Toward a Water Resources Management Decision Support System for the Great Lakes-St. Lawrence River Basin

The Great Lakes and Resource Demands

The Great Lakes, their connecting channels and the St. Lawrence River collectively comprise the world's largest body of fresh surface water, which provides the region's eight states and two provinces with an abundance of high quality fresh surface water. The Great Lakes system contains 6.5 quadrillion gallons (24.6 quadrillion litres) of fresh surface water, 20 percent of the world's supply. The Great Lakes influence and are inseparably linked to the region's environmental health, economic well being and quality of life, and play an important role in advancing and sustaining regional and national economies. The Great Lakes ecosystem is fragile, and even minor physical, chemical or biological changes can have individual and cumulative effects with lasting implications for the conservation, protection and use of the resource.


Satellite image, Great Lakes-St. Lawrence River basin

In many areas of North America (and beyond), water sources and associated ecosystems are being stressed by withdrawals and diversions from aquifers, lakes, rivers and reservoirs to meet the needs of cities, farms, homes and industries. The water rich Great Lakes-St. Lawrence River region has been relatively immune from serious water shortages and other water supply problems. However, as population and economic growth in the region has occurred, in-basin water uses have increased and are projected to continue (Tate and Harris, 1999). Communities situated just outside Great Lakes basin surface water boundaries also have looked to basin water sources for their supply, as have communities far removed from the Great Lakes-St. Lawrence River region. Implications of this increased interest present a significant challenge for Great Lakes policymakers and resource managers at the federal, state, provincial and municipal levels.

Water Resources Management Decisionmaking

As scientists, managers and policymakers gain an increased understanding of the range and complexity of issues surrounding the region's needs and demands for high quality fresh water, they increasingly rely upon data, information and technology to inform their research and answer difficult questions. Decision support systems are becoming an important tool in the fields of water resources science, planning and management. A decision support system is a broad concept that typically involves both descriptive information systems as well as standard, prescriptive optimization approaches. It may be defined as "any and all data, information, expertise and activities that contribute to option selection" (Andriole, 1989).

The Great Lakes Commission and its project collaborators initiated a project, titled *A Water Resources Management Decision Support System for the Great Lakes,* in August 2000 in response to the increasing need for data and information to inform state and provincial decisionmaking on issues involving the withdrawal, use and consumption of Great Lakes-St. Lawrence River water resources. (This title was changed during the project to *Toward a Water Resources Management Decision Support System for the Great Lakes-St. Lawrence River Basin.)* This multi-year initiative has involved the compilation and synthesis of information on the status of Great Lakes water resources, current water withdrawals and uses, and the ecological impacts of individual and cumulative water withdrawals.

The impetus for this project can be traced to a statement issued by the Council of Great Lakes Governors in late 1999 providing a set of principles for a stronger water resources management framework for the region. Through this statement, which built upon the Great Lakes Charter of 1985 and led to the development of the Great Lakes Charter Annex in 2001, the governors and premiers agreed that a durable, simple, and efficient water management regime is needed to protect the resource and retain decisionmaking authority within the basin. The project was initiated prior to the signing of the Annex, and subsequently modified to maximize its relevance to the activities of a Working Group charged with Annex implementation.

Project Outcomes

This project has produced several major products which, singly and collectively, will strengthen water quantity decisionmaking processes at the federal, state, provincial and municipal levels. Chapter one provides a report overview. Chapters two through six describe specific project activities and outcomes, Chapter seven examines information and communications needs, and Chapter eight synthesizes project work. Report findings and recommendations provide valuable information for guiding the next steps in decision support system development. Appendices, which include the full text of reports summarized in this document, are attached in CD-ROM form and are available at www.glc.org/wateruse/wrmdss.html.

Presented below is a chapter-by-chapter summary of the key project findings and recommendations for consideration by the region's policymakers, resource managers and scientists. Once implemented, these recommendations can provide the basis for a Water Resources Management Decision Support System (WRMDSS), and for accessing the data and information needed to maximize its value in promoting the informed use, management and protection of the region's valuable water resources.

