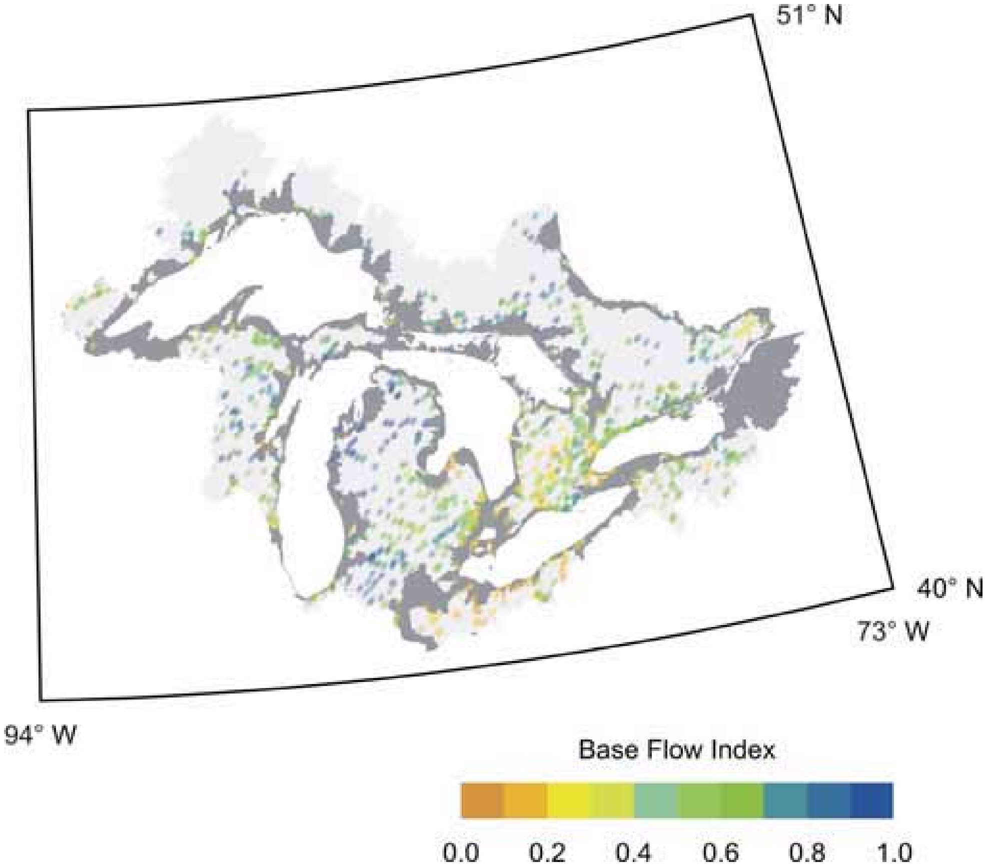


Figure 1. Hydrograph of observed total stream flow (black) and calculated base flow (red) for the Nith River at New Hamburg during 1993.
Source: Environment Canada and the U.S. Geological Survey



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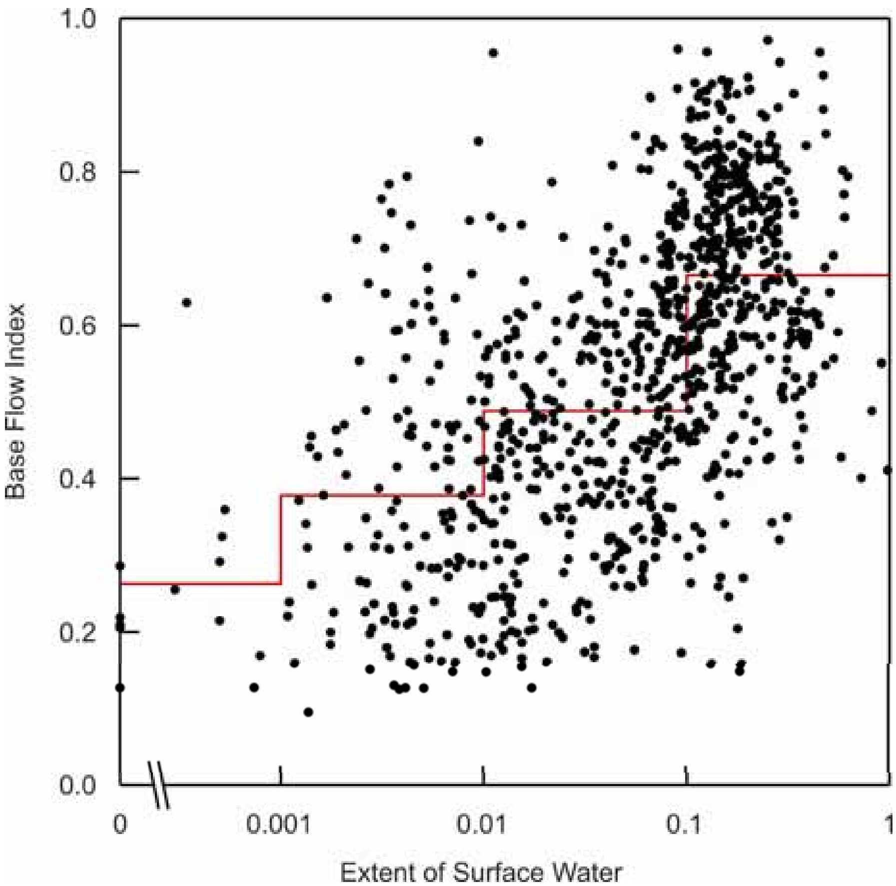
Source: Environment Canada and the U.S. Geological Survey



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Source: Environment Canada and the U.S. Geological Survey

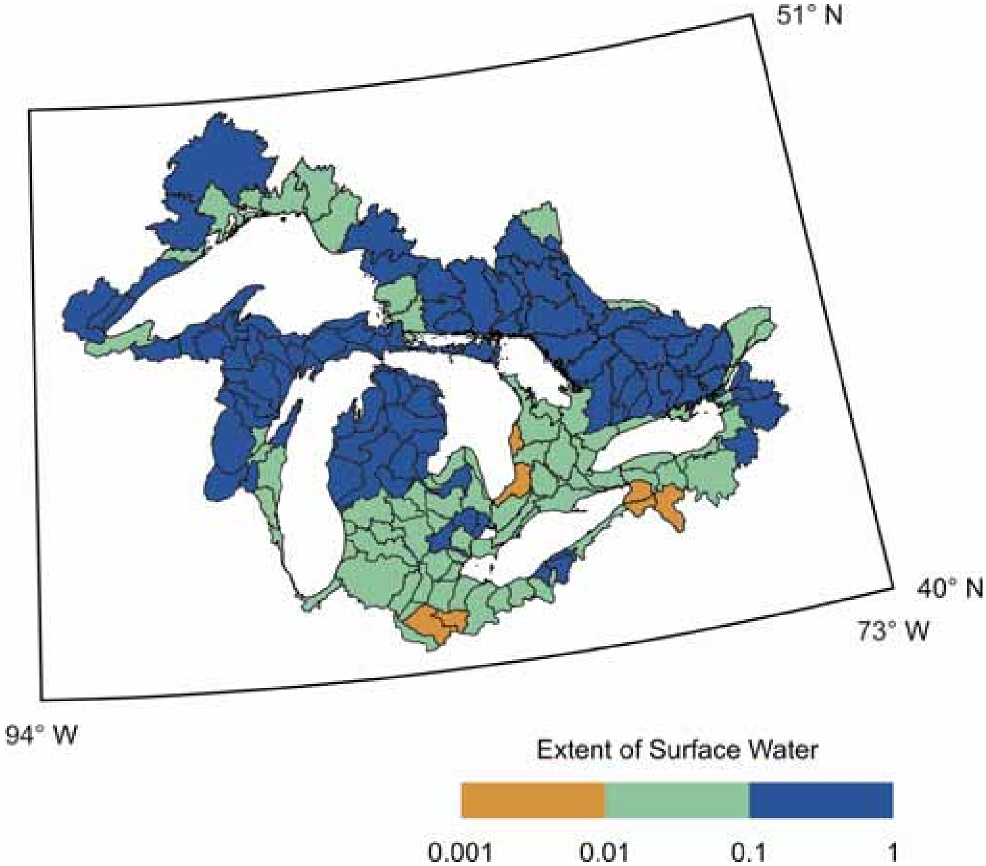

Figure 4. Distribution of the extents of surface water for the ungauged watersheds.
Source: Environment Canada and the U.S. Geological Survey

