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

Status of Data and Information on Water Resources, Water Use, and Related Ecological Impacts

Prepared by the
Great Lakes Commission for the Great Lakes States and Provinces

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Preface

This report presents the research, findings and recommendations resulting from the project, *Toward a Water Resources Management Decision Support System for the Great Lakes* (WRMDSS), supported by the Great Lakes Protection Fund and authored by the Great Lakes Commission and its collaborators. The objective was to compile and synthesize information on the status of Great Lakes water resources, current uses, and ecological impacts of water withdrawals. In so doing, it lays the foundation for the development of a regional water resources management decision support system that will facilitate scientifically sound decisionmaking.

The Commission's involvement in this project reflects its long-term interest in Great Lakes water resources management activities consistent with its mandate to "promote the orderly, integrated and comprehensive development, use and conservation of the water resources of the Great Lakes basin" (Article I, Great Lakes Basin Compact).

This report has benefitted from the significant input and collaboration of numerous partners that comprised a Project Management Team (PMT), three technical subcommittees (TSCs) and a Stakeholders Advisory Committee (SAC). The findings and recommendations of this report address data and information gaps and needs, and provide valuable information for guiding the next steps in the process of developing a decision support system. The recommendations presented in the report were developed by the TSCs and the Great Lakes Commission staff, and received the general concurrence of the PMT and SAC members.

The Commission's work, which began in August 2000, has supported the ongoing efforts of the Great Lakes governors and premiers who, in 1999, established principles to guide development of a water resources management framework for the region. These principles were further developed in 2001, after the commencement of the WRMDSS project, through the June 2001 signing of the Great Lakes Charter Annex. This report provides regional leaders with much of the needed information for Charter Annex implementation.

This report, and the project's many associated components, provide a wealth of information about the water resources and associated policies related to the Great Lakes-St. Lawrence system. Report appendices, which include technical reports generated by the project, are attached in CD-ROM form and are available at www.glc.org/wateruse/wrmdss.html.

Acknowledgments

The Great Lakes Commission gratefully acknowledges the Great Lakes Protection Fund for its support of the Water Resources Management Decision Support System project. The Commission extends its deep appreciation to the individuals serving on the Project Management Team (PMT), its three Technical Subcommittees (TSCs) and the Stakeholders Advisory Committee (SAC) for their significant contributions of time, talent and ideas in the conduct and successful completion of the project. Membership lists of these five groups are included in the Appendix.

The Commission further acknowledges the work of the following individuals for their leadership and contributions to the final report and other project products: Richard S. Bartz, Ohio Department of Natural Resources, who served as Project Management Team Chair; Wendy Leger, Environment Canada, who co-chaired the Ecological Impacts Technical Subcommittee with me; Thomas Crane, Great Lakes Commission, who served as chair of the Water Withdrawal and Use Technical Subcommittee; and James Nicholas, U.S. Geological Survey, who served as chair of the Status Assessment of Water Resources Technical Subcommittee.

The Commission also extends its appreciation to the Council of Great Lakes Governors and its Annex 2001 Working Group, for guidance, input and support.

Gratitude and appreciation are also extended to the principal staff members serving the project. Daniel Blake, Thomas Crane, Roger Gauthier and Rebecca Lameka, led and coordinated project activities, authored various chapters and oversaw project management. Rita Straith managed report production, and Jon Colman, Stuart Eddy, Laura Kaminski, Christine Manninen, Victoria Pebbles, Marilyn Ratliff, Thomas Rayburn, Kevin Yam and Hao Zhuang contributed their many talents to the effort as well. Finally, the Commission expresses its appreciation to Wendy Larson, Dr. Joseph Depinto and Dr. John Wolfe, project consultants from Limno-Tech, Inc.; and to Brian Neff, U.S.Geological Survey, all of whom contributed significantly to research and writing.

Sincerely,

Michael J. Donahue, Ph.D.
President/Chief Executive Officer
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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).