Status Assessment of Great Lakes-St. Lawrence River Water Resources (Chapter Two):

Chapter two summarizes the work of the Status Assessment of Water Resources Technical Subcommittee. It describes the hydrology of the Great Lakes system, the process for measuring levels and flows, and the uncertainty associated with such measurements. The chapter also recommends improvements to current monitoring activities that will enhance decisionmaking processes. In so doing, it helps lay the groundwork for a decision support system that is applicable to a broad range of variables and geographic areas ranging from small sub-basins (e.g., a single tributary) to the entire Great Lakes-St. Lawrence River system.

Although a significant amount of hydrologic monitoring occurs in the Great Lakes basin, current efforts target specific needs that may not fully address the decisionmaking standard embodied in the Great Lakes Charter Annex. Several agencies collect Great Lakes hydrologic data and calculate levels and flows, typically using different methods. Further, complete flow data are not available on a binational basis; coordination between U.S. and Canadian jurisdictions on its collection and analysis is inadequate. Problems include the diversity of hydrologic data and information sources, inconsistencies in metadata, lack of compatibility with geographic information systems for some data, and limited accessibility to data on the Internet.

It is important to understand and consider the variability of the hydrologic system and the limitations of hydrologic measurement. All levels and flows are variable in the short and long-term and at many spatial scales. Also, all measurements and calculations are inherently uncertain. However, most reported flows are long-term averages at large spatial scales, and associated data uncertainties are not reported and often not calculated.

Uncertainties associated with measurements of levels and flows hinder the ability to assess ecological effects from withdrawals on a system-wide level. Even though the effects of a withdrawal on levels and flows cannot currently be detected by measurements, existing models can accurately predict the effects of withdrawals on connecting channel flows, lake levels, or hydroelectric production.

On a sub-watershed scale, streamflow and groundwater data are insufficient in many areas of the basin to predict ecological effects of instream and groundwater withdrawals. Only large-scale groundwater or cumulative withdrawals are likely to be detected in streamflow, but this ability depends on the scale of withdrawal relative to the scale of baseflow. Standard approaches are, for the most part, available to collect the hydrologic information needed to make decisions on instream and groundwater withdrawals, but they have not yet been applied to all areas of the basin.

The contribution of groundwater to the hydrology of the Great Lakes has only recently been more fully recognized. As a result, the complex dynamics of groundwater recharge, flow, and discharge and the implications of these factors relative to both water quantity and quality require special attention.

Chapter Two Recommendations

Monitoring/Modeling

1) Evaluate the adequacy of hydrologic/hydraulic monitoring systems, within the context of the Annex, after a decisionmaking standard is agreed upon.
2) Secure agency commitments to core, long-term, geographically distributed hydrologic/hydraulic monitoring that will be needed to implement the decisionmaking standard.
3) Support the continued maintenance and enhancement of the Great Lakes water level gauging network, and quantify and report uncertainties.
4) Develop coordinated binational methods for evaluating groundwater flow directly and indirectly to the Great Lakes and their tributary watersheds, using common data standards and models.
5) Systematically evaluate the adequacy of existing tributary stream gauging to meet Annex implementation needs and develop coordinated binational methods for calculating streamflow for all ungauged areas.
6) Develop coordinated binational methods, with measures of uncertainty, for calculating over-lake precipitation and evaporation processes using existing remote sensing techniques.
7) Develop coordinated binational methods, with measures of uncertainty, for calculating and/or measuring flows, customized for each connecting channel, St. Lawrence River and diversion into/out of the Great Lakes.
8) Continue development and refinement of systemwide hydraulic routing models so that effects of proposed withdrawals and the uncertainty of the effects can be predicted.

Information Availability

9) Develop common data standards and reporting practices for hydraulic/hydrologic data and other information relevant to the Annex, with emphasis on determining watershed impacts.
10) Ensure easy access to hydraulic/hydrologic data for decisionmakers and other interested parties via clearinghouse services, and conventional and electronic communications technology.

Information Use

11) Incorporate an understanding of hydrologic variability and uncertainty at the appropriate temporal and spatial scales in the decisionmaking process.

Inventory of Water Withdrawal and Use Data and Information (Chapter Three):

Chapter three describes the outcomes of the work of the Water Withdrawal and Use Technical Subcommittee, including an assessment of state and provincial water use data collection programs, the functionality of the Great Lakes Regional Water Use Database, and consumptive use accounting. The role of demand forecasting in regional water resources management is also examined. Commitments under the Great Lakes Charter are used as a yardstick to measure the progress made in water use data collection and the contribution of that data to water resources management activities.