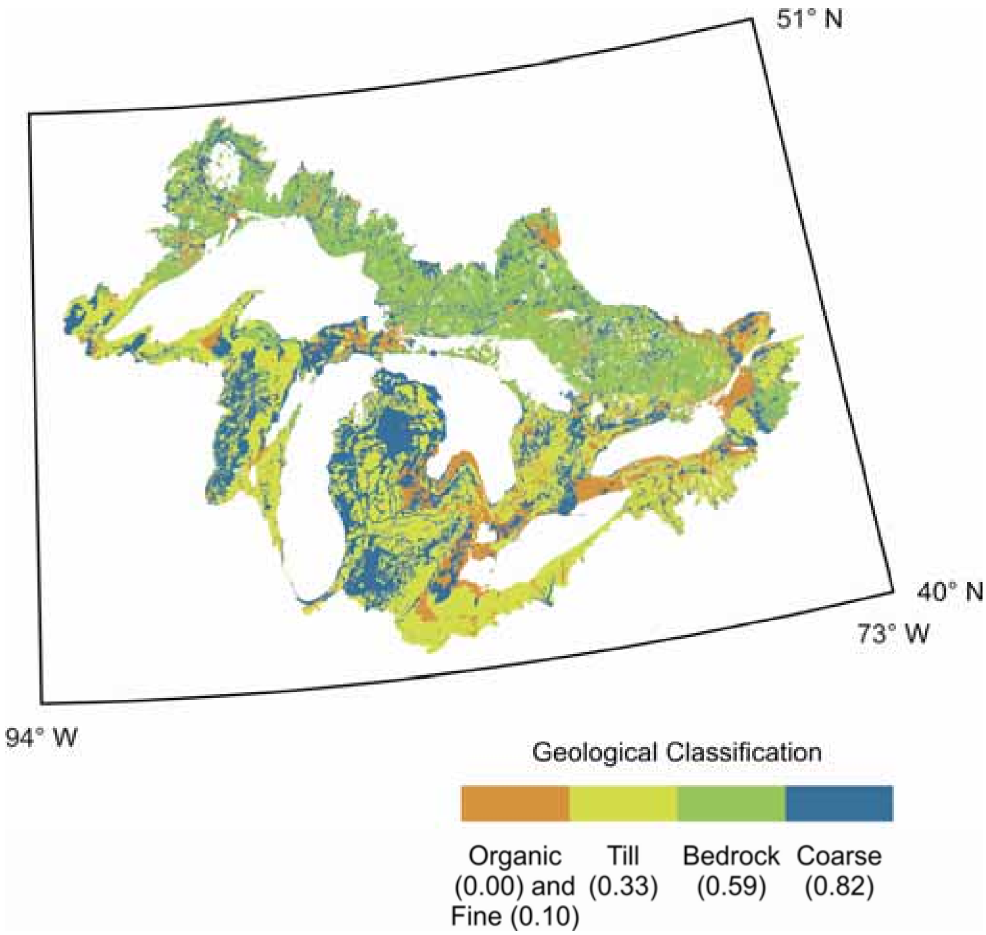

Figure 5. Distribution of the geological classifications. The classifications are shaded using the estimated values of the geological component of base flow index shown in parentheses.
Source: Environment Canada and the U.S. Geological Survey

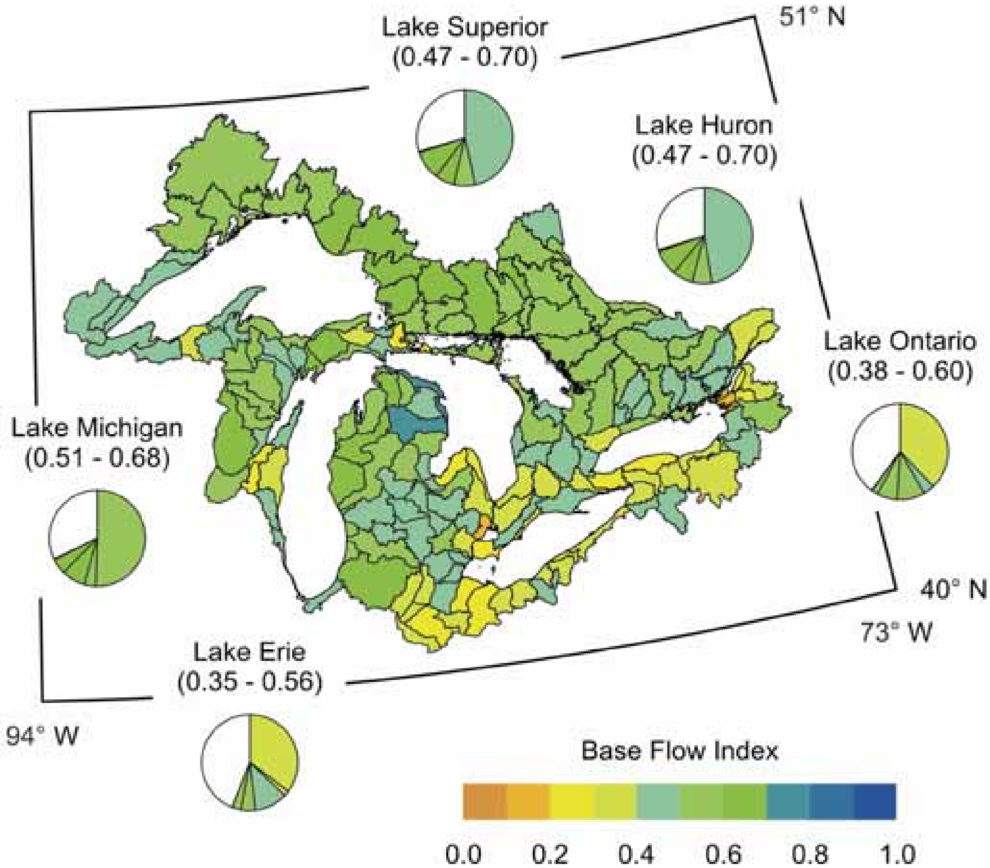

Figure 6. Distribution of the estimated values of the geological component of base flow index for the ungauged watersheds. The pie charts indicate the estimated values of the geological component of base flow index for the Great Lakes sub-basins corresponding to the six methods of hydrograph separation. The charts are shaded using the six values of base flow index and the numbers in parentheses are the range of the values.
Source: Environment Canada and the U.S. Geological Survey