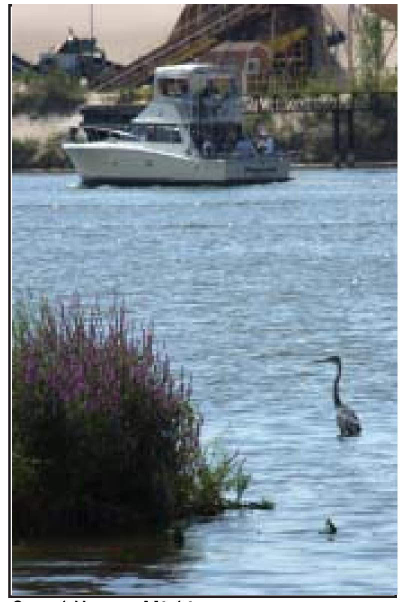
Using hierarchical, or nested, watershed designs to support water management decisionmaking is one approach that provides opportunities to analyze conditions at multiple scales of resolution. Each scale is important in understanding the system and the relationship between water supply, withdrawal and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

A Project Overview

Introduction

As water resources scientists, managers and policymakers gain understanding of the range and complexity of issues surrounding the region's needs and demands for high quality fresh water, they are increasingly relying on data, information and technology to answer difficult questions. Decision support systems are becoming crucial tools in the fields of water resources science, planning and management. Such systems, which include both descriptive information and normative, prescriptive optimization approaches, link a combination of decision analysis tools (e.g., maximization, cost-benefit analysis) and information components into a decisionmaking process. The objective is to integrate data, information and knowledge from different sources to facilitate informed decisions. Access to accurate and uniform data to inform research and the decisionmaking process is therefore essential.

The Great Lakes Commission and its project collaborators initiated a project, titled *Toward a Water Resources Management Decision Support System for the Great Lakes*, in August 2000. The project responds to the increasing need for data and information on Great Lakes-St. Lawrence River system water resources and the renewed attention and commitment to water resources management on the part of the governors and premiers. This two-year initiative was planned and designed to ensure that scientifically sound technical information on the status of Great Lakes water resources, current water uses, and ecological impacts of individual and cumulative water withdrawals and uses is available to regional decisionmakers.

Background on Great Lakes Water Resources Management and Decisionmaking

Historical Overview

Formal mechanisms for water quantity management within the binational Great Lakes-St. Lawrence River system date back to the Boundary

The Great Lakes-St.Lawrence River governors and premiers signing the Great Lakes Charter in February 1985

Waters Treaty of 1909 between Great Britain and the United States. The Boundary Waters Treaty established the International Joint Commission (IJC), a binational agency consisting of six commissioners; three each appointed by the president of the United States and the governor-in-council of Canada. The IJC has quasi-judicial, arbitration and advisory powers over U.S./Canada boundary waters. The IJC's judicial powers stem from its authority to approve all new "uses, obstructions and diversions" which affect the levels and flows of boundary waters or those crossing the boundary. The Treaty assigns the IJC the power to arbitrate in all matters of difference arising between the two countries that are referred by both to the Commission. This power has yet to be used. The Treaty also enables the governments to refer any matter to the IJC for investigation and recommendations.

The IJC develops Orders of Approval for the regulation of outflows from Lake Superior (1914, 1978, 1979) and Lake Ontario (1952, 1956). Administration for the distribution of flows in the Niagara River between the United States and Canada dates back to the provisions of the Niagara Treaty of 1950, which explicitly recognizes intrabasin flows through the Welland Canal and the New York Barge Canal. Outflows through the Lake Michigan Diversion at Chicago have been managed under Supreme Court oversight since 1905. During World War II, diplomatic letters between the U.S. and Canada provided for diversion of flows through

Long Lac and the Ogoki River from the Albany River watershed into Lake Superior.

Dating back as far as the mid-1850s, dredging, sand mining and/or encroachments in most of the connecting waterways of the Great Lakes-St. Lawrence River system have occurred episodically (and increasingly), and the impacts have been largely unremediated. This has led to significant modification of channel efficiencies and regime changes upstream. Each of these anthropogenic changes to the water balance of the Great Lakes has had profound effects on the storage and retention of water supplies in one part of the system or another, outweighing cumulative impacts of diversions, withdrawals or consumptive uses within the region. The term "water-balance" is a measure of the amount of water entering and leaving a system and any associated changes in storage of waters in a lake system. Frequently, decades of quality controlled water level data distributed across the lakes are required to infer the effects of these altered regime changes in the magnitude of a few centimeters. These facts illustrate that accurate decisionmaking requires a long-term and thorough commitment to data collection, information management and retrieval.