A number of findings can be derived from the assessment of state and provincial water use data collection programs. Many aspects of current state/provincial programs, for example, must be further developed and coordinated if regional water management efforts are to be strengthened and the full potential of the Great Lakes Charter and Annex are to be realized. Most jurisdictions collect some data at or below the Great Lakes Charter established 100,000 gallon (380,000 litre) per day threshold, but the ability of several jurisdictions to collect and report water use data for all water use categories is lacking. About half of the members of the Water Withdrawal and Use Technical Subcommittee state that their jurisdiction is presently able to fulfill the Charter data collection and reporting requirements in terms of both legislative/regulatory authority and implementation effort for most water use categories. The balance indicate that their jurisdiction has relatively strong legislative/regulatory authority but weak implementation provisions. Jurisdictions that have mandatory reporting requirements built into their programs appear to be more effective than those that do not, due to the more stringent requirements and the availability of enforcement mechanisms.

Progress has been made in the area of water withdrawal and use data collection and reporting since the Great Lakes Regional Water Use Database became operational in 1988. The database, however, has limited utility as a management tool because it does not include site-specific data and constraints exist in the state/provincial data collection and reporting programs. Data is aggregated for multiple facilities, estimated in many cases, reported at an annual interval and, in some jurisdictions, focuses solely on surface water. This level of data quality is inadequate for identifying hydrological impacts and associated ecological effects with the confidence needed for demand forecasts and other planning activities.

The current status of consumptive use accounting is similar to that of water use data collection. However, the level of confidence is much lower because the amount of water lost to the system is difficult to determine. Consumptive use calculations are inadequate for providing meaningful and defensible consumptive use information because they are based on partially estimated water withdrawal and use data. Current evidence does not validate consumptive use coefficients, and jurisdictions do not generate comparable data with the current variety of coefficients.

Demand forecasting is an essential water resources management tool for informing water resources planning activities at the regional, jurisdictional and local levels. Forecasts generate crucial information on where water demand is likely to increase and where financial and other resources may need to be applied to help address priority areas. Although demand forecasts are important, they often lack financial and programmatic support at the jurisdictional level. Without knowing what and where future demand is likely to be, planners and policymakers have difficulty developing and implementing effective and comprehensive water management programs that include elements such as water conservation and drought contingency planning.

Chapter Three Recommendations

1) Develop state/provincial legislative and programmatic authority with adequate funding and technical support to carry out the water withdrawal and use data collection and reporting commitments in the Great Lakes Charter and Charter Annex.
2) Evaluate the effectiveness of the Great Lakes Regional Water Use Database in supporting the decisionmaking process and revise and upgrade as needed to make it a more useful planning tool.
3) Provide a more uniform and consistent base of data and information through the state/provincial water use data collection and reporting programs to facilitate comparison and evaluation.
4) Develop reporting requirements for incorporation into state/provincial water use data collection and reporting programs.
5) Improve state/provincial consumptive use reporting processes to ensure reliable and accurate data.
6) Develop and apply uniform consumptive use coefficients for each water use category until such time that a better method of measuring consumptive water use is available.
7) Develop and regularly pursue a uniform regional approach to demand forecasting in the interest of strengthening jurisdictional and regional planning processes.

Water Conservation in the Great Lakes-St. Lawrence River Region (Chapter Four):

Under the direction of the Water Withdrawal and Use Technical Subcommittee, water conservation information presented in Chapter four was gathered through a survey of state and provincial programs and associated information on best management practices.

A commitment to "environmentally sound and economically feasible water conservation measures," as stated in the Great Lakes Charter Annex, is critically important if the region is to demonstrate a capability to responsibly manage its own resources.

This growing emphasis on water conservation signals a significant shift from past water management practices that viewed Great Lakes water as a virtually limitless resource that could accommodate all current and anticipated in-basin demands. Water conservation is now considered a viable solution to current shortages in some communities experiencing water supply problems, and as a means to lower costs and provide ecological benefits in areas with abundant water. In particular, areas of unique ecological and hydrological characteristics – and associated sensitivities – will benefit from targeted water conservation efforts.