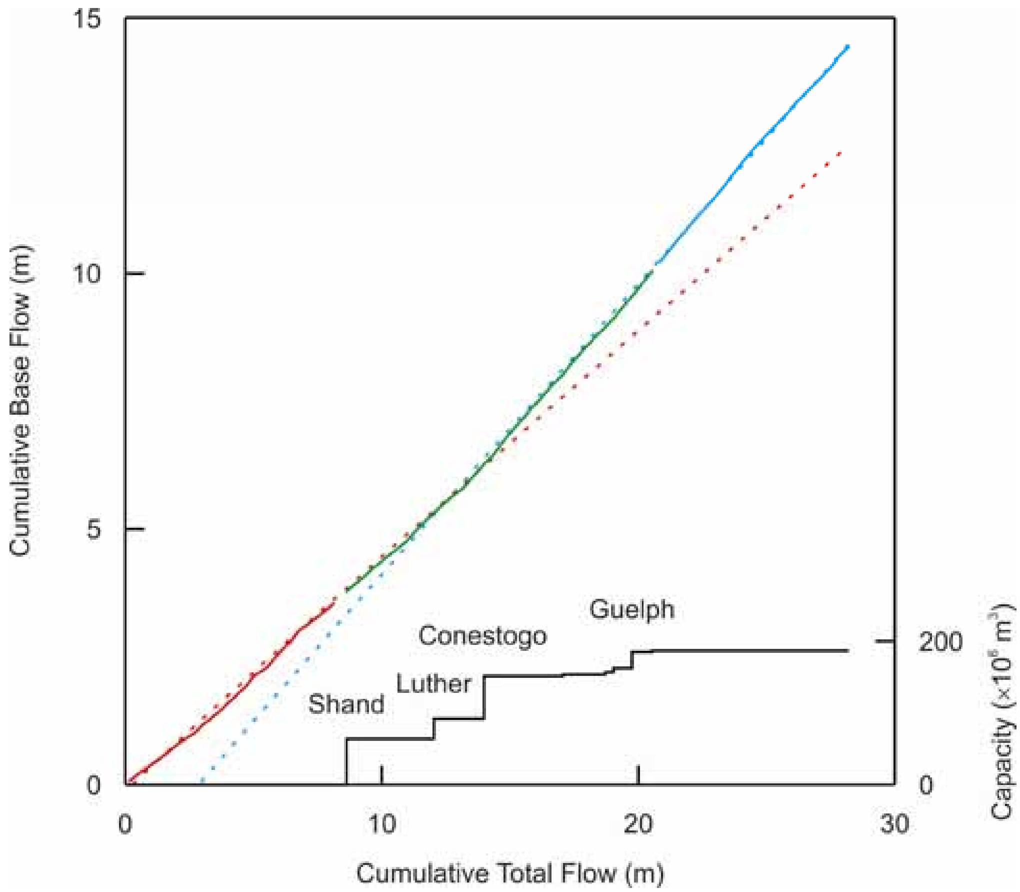

Figure 7. Cumulative base flow as a function of cumulative total flow for the Grand River at Galt prior to (red), during (green), and following (blue) the construction of the reservoirs that are located upstream of the stream flow gauge. The step plot indicates the cumulative storage capacity of the reservoirs where the construction of the largest four reservoirs is labeled. The dashed red and blue lines indicate uniform accumulation of flow based on data prior to and following, respectively, the construction of the reservoirs.
Source: Environment Canada and the U.S. Geological Survey

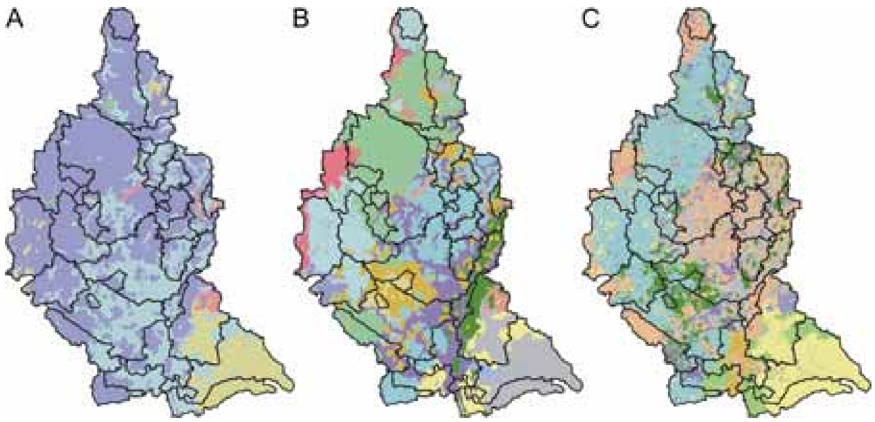

Figure 8. Geology of the gauged portion of the Grand River watershed based on the classification (A) and full resolution (B) of the 1:1,000,000 scale Quaternary geology mapping and the full resolution of the 1:50,000 scale Quaternary geology mapping (C) where random colours are used to differentiate the various geological classifications and units.
Source: Environment Canada and the U.S. Geological Survey

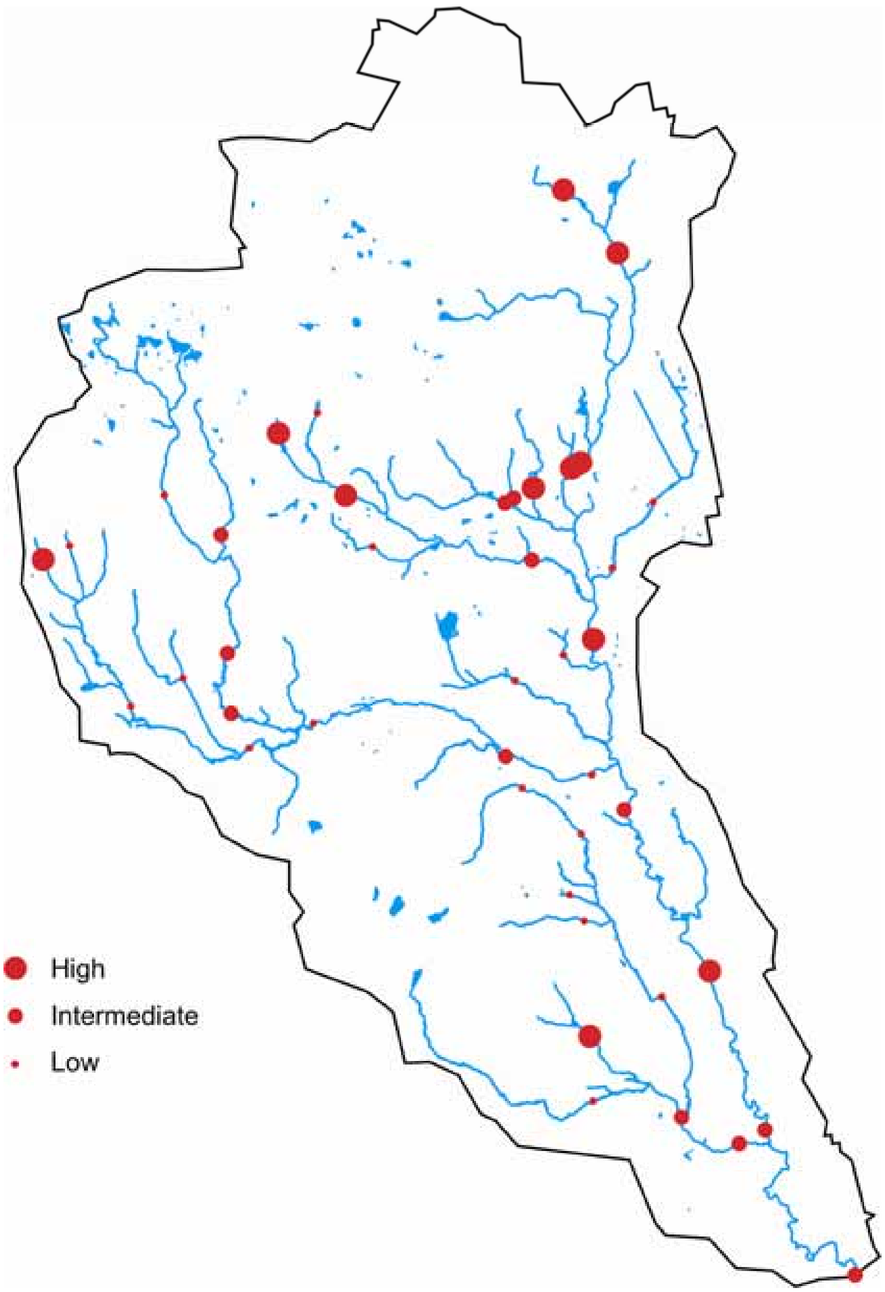

Figure 9. Distribution of the standardized values of low flow within the watershed of Duffins Creek above Pickering.
Source: Environment Canada and the U.S. Geological Survey, Geological Survey of Canada, and Ontario Ministry of Natural Resources