Various large-scale proposals to remove water from the Great Lakes-St. Lawrence River system (or bring water into the system) have been around almost a century. Many of the early proposals did not generate significant attention because they were considered economically and/or environmentally unviable. In the late 1970s, due to apparent heightened interest from regions outside the basin to divert and use Great Lakes water, the Great Lakes governors and premiers began to consider the importance of a regional approach to managing the system's water resources. In 1983, this interest culminated in the appointment, by the governors and premiers, of a Task Force on Water Diversion and Great Lakes Institutions. This task force was established to address ongoing concerns about future management of the Great Lakes-St. Lawrence River system and the perceived significant economic and environmental consequences to the region from large-scale diversions. The report of the task force, in January 1985, addressed three main areas: the need for regional action in the area of water management; the need to protect the resource; and institutional capabilities and needs. An outcome of this study was the Great Lakes Charter of 1985, a series of principles and procedures for the management of Great Lakes water resources.

One of the central themes of the task force's 1985 report was that the best defense against outgoing interbasin diversions and intra-regional conflicts over water use is for the region to develop an effective, comprehensive program to manage its water resources. The report states, "developing such a program, of which a common base of data is a first step, will entail a major long-range commitment on the part of the Great Lakes states and provinces." The task force also concluded "it is important to begin this process now, while public concern is high and political will is strong."

The Charter calls for the development of a Water Resources Management Program to guide the future development, management and conservation of the water resources of the basin. The following elements are included:

- An inventory of the basin's surface and groundwater resources;
- An identification and assessment of existing and future demands for diversions (both interbasin and intrabasin), withdrawals and consumptive uses and the ecological considerations of these uses;
- The development of cooperative policies and practices to minimize the consumptive use of the basin's water resources; and
- Policies to guide the coordinated conservation, development, protection, use and management of the water resources of the basin.

The Great Lakes-St. Lawrence River governors and premiers signing the Great Lakes Charter Annex in June 2001

Since the signing of the Charter, the management framework has been slow to evolve due to changes in regional leadership, public interest that has waxed and waned, and inconsistent financial, programmatic and legislative support of water management programs, particularly those involving data collection and reporting.

Implementation of Charter principles has also been compromised by numerous other factors:

- The lack of scientifically sound data and information on water withdrawals, diversions and consumptive uses;
- The lack of scientific understanding of, and the limited ability to measure the various components of the Great Lakes hydrologic system that contribute to the development of a water balance;
- The lack of understanding of how individual, collective and cumulative withdrawals, diversions and consumptive uses impact the Great Lakes ecosystem;
- The lack of priority attention given to implementation of the Charter;
- Insufficient legislative and programmatic authority to implement Charter requirements;
- The lack of financial support necessary to carry out Charter requirements;
- The failure to consistently bring different interests and disciplines together to address the complex issues surrounding water resources management; and
- The tendency for the region to be reactive, rather than proactive, when faced with the decisionmaking demands of a water withdrawal or export proposal.

Passage of Water Resources Development Act (WRDA) of 1986 added another dimension to the issue. Section 1109 of WRDA prohibits any new or increased diversion of Great Lakes water without the unanimous approval of the Great Lakes governors. This section, while adding significant legal authority to the governors' ability to protect Great Lakes water resources from outside interests, also affected the process for cooperative water resources management decisionmaking laid out by the Charter. By giving the governors veto power over new diversions of any size, Section 1109 counteracted the Charter trigger level provision that requires prior notice and consultation only for diversions that exceed 5 million gallons per day (mgd) (19 million litres per day) average over a thirty-day period. Section 1109 did not specify any consultation requirements, although a case-by-case consultation process has been used for those few diversion and consumptive use proposals that have been evaluated since 1986. Section 1109 also created a new dynamic with the Great Lakes-St. Lawrence provinces, which are not subject to U.S. law and, therefore, have no legal standing in the WRDA decisionmaking process.

The need to revisit regional water resources management decisionmaking was rekindled in 1999, following a thwarted proposal by an Ontario company (Nova Group) to secure a permit to withdraw Lake Superior water with the intent of establishing an overseas market for bulk water export. This event triggered passage of Regulation 285/99 of the Ontario Water Resources Act, stipulating that "no person shall use water by transferring it out of one of Ontario's three water basins" (section 3(2)). In addition, the IJC completed a study requested by Canada and the United States and released the corresponding report, Protection of the Waters of the Great Lakes, in February 2000. The report concludes that the ecological integrity of the Great Lakes needs protection, especially in light of the uncertainties, pressures and cumulative impacts from water withdrawals, consumption, population growth, economic growth and climate change. In December 2001, Canada amended its Boundary Waters Treaty Act to prohibit bulk water removals from the Great Lakes and other boundary waters and to set in place a licensing regime for boundary waters projects such as dams and other works.