Several Great Lakes states and provinces have the authority to implement basic water conservation programs, but these programs vary widely in scope and content, and are usually part of a drought contingency plan. Many conservation programs are in place at the local level but programs and models to promote region-wide coordination are lacking.

Chapter four details 15 types of water conservation practices ranging from financial incentives to technological improvements, singly and in combination.

Chapter Four Recommendations

1) Develop and apply water conservation models that foster a coordinated regional approach and address the Charter Annex standard of "environmentally sound and economically feasible."
2) Establish an information clearinghouse to publicize best management practices pertaining to individual sectors of water use.
3) Develop and update state/provincial drought contingency plans to ensure adequate attention to water conservation.
4) Develop specific water conservation provisions as part of state/provincial water management programs.
5) Undertake an economic analysis to identify the financial benefits of water conservation, and use results to promote adoption of such practices at the local level.
6) Develop a regional information/education program to promote the adoption of water conservation practices.

Ecological Impacts Associated with Great Lakes Water Withdrawals (Chapter Five)

Chapter five examines the prospective individual and cumulative ecological impacts of water withdrawals based on the work of the Inventory of Information on Ecological Impacts Technical Subcommittee. This chapter presents a list of "essential questions" (aided by an Experts Workshop) regarding potential ecological impacts that should be addressed in reviewing water withdrawal proposals, a literature search and analysis, and an inventory and assessment of existing computer models with some relevance to assessing ecological impacts from water withdrawals. The subcommittee also examined, through a case study approach, various prospective definitions and applications of the resource-based decisionmaking standard as presented in the Great Lakes Charter Annex. Research and data collection priorities to help inform the decisionmaking process associated with new or increased Great Lakes basin water withdrawals were then developed.

The Experts Workshop, drawing leading researchers from more than a dozen relevant disciplines, yielded an excellent starting point for assessing potential ecological impacts of water withdrawals. Many essential questions were identified that must be considered to fully assess these impacts. The questions vary in complexity, ranging from basic questions about the location of the withdrawal to questions related to potential cumulative impacts of multiple water withdrawals and other stressors. The literature review and model inventory "mined" a large knowledge base to support this assessment. Selected past and ongoing research studies and existing modeling tools provide useful resources to answer some of the essential questions.

These project activities also highlighted gaps in our knowledge and understanding of ecological impacts. The literature offers few practical approaches for addressing questions related to cause-effect relationships and cumulative impacts of changes in levels and flows, but some studies may help guide establishment of monitoring protocols and agendas for scientific research. A key observation is that the lack of integrative modeling tools currently confounds the assessment of cumulative ecological impacts from multiple stressors. This is supported by a primary outcome of the model review: no single model can, in and of itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario.

The importance of assessing *cumulative* impacts was highlighted during the Experts Workshop given the spatial (i.e., watershed, lake, river, or whole basin) and temporal (e.g., immediate, multi-year) dimensions of any prospective water withdrawal and associated ecological impact. Based on the research of the subcommittee, the ecological impacts of a water withdrawal will be most clearly discernible at the nearshore and sub-watershed levels, where relatively small changes in water levels and flows could affect the supported ecosystems.

Chapter Five Recommendations

1) Review and refine the list of "essential questions" to ensure comprehensiveness and feasibility in a decision support framework.
2) Funding for research and development should be directed at a) mining data from existing sources, and b) studies of both qualitative and quantitative stress-response relationships. Data and information gaps should be identified and studies conducted to fill those gaps, with a particular focus on sub-watersheds.
3) Developing indicators and thresholds to inform the discussion of "no significant adverse individual or cumulative impacts" relating to ecological impacts from water withdrawals.
4) Synthesize and model the quantitative relationships between water withdrawals/diversions in various types of Great Lakes-St. Lawrence River ecosystems (large lakes, inland lakes, streams and rivers, groundwater) and potential ecological impacts of those water withdrawals.
5) Develop linked model frameworks for selected water withdrawal scenarios by building on the existing model inventory.
6) Intensify and enhance research that supports more accurate predictions of regional climate change, population growth, demand forecasting and land use changes, and use this information to help evaluate ecological sensitivities.
7) Improve data to assess and model ecological impacts of water withdrawals at different temporal and spatial scales, particularly on a nearshore and sub-watershed basis, where impacts are most discernible.
8) Improve understanding of variability and uncertainty in levels and flows to strengthen the decision support system.
9) Monitor ecological and hydrological responses to water withdrawal activities, with