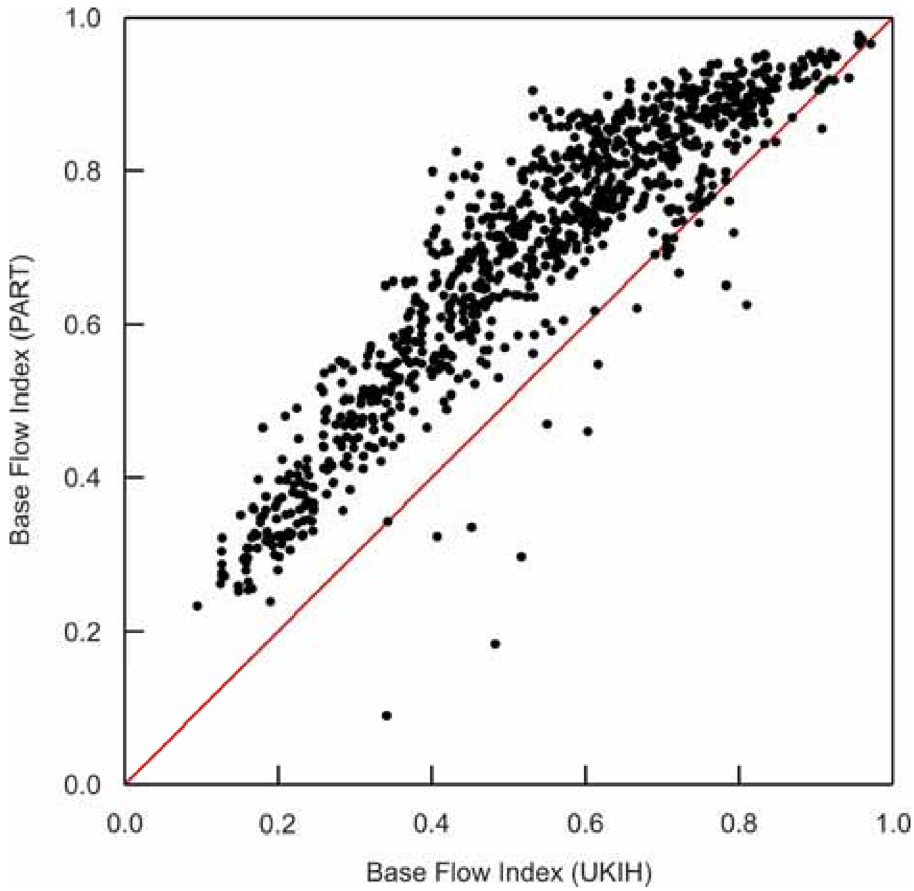

Figure 10. Comparison of the values of base flow index calculated using the PART method of hydrograph separation to the values calculated using the UKIH method.
Source: Environment Canada and the U.S. Geological Survey

Groundwater Dependant Plant and Animal Communities

Indicator #7103

Assessment: Not Assessed

Note: This indicator report uses data from the Grand River watershed only and may not be representative of groundwater conditions throughout the Great Lakes basin. Additionally, there is insufficient biological and physical hydrological data for most of the streams in the Grand River watershed to report on many of the selected species reliant on groundwater discharge, hence this discussion focuses on brook trout (*Salvelinus fontinalis*) as an indicator of groundwater discharge.

Purpose

- To measure the abundance and diversity as well as presence or absence of native invertebrates, fish, plant and wildlife (including cool-water adapted frogs and salamanders) communities that are dependent on groundwater discharges to aquatic habitat;
- To identify and understand any deterioration of water quality for animals and humans, as well as changes in the productive capacity of flora and fauna dependant on groundwater resources;
- To use biological communities to assess locations of groundwater intrusions; and
- To infer certain chemical and physical properties of groundwater, including changes in patterns of seasonal flow.

Ecosystem Objective

The goal for this indicator is to ensure that plant and animal communities function at or near maximum potential and that populations are not significantly compromised due to anthropogenic factors.

State of the Ecosystem

Background

The integrity of larger water bodies can be linked to biological, chemical and physical integrity of the smaller watercourses that feed them. Many of these small watercourses are fed by groundwater. As a result, groundwater discharge to surface waters becomes cumulatively important when considering the quality of water entering the Great Lakes. The identification of groundwater fed streams and rivers will provide useful information for the development of watershed management plans that seek to protect these sensitive watercourses.

Human activities can change the hydrological processes in a watershed resulting in changes to recharge rates of aquifers and discharges rates to streams and wetlands. This indicator should serve to identify organisms at risk because of human activities can be used to quantify trends in communities over time.

Status of Groundwater Dependent Plant and Animal Communities in the Grand River Watershed

The surficial geology of the Grand River watershed is generally divided into three distinct regions; the northern till plain, central moraines with large sand and gravel deposits, and the southern clay plain (Figure 1). These surficial overburden deposits are underlain by thick sequences of fractured carbonate rock (predominantly dolostone).

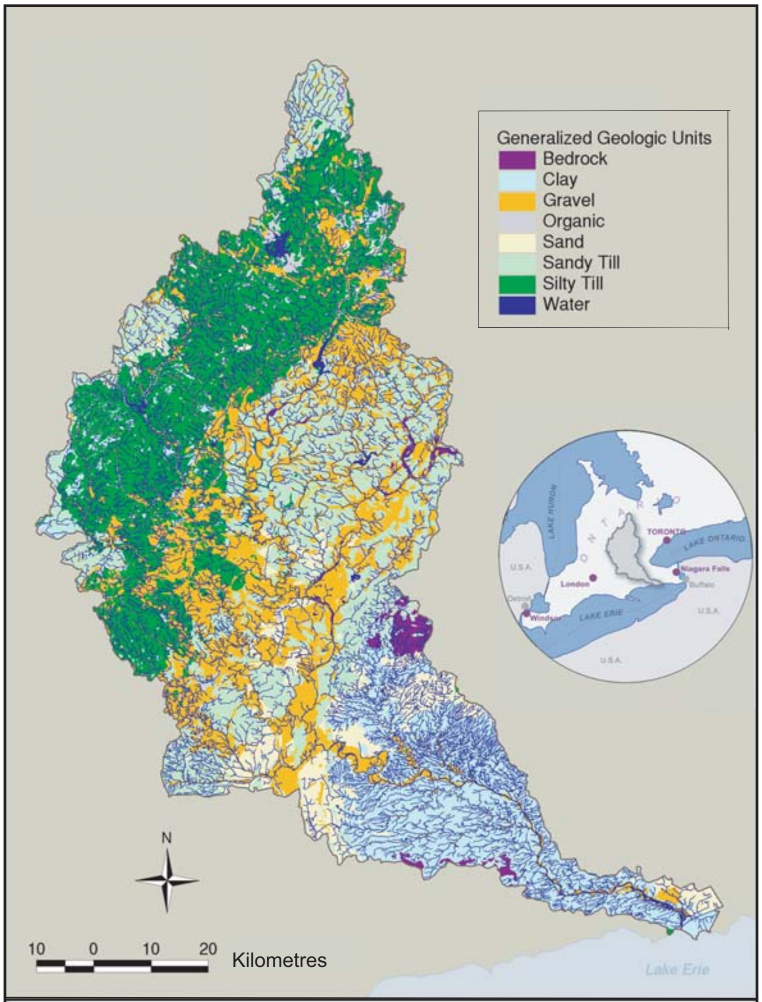

Figure 1. Surficial geology of the Grand River watershed.
Source: Grand River Conservation Authority

The Grand River and its tributaries form a stream network housing approximately 11,329 km of stream habitat. The Ontario Ministry of Natural Resources (OMNR) has classified many of Ontario's streams based on habitat type. While many streams and rivers in the Grand River watershed remain unclassified, the MNR database currently available through the Natural Resources and Values Information System (NRVIS) has documented and classified about 22% of the watershed's streams (Figure 2). Approximately 19% of the classified streams are cold-water habitat and therefore dependent on groundwater discharge. An additional 16% of the classified streams are considered potential cold-water habitat. The remaining 65% of classified streams are warm-water habitat.