Resource Improvement Standard for Water Resources Projects (Chapter Six):

Chapter six presents an analysis of the issues and potential application associated with the "resource improvement" concept embodied in the Great Lakes Charter Annex. This work, accomplished under the direction of the Inventory of Information on Ecological Impacts Technical Subcommittee, supports development of a new regional water resources management decisionmaking standard, as outlined in Directive #3. Elements of the "resource improvement" concept have been interpreted and applied in many settings throughout North America and, while these approaches inform the Annex process, none fully meet the needs of the Annex. Project research did point out that the Annex decisionmaking standard requires "no significant adverse individual or cumulative impacts." Hence, the term "mitigation," as used in the Annex's "definition" section, pertains only to resource improvement measures that mitigate impacts of existing withdrawals, not the prospective impacts of the proposed withdrawal.

Development and application of the resource improvement standard will require further definition and interpretation of Directive #3 terminology; transformation of the four associated principles into policy measures; and additional attention to application issues, including assignment of spatial/temporal scales and accommodation of prospective cumulative impacts. Resource improvement measures should be directed toward a baseline and baseline conditions should be specified. Consideration must also be given to both the design of an appropriate methodology, and the data, information and resource requirements to support the standard and its measurement. The resource improvement standard should be specific enough to provide scientifically sound guidance, yet flexible enough to accommodate the inherent uniqueness of individual proposals.

Chapter Six Recommendations

1) Develop precise definitions for terms in Directive #3 of the Annex; guidance on the application of spatial and temporal dimensions of "resource improvement"; and a science-based evaluation methodology that presents acceptable procedures for assessing withdrawal proposals.

2) Continue and improve case study analysis and "scenario testing" to explore applications of a resource improvement standard.
3) Conduct a more thorough study of the resource improvement concept.

Information and Communications (Chapter Seven):

Chapter seven presents examples of a decision support system (DSS) and communication tools that can assist in the decisionmaking process. Key points to consider when integrating data and information into a DSS are presented, and include the promotion, development and implementation of data and information standards; the variability of hydrologic and hydraulic data in density, resolution, scale and temporal characteristics; and improvements in computer modeling and associated visualization tools. The chapter also offers an overview of evolving technologies, such as Internet, real time data, metadata and GIS that may contribute significantly to water resources management decisionmaking.

The chapter describes the primary function of a DSS: to support and promote decisions through informed discussion and debate where multiple and sometimes conflicting goals and interests are involved. Various information dissemination and communication tools that can be applied to a WRMDSS are presented, and include the Internet, intranet portals, online GIS, and conventional communications (e.g., print, meetings and conferences).

Chapter Seven Recommendations

1) Develop integrated Internet web pages to facilitate data and information exchange, distribution and access.
2) Develop metadata to accompany all geospatial and temporal data used in a Water Resources Management Decision Support System.
3) Incorporate a robust communications strategy into the Water Resources Management Decision Support System, involving a range of interrelated tools such as Internet technologies; email and online discussion groups; and conventional communications including printed materials, meetings, conferences and symposia.

Pulling it All Together: Project Synthesis (Chapter Eight):

The conclusion of this project activity signals the beginning of the next critical step: implementing recommendations in the interest of designing and operating a decision support system for addressing water resources data and information needs. Principal among these needs are: 1) the challenges of meeting present and future data and information needs; 2) issues of scale in assessing ecosystem impacts of water withdrawals; 3) cumulative impacts occurring over space and time; 4) groundwater hydrology in the basin; and 5) the full range of ecological impacts associated with water withdrawal. Each is summarized below followed by a series of concluding observations.