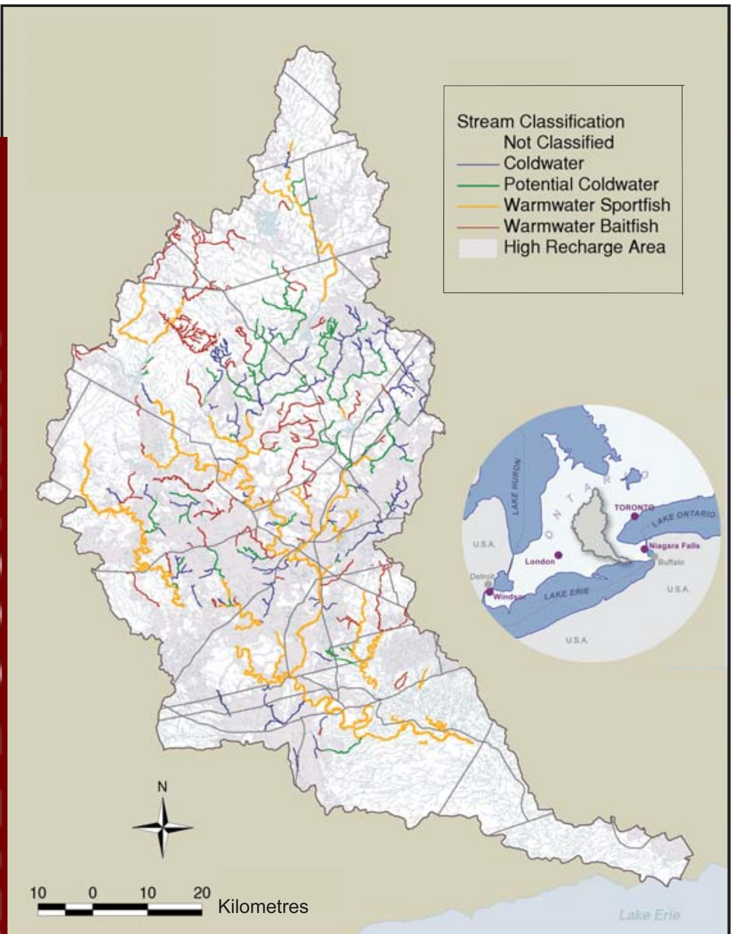

Figure 2. Streams of the Grand River watershed.
Source: Grand River Conservation Authority

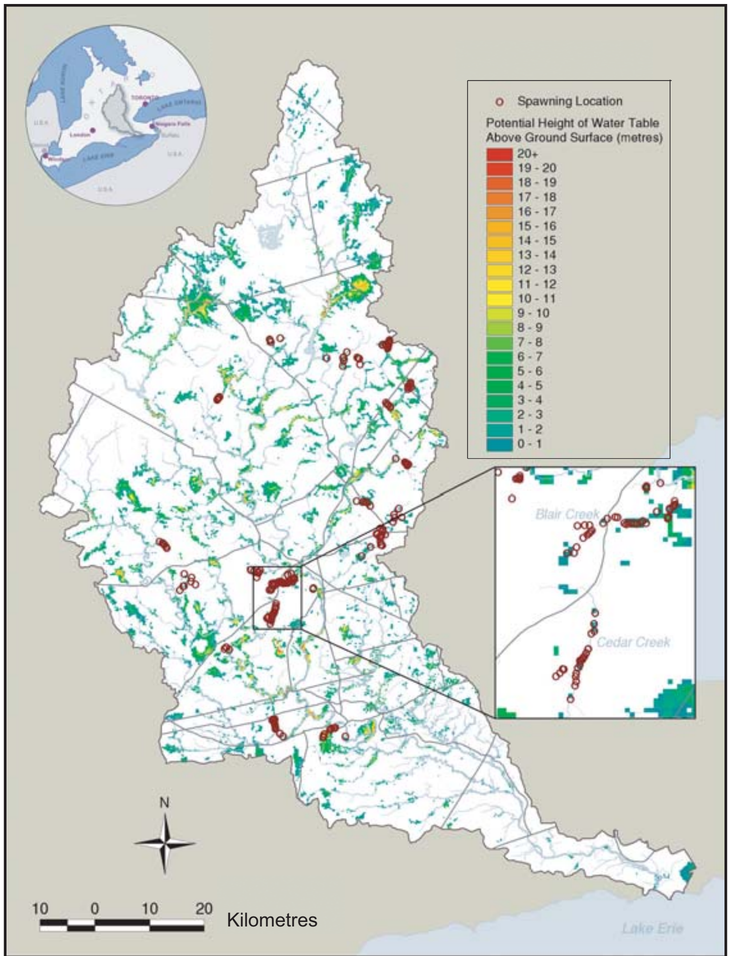

Figure 3. Map of potential discharge areas in the Grand River watershed.
Source: Grand River Conservation Authority

A map of potential groundwater discharge areas was created for the Grand River watershed by examining the relationship between the water table and ground surface (Figure 3). This map indicates areas in the watershed where water well records indicate that the water table could potentially be higher than the ground surface. In areas where this is the case, there is a strong tendency toward discharge of groundwater to land, creating cold-water habitats. Groundwater discharge appears to be geologically controlled with most potential discharge areas noted associated with the sands and gravels in the central moraine areas and little discharge in the northern till plain and southern clay plain. The map suggests that some of the unclassified streams in Figure 2 may be potential cold-water streams, particularly in the central portion of the watershed where geological conditions are favourable to groundwater discharge.

Brook trout is a freshwater fish species native to eastern Canada. The survival and success of brook trout is closely tied to cold groundwater discharges in streams used for spawning. Specifically, brook trout require inputs of cold, clean water to successfully reproduce. As a result, nests or redds are usually located in substrate where groundwater is upwelling into surface water. A significant spawning population of adult brook trout generally indicates a constant source of cool, good quality groundwater.

Locations of observed brook trout redds are shown on Figure 3. The data shown are a compilation of several surveys carried out on selected streams in 1988 and 1989. Additional data from several sporadic surveys carried out in the 1990s are also included. These redds may represent single or multiple nests from brook trout spawning activity. The results of these surveys illustrate that there are significant high quality habitats in several of the subwatersheds in the basin.

Cedar Creek is a tributary of the Nith River in the central portion of the watershed. It has been described as containing some of the best brook trout habitat in the watershed. Salmonoid spawning surveys for brook trout were carried out over similar stretches of the creek in 1989 and 2003 (Figure 4). In 1989 a total redd count of 53 (over 4.2 km) was surveyed while in 2003 the total redd count was 59 (over 5.4 km). In both surveys, many of the redds counted were multiple redds meaning several fish had spawned at the same locations. Redd densities in 1989 and 2003 were 12.6 redds/km and 10.9 redds/km respectively. From Figure 4 it appears that in 2003 brook trout were actively spawning in Cedar Creek in mainly the same locations as in 1989. While redd density in Cedar Creek has decreased slightly, the similar survey results suggest that groundwater discharge has remained fairly constant and reductions in discharge have not significantly affected aquatic habitat.

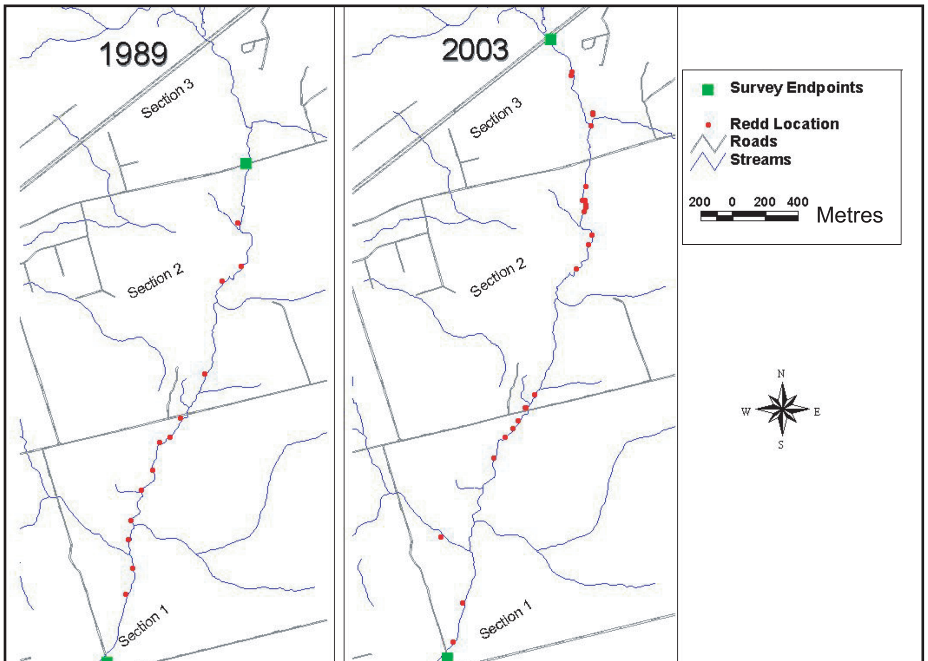

Figure 4. Results of brook trout spawning surveys carried out in the Cedar Creek subwatershed in 1989 and 2003.
Source: Grand River Conservation Authority

Pressures

The removal of groundwater from the subsurface through pumping at wells reduces the amount of groundwater discharging into surface water bodies. Increasing impervious surfaces reduces the amount of water that can infiltrate into the ground and also ultimately reduces groundwater discharge into surface water bodies. Additionally, reducing the depth to the water table from ground surface will decrease the geological protection afforded groundwater supplies and may increase the temperature of groundwater. Higher temperatures can reduce the moderating effect groundwater provides to aquatic stream habitat. At local scales the creation of surface water bodies through mining or excavation of aggregate or rock may change groundwater flow patterns, which in turn might decrease groundwater discharge to sensitive habitats.

In the Grand River watershed, groundwater is used by about 80% of the watershed's residents as their primary water supply. Additionally, numerous industrial and agricultural users also use groundwater for their operations. Growing urban communities will put pressure on the resource and if not managed properly will lead to decreases in groundwater discharge to streams. Development in some areas can also lead to decreased areas available for precipitation to percolate through the ground and recharge groundwater supplies.

Management Implications

Ensuring that an adequate supply of cold groundwater continues to discharge into streams requires protecting groundwater recharge areas and ensuring that groundwater withdrawals are undertaken at sustainable rates. Additionally, an adequate supply of groundwater for habitat purposes does not only refer to the quantity of discharge but also to the chemical quality, temperature and spatial location of that discharge. As a result, protecting groundwater resources is complicated and generally requires multi-faceted strategies including regulation, voluntary adoption of best management practices and public education.

Acknowledgments

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Authors' Commentary

This report has focused on only one species dependent on groundwater discharge for its habitat. The presence or absence of other species should be investigated through systematic field studies.

Last Updated

State of the Great Lakes 2005

Area, Quality and Protection of Special Lakeshore Communities - Alvars

Indicator #8129 (Alvars)

Assessment: Mixed, Trend Not Assessed

Purpose

- To assess the status of Great Lakes alvars (including changes in area and quality), one of the 12 special lakeshore communities identified within the nearshore terrestrial area;
- To infer the success of management activities; and
- To focus future conservation efforts toward the most ecologically significant alvar habitats in the Great Lakes.

Ecosystem Objective

The objective is the preservation of the area and quality of Great Lakes alvars, individually and as an ecologically important system, for the maintenance of biodiversity and the protection of rare species. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Alvar communities are naturally open habitats occurring on flat limestone bedrock. They have a distinctive set of plant species and vegetative associations, and include many species of plants, molluscs, and invertebrates that are rare elsewhere in the basin. All 15 types of alvars and associated habitats are globally imperiled or rare.

A four-year study of Great Lakes alvars completed in 1998 (the International Alvar Conservation Initiative-IACI) evaluated conservation targets for alvar communities, and concluded that essentially all of the existing viable occurrences should be maintained, since all types are below the minimum threshold of 30-60 viable examples. As well as conserving these ecologically distinct communities, this target would protect populations of dozens of globally significant and disjunct species. A few species, such as lakeside daisy (*Hymenoxis herbacea*) and the beetle *Chlaenius p. purpuricollis*, have nearly all of their global occurrences within Great Lakes alvar sites.

Status of Great Lakes Alvars

Alvar habitats have likely always been sparsely distributed, but more than 90% of their original extent has been destroyed or substantially degraded by agriculture and other human uses. Approximately 64% of the remaining alvar area occurs within Ontario, with about 16% in New York State, 15% in Michigan, 4% in Ohio, and smaller areas in Wisconsin and Quebec. Data from the IACI and state/provincial alvar studies were screened and updated to identify viable community occurrences.

Just over two-thirds of known Great Lakes alvars occur close to the shoreline, with all or a substantial portion of their area within one kilometre of the shore.

	Total in Basin	Nearshore
No. of alvar sites	82	52
No. of community occurences	204	138
Alvar area (ha)	11,523	8,097

Table 1. Number of alvar sites/communities found nearshore and total in the basin.
Source: Ron Reid, Bobolink Enterprises

Typically, several different community types occur within each alvar site. Among the 15 community types documented, six types show a strong association (over 80% of their area) with nearshore settings. Four types have less than half of their occurrences in nearshore settings.

The current status of all nearshore alvar communities was evaluated by considering current land ownership and the type and severity of threats to their integrity. As shown in Figure 1, less than one-fifth of the nearshore alvar area is currently fully protected, while over three-fifths is at high risk.

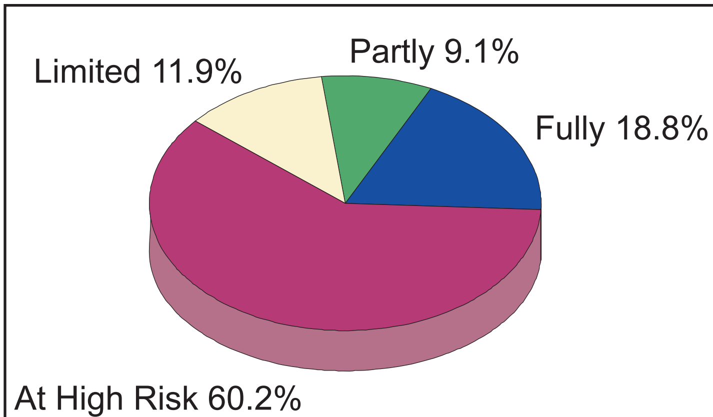

Figure 1. Protection status of nearshore alvar area (2000).
Source: Ron Reid, Bobolink Enterprises

The degree of protection for nearshore alvar communities varies considerably among jurisdictions. For example, Michigan has 66% of its nearshore alvar area in the Fully Protected category, while Ontario has only 7%. In part, this is a reflection of the much larger total shoreline area in Ontario, as shown in Figure 2. (Other states have too few nearshore sites to allow comparison).