Meeting Present and Future Data and Information Needs

A wealth of water use data and information on the Great Lakes-St. Lawrence River system has been gathered over time, but its utility has been compromised because it lacks the breadth, focus and accuracy needed to address current and future management challenges. A decision support system for water resources management needs to withstand the "test of time"; it needs to be dynamic and flexible to adapt to ever-evolving demands placed upon it. Unanticipated stresses on the ecosystem are certain to arise, whether they be of a local (e.g., coastal development, water use demand) or global (e.g., climate change) nature. Thus, a decision support system "designed to learn," coupled with a recognition that data and information needs will continually evolve, are prerequisites to better informed management efforts. Concluding observations in this chapter reinforce these considerations, which were also affirmed at a project workshop exploring the range of data and information needs relating to system hydrology/hydraulics, water withdrawal, ecological impacts and cumulative effects.

Appropriate Scales for Water Resources Assessment

The issue of scale is a critical consideration in the design of a decision support system for water resources management. Decisionmakers, for example, are confronted with a fundamental question: "How sensitive is the Great Lakes-St. Lawrence River system to the ecological impacts of water withdrawal, and at what level can these impacts be assessed?"

This question was addressed in detail over the course of the project, with the finding that any such impacts will be most discernable at the sub-watershed level. This suggests the need for reevaluation of current data gathering and analysis practices, which have historically focused on a macro-scale (i.e., lake basin and systemwide) and emphasized physical (i.e., levels and flows) impacts as opposed to broader ecosystem impacts (i.e., habitat, biological resources).

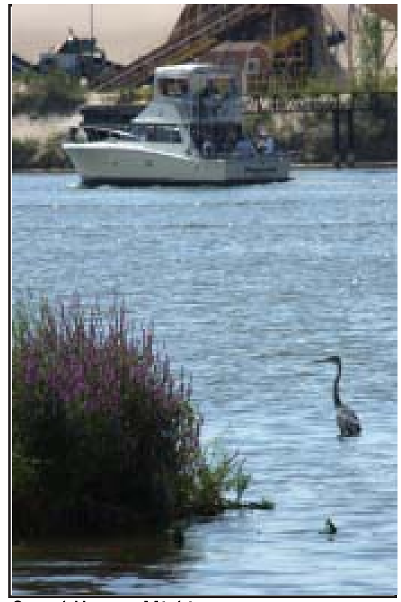
Using hierarchical, or nested, watershed designs to support water management decisionmaking is one approach that provides opportunities to analyze conditions at multiple scales of resolution. Each scale is important in understanding the system and the relationship between water supply, withdrawal and ecological impacts.

Understanding the sensitivities tied to the varying characteristics of watersheds will be important in developing informed water resource management decisions. Size, shape, slope, elevation, density of channels, channel characteristics (depth/width), vegetation, land use, soil type, hydrogeology, lakes, wetlands, artificial drainage, water use and ecology represent some of the important characteristics of a drainage basin. Additionally, at the global scale, climate change may cause alterations to the levels and flows of the Great Lakes-St. Lawrence River system. These natural and anthropogenic factors will influence the ecologic and hydrologic sensitivities of watersheds. A categorization of watersheds in terms of their sensitivities may be a first step toward providing the context within which water management decisions are made.

Groundwater Data and Information

Groundwater discharges directly into the Great Lakes and connecting channels, and also contributes to tributary stream flow in many portions of the Great Lakes-St. Lawrence River system. Such discharges are critical ecosystem elements in that they provide base flows, moderate water temperature and help maintain water quality during periods of low flows.

Aside from a growing recognition of its importance in the hydrologic cycle and contribution to ecosystem health, much is unknown about the region's groundwater resources. Historically, the role of groundwater in the Great Lakes-St. Lawrence River system, particularly its relationship to surface water, has been poorly understood and inadequately studied. On a sub-watershed scale, groundwater data to assess the likely effects of in-stream and groundwater withdrawals are available in only selected areas. Expansion of tributary stream gauging and networks for groundwater and climate monitoring, as well as water withdrawal data on a sub-watershed scale, will be critical if a Water Resources Management Decision Support System is to support investigations in areas which have been heretofore "data poor." Also, a need exists for a basin-wide groundwater flow model.



Grand Haven, Michigan

Ecological impacts

The need to consider ecological impacts associated with water withdrawals has placed new demands on scientists and resource managers who have traditionally approached water resources projects primarily from a hydrologic/hydraulic standpoint. As our understanding of the complexities of the Great Lakes-St. Lawrence River system have improved, concerns have been expressed with regard to the ecological effects of water withdrawals, particularly in the nearshore zone and at the sub-watershed level, where biota appears more likely to be impacted by water withdrawals. Also, the cumulative ecological effect of a withdrawal (or series of withdrawals) incrementally over time and space offers an added challenge.