Each location of an alvar community or rare species has been documented as an “element occurrence” or EO. Each alvar com-

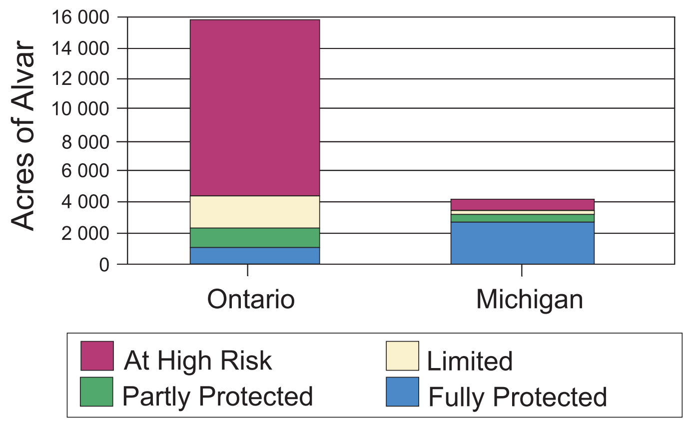

Figure 2. Comparison of the protection status of nearshore alvars (in acres) for Ontario and Michigan.
Source: Ron Reid, Bobolink Enterprises

munity occurrence has been assigned an "EO rank" to reflect its relative quality and condition ("A" for excellent to "D" for poor). A and B-ranks are considered viable, while C-ranks are marginal and a D ranked occurrence is not expected to survive even with appropriate management efforts. As shown in Figure 3, protection efforts to secure alvars have clearly focused on the best quality sites.

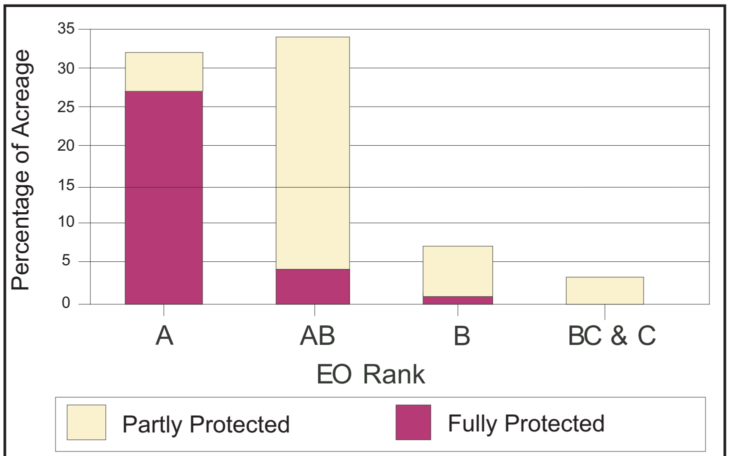

Figure 3. Protection of high quality alvars. EO Rank = Element Occurrence (A is excellent, B is good and C is marginal).
Source: Ron Reid, Bobolink Enterprises

Documentation of the extent and quality of alvars through the IACI has been a major step forward, and has stimulated much greater public awareness and conservation activity for these habitats. Over the past two years, a total of 10 securement projects have resulted in protection of at least 2140.6 ha of alvars across the Great Lakes basin, with 1353.5 ha of that within the nearshore area. Most of the secured nearshore area is through land acquisition, but 22.7 ha on Pelee Island (ON) are through a conservation easement, and 0.6 ha on Kelleys Island (OH) are through state dedication of a nature reserve. These projects have increased the area of protected alvar dramatically in a short time.

Pressures

Nearshore alvar communities are most frequently threatened by habitat fragmentation and loss, trails and off-road vehicles, resource extraction uses such as quarrying or logging, and adjacent land uses such as residential subdivisions. Less frequent threats include grazing or deer browsing, plant collecting for bonsai or other hobbies, and invasion by non-native plants such as European buckthorn and dog-strangling vine.

Acknowledgments

Authors: Ron Reid, Bobolink Enterprises, Washago, ON; and Heather Potter, The Nature Conservancy, Chicago, IL.

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Authors' Commentary

Because of the large number of significant alvar communities at risk, particularly in Ontario, their status should be closely watched to ensure that they are not lost. Major binational projects hold great promise for further progress, since alvars are a Great Lakes resource, but most of the unprotected area is within Ontario. Projects could be usefully modeled after the 1999 Manitoulin Island (ON) acquisition of 6880 ha through a cooperative project of The Nature Conservancy of Canada, The Nature Conservancy, Federation of Ontario Naturalists, and Ontario Ministry of Natural Resources.

Last Updated

State of the Great Lakes 2001

Area, Quality and Protection of Special Lakeshore Communities - Cobble Beaches

Indicator #8129 (Cobble Beaches)

Assessment: Mixed, Deteriorating

Purpose

- To assess the status of cobble beaches, one of the 12 special shoreline communities identified within the nearshore terrestrial area. To assess the changes in area and quality of Great Lakes cobble beaches;
- To infer the success of management activities; and
- To focus future conservation efforts toward the most ecologically significant cobble beach habitats in the Great Lakes.

Ecosystem Objective

The objective is the preservation of the area and quality of Great Lakes cobble beaches, individually and as an ecologically important system, for the maintenance of biodiversity and the protection of rare species. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Background

Cobble beaches are shaped by wave and ice erosion. They are home to a variety of plant species, several of which are threatened or endangered provincially/statewide, globally, or both making them one of the most biodiverse terrestrial communities along the Great Lakes shoreline. Cobble beaches serve as seasonal spawning and migration areas for fish as well as nesting areas for the piping plover, a species listed in the U.S. as endangered.

Status of Cobble Beaches

Cobble beaches have always been a part of the Great Lakes shoreline. The number and area of these beaches, however, is decreasing due to shoreline development. In fact, cobble shorelines are becoming so scarce that they are considered globally rare.

Lake Superior has the most cobble shoreline of all the Great Lakes with 958 km of cobble beaches (Figure 1); 541 km on the Canadian side and 417 km on the U.S. side. This constitutes 20% of the whole Lake Superior shoreline (11.3% on the Canadian side and 8.7% on the U.S. side).

Lake Huron has the 2nd most cobble shoreline with approximately 483 km of cobble shoreline; 330 km on the Canadian side and 153 km on the U.S. side. Most of the cobble beaches are found along the shoreline of the Georgian Bay (Figure 2). This constitutes approximately 9% of the whole Lake Huron shoreline (6.1% on the Canadian side and 2.8% on the U.S. side).

Approximately 164 km of the Lake Michigan shoreline is cobble, representing 6.1% of its shoreline. Most of these beaches are located at the northern end of the lake in the state of Michigan (Figure 3).

Lake Ontario has very little cobble shoreline of about 35 km, representing only 3% of its shoreline (Figure 4).

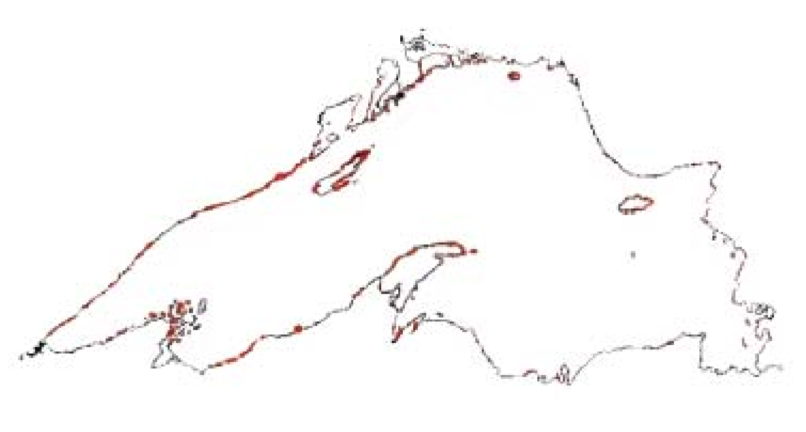

Figure 1. Cobble beaches along Lake Superior's shoreline (red = cobble beach locations).
Source: Lake Superior Binational Program, Lake Superior LaMP 2000, Environment Canada, and Dennis Albert

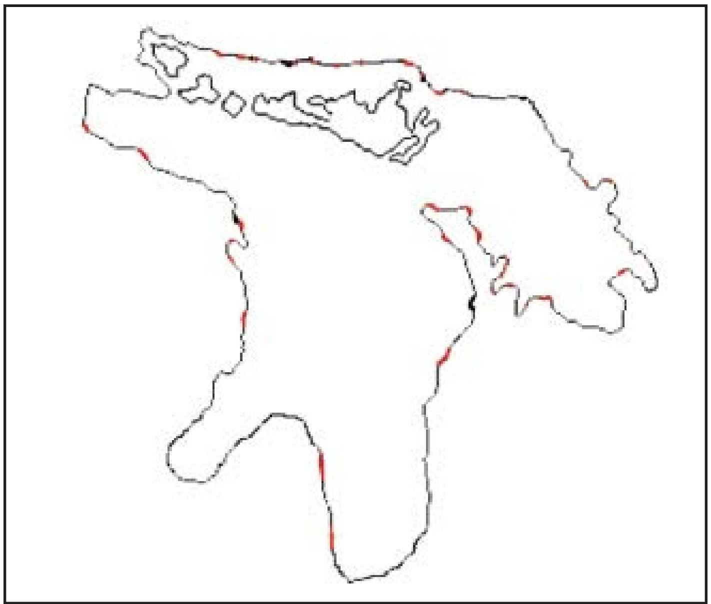

Figure 2. Cobble beaches along Lake Huron's shoreline (red = cobble beach locations).
Source: Environment Canada

Figure 3. Cobble beaches along Lake Michigan's shoreline (red = cobble beach locations).
Source: Albert 1994a, Humphrys *et al.* 1958

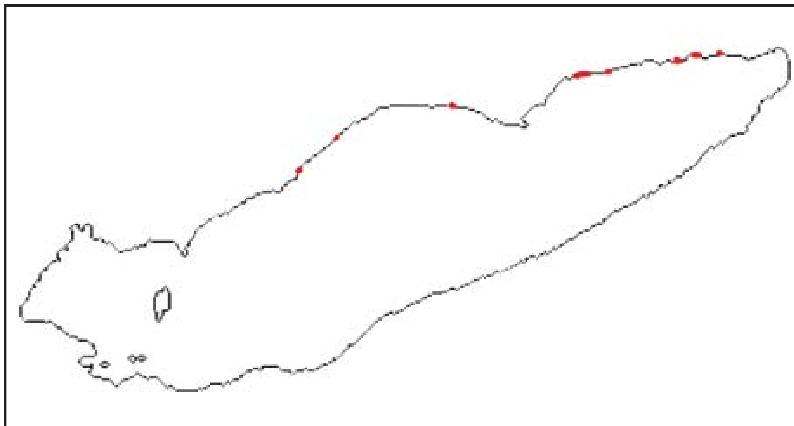

Figure 5. Cobble beaches along Lake Erie's shoreline (red = cobble beach locations).
Source: Environment Canada

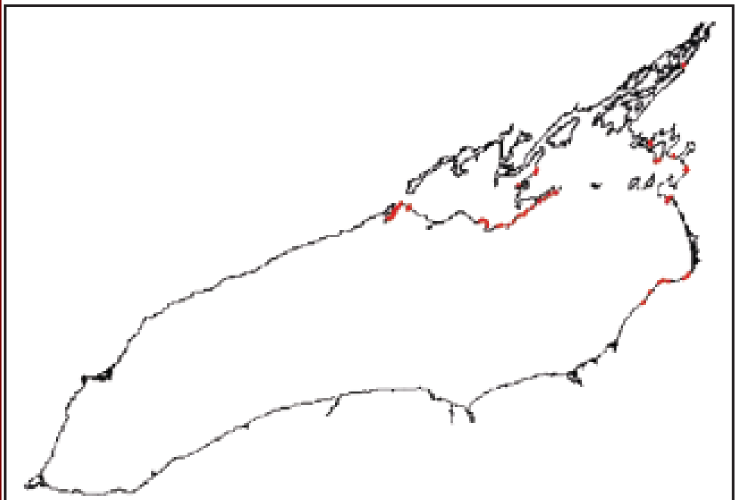

Figure 4. Cobble beaches along Lake Ontario's shoreline (red = cobble beach locations).
Source: International Joint Commission (IJC) and Christian J. Stewart

Lake Erie has the smallest amount of cobble shoreline of all the Great Lakes with only 26 km of cobble shore. This small area represents approximately 1.9% of the lake's shoreline (Figure 5).

While the cobble beaches themselves are scarce, they do have a wide variety of vegetation associated with them, and they serve as home to plants that are endemic to the Great Lakes shoreline.

Lake Superior's large cobble shoreline provides for several rare plant species (Table 1) some of which include the Lake Huron tansy and redroot. It is also home to the endangered heart-leaved plantain, which is protected under the Ontario Endangered Species Act.

Lake Superior	
Common Name	**Scientific Name**
Bulrush sedge	*Carex scirpoidea*
Great northern aster	*Aster modestus*
Northern reedgrass	*Calamagrostis lacustris*
Purple clematis	*Clematis occidentalis*
Northern grass of Parnassus	*Parnassia palustris*
Mountain goldenrod	*Solidago decumbens*
Narrow-leafed reedgrass	*Calamagrostis stricta*
Downy oat-grass	*Trisetum spicatum*
Pale Indian paintbrush	*Castilleja septentrionalis*
Butterwort	*Pinguicula vulgaris*
Pearlwort	*Sagina nodosa*
Calypso orchid	*Calypsa bulbosa*
Lake Huron tansy	*Tanacetum huronense*
Redroot	*Lachnanthes caroliana*
Heart-leaved plantain	*Plantago cordata*

Table 1. Rare plant species on Lake Superior's cobble shoreline.
Source: Lake Superior LaMP, 2000

Lake Michigan and Lake Huron's cobble shorelines are home to Houghton's goldenrod and the dwarf lake iris, both of which are endemic to the Great Lakes shoreline (Table 2, Table 3). Some other rare species on the Lake Michigan shoreline include the Lake Huron tansy and beauty sedge (Table 2).

Not many studies have been conducted on the cobble shorelines of Lake Ontario and Lake Erie because these areas are so small. The report author was unable to find any information about the vegetation that grows there.

Lake Michigan	
Common Name	**Scientific Name**
Dwarf lake iris	*Iris lacustris*
Houghton's goldenrod	*Solidago houghtonii*
Slender cliff-brake	*Cryptogramma stelleri*
Lake Huron tansy	*Tanacetum huronense*
Beauty sedge	*Carex concinna*
Richardson's sedge	*Carex richardsonii*

Table 2. Rare plant species along Lake Michigan's cobble shoreline.
Source: Dennis Albert

Lake Huron	
Common Name	**Scientific Name**
Dwarf lake iris	*Iris lacustris*
Houghton's goldenrod	*Solidago houghtonii*

Table 3. Rare plant species along Lake Huron's cobble shoreline.
Source: Environment Canada

Pressures

Cobble beaches are most frequently threatened and lost by shoreline development. Homes built along the shorelines of the Great Lakes cause the number of cobble beaches to become limited. Along with the development of homes also comes increased human activity along the shoreline resulting in damage to rare plants in the surrounding area and ultimately a loss of terrestrial biodiversity on the cobble beaches.

Acknowledgments

Author: Jacqueline Adams, Environmental Careers Organization, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office.

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Authors' Commentary

Not much research has been conducted on cobble beach communities; therefore, no baseline data have been set. A closer look into the percentage of cobble beaches that already have homes on them or are slated for development would yield a more accurate direction in which the beaches are headed. Also, a look at the percentage of these beaches that are in protected areas would provide valuable information. Projects similar to Dennis Albert's *Bedrock Shoreline Surveys of the Keweenaw Peninsula and Drummond Island in Michigan's Upper Peninsula* (1994) for the Michigan Natural Features Inventory, as well as the International Joint Commission's *Classification of Shore Units Coastal Working Group*: *Lake Ontario and Upper St. Lawrence River* (2002), would be very useful in determining exactly where the remaining cobble beaches are located and what is growing and living within them.

Last Updated

State of the Great Lakes 2005