Another consideration is that water withdrawals may be only one of many factors, or stressors, present in a given watershed. The impact of a single withdrawal (or even a series of withdrawals) may not be readily measurable in many cases but, combined with other stressors, (i.e., land-use changes, pollutant loads) the total impact may be both measurable and significant.

Cumulative effects

Any water withdrawal will have an incremental cumulative effect on the Great Lakes-St. Lawrence River ecosystem over space and time. An individual withdrawal will have a greater ecological and hydrological impact locally than further downstream. An individual withdrawal, given persistence over time, will impact conditions first within its own watershed and then further downstream. Multiple water withdrawals from any given Great Lakes may not have measurable ecological impacts on that particular lake, but their cumulative ecological effects may be magnified on the lower St. Lawrence River. The cumulative ecological effects will also be a function of multiple other factors, or stressors, that can range from local modifications (e.g., source water changes, channelization, sediment loading) to large-scale changes (e.g., global climate information).

Assessing the cumulative ecological impacts from water withdrawals is a complex, challenging undertaking. It is clear from project outcomes (and from an Annex 2001 implementation standpoint) that a decision support system for water resources management must have a cumulative dimension for ecological and hydrological impacts and provide for the necessary data and information to inform the decisionmaking process accordingly. Mechanisms for assessing these impacts with any degree of precision have yet to be developed.

Concluding Observations

Project research has identified a significant amount of relevant water resources data and information pertaining to water withdrawal and use proposals and their impacts. However, there are equally significant inadequacies in data and information that until addressed, will compromise the region's ability to make scientifically sound water resources management decisions. The numerous recommendations of this report address the need to improve the quality and quantity of this data and information.

This being said, some concluding points need to be made regarding the importance of data and information to guide water resources management decisionmaking:

- Existing laws, policies, programs and agreements at the state, provincial, federal and binational levels provide the context within which a WRMDSS must be developed and associated data and information needs determined;
- Understanding the uncertainties associated with available data and information can, in many cases, be as critical as the information itself;
- Data needed for decisionmaking on hydrologic and hydraulic processes throughout the system have varied characteristics. For instance, sub-watershed level analyses will likely require denser spatial and temporal detail than assessments conducted on the open lakes or for the interconnecting waterways;
- A pressing need exists to improve the collection and reporting of accurate, consistent and uniform water withdrawal and use data;
- Much is still unknown about the region's groundwater resources. Expansion of tributary stream gauging and groundwater monitoring networks will be critical in accessing the data and information needed to support a WRMDSS;
- Using hierarchical, or nested, watershed designs to support water withdrawal decisionmaking is one approach that provides opportunities to analyze conditions at multiple scales of resolution. Categorization of watersheds in terms of their sensitivities is an important first step;
- Climate change effects could become the primary stressor to levels and flows and would influence demand forecasts, cumulative impacts assessments, and even future individual water withdrawal decisions. As such, understanding the magnitude and nature of potential climate change effects should be a research priority;
- Scientifically sound data and information are being collected under highly compatible programs and should be exploited to the fullest extent to reduce costs. The best examples are the binational monitoring programs evolving to implement the State of the Lakes Ecosystem Conference (SOLEC) indicator suite;
- Improving the base of data related to water withdrawal and use, surface water and groundwater resources, and ecological/biological effects will require substantial commitment on the part of all units of government;
- To be useful, the commitment to improve this base of data must be long-term, requiring dedicated support for programs over time;
- While data and information shortfalls are being resolved, regional water resources management decisions will still need to be made. Decisionmakers should evaluate projects using the best available information, tools and decision support options, while recognizing their uncertainties. If there is reason to believe that a technology or activity may result in harm and there is scientific

uncertainty regarding the nature and extent of that harm, then measures to anticipate and prevent harm may be necessary and justifiable; and

- An implementation plan for this report's recommendations needs to be developed and implemented in consultation with relevant state and provincial officials. This should include prioritization and costing-out of recommendations and a strategy to conduct needed research and policy analysis to address and apply them as a WRMDSS is developed.

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