Addressing the precedent-setting nature of the proposal and the region's response to it, the Council of Great Lakes Governors issued a statement in 1999 outlining a set of principles to guide the development and maintenance of a strengthened water resources management framework for the Great Lakes-St. Lawrence River system. This statement refocused regional discussion on these issues and led to the development of the Great Lakes Charter Annex, signed by the governors and premiers on June 18, 2001. The statement reaffirmed the governors' and premiers' commitment to the 1985 Charter, and outlined the following set of principles for a water management regime:

- "It must protect the resource. Resource protection, restoration and conservation must be the foundation for the legal standard upon which decisions concerning water withdrawals are based.
- It must be durable. The framework for decisions must be able to endure legal challenges based upon, but not limited to, interstate commerce and international trade. It must be constitutionally sound on a bi-

national basis, and the citizens of the Basin must support this framework.

- It must be simple. The process for making decisions and resolving disputes should be straightforward, transparent and based on common sense.
- It must be efficient. Implementation of the decisionmaking process should engage existing authorities and institutions without necessitating the establishment of new and large bureaucracies. The decisionmaking process should be flexible and responsive to the demands it will confront.
- It must retain authority in the basin. Decisionmaking must remain vested in those authorities, the Great Lakes governors and premiers, who manage the resource on a day-to-day basis."

In signing Annex 2001, the governors and premiers reaffirmed their commitment to the broad principles set forth in the Great Lakes Charter, but also acknowledged the need to re-examine the strength and adequacy of Charter provisions, particularly regarding the legal foundations upon which current regional water management authorities rest.

Annex 2001 is a non-binding agreement that serves as a blueprint for water management programs to be developed over a period of several years. Annex objectives were developed on the basis of state and provincial experience with water management, and were influenced by the Great Lakes Charter and Section 1109 of WRDA 1986. The Annex also reflects the governors' 1999 statement on water management, findings from the February 2000 International Joint Commission reference study report on water export, and a study commissioned by the governors on Great Lakes and international water law. That study was supported by the Great Lakes Protection Fund and completed in May 1999.

Annex 2001, through a series of six directives, commits the Great Lakes governors and premiers to the following:

- Developing a set of binding agreements;
- Developing a broad-based public participation program;
- Establishing a new decisionmaking standard for reviewing proposed withdrawals;
- Consulting with the premiers of Ontario and Québec on proposed diversions of Great Lakes water under WRDA 1986;
- Developing a Water Resources Management Decision Support System;
- Additional commitments associated with implementing the Annex.

The Resource and its Ecological/Economic Attributes

The eight states and two provinces that constitute the binational Great Lakes-St. Lawrence River region are blessed with an abundance of high quality fresh surface water. The Great Lakes-St. Lawrence River system contains 6.5 quadrillion gallons (24.6 quadrillion litres) of fresh surface water, a full 20 percent of the world's supply and 95 percent of the supply in the contiguous United States. The magnitude of the resource has fostered the perception of a seemingly inexhaustible supply of fresh water that can accommodate all current and projected uses. In reality, the system's water resources are finite, intensively used and ecologically fragile.

In recent years, renewed interest and attention has been focused on Great Lakes water resources management and water supply issues. This interest has been generated, at least in part, from proposals for increased in-basin water use and out-of-basin diversions to nearby communities and beyond. These proposals have raised concerns that current management principles may not provide for sustainable use of the basin's water resources, and have prompted studies and policy discussions at the state, provincial, regional and federal levels.

The Great Lakes-St. Lawrence River system represents a complex ecosystem with attributes that are related to and dependent upon one another. The nearshore zone is particularly important from both economic and ecological standpoints and is also where the impacts from water withdrawals are most discernable. Even minor chemical, physical or biological changes that might have no immediate measurable impact from a systemwide standpoint may be important when viewed from a nearshore or sub-watershed perspective. Also, cumulative impacts from single or multiple withdrawals will occur over time and space, and may even be seen on a systemwide scale.

The Management Opportunity

Throughout North America, many aquifers, lakes, rivers and reservoirs are being stressed by withdrawals and diversions to meet the needs of cities, farms, homes and industries. The Great Lakes-St. Lawrence River region has historically been largely immune from serious, prolonged water shortages and water supply problems. However, as other parts of the continent experience water supply shortages, the Great Lakes are increasingly viewed as a source of high quality freshwater to serve their needs. The needs of communities within Great Lakes jurisdictions that lie just outside Great Lakes basin boundaries have also become a major policy issue. Implications of this interest present a significant challenge for policy officials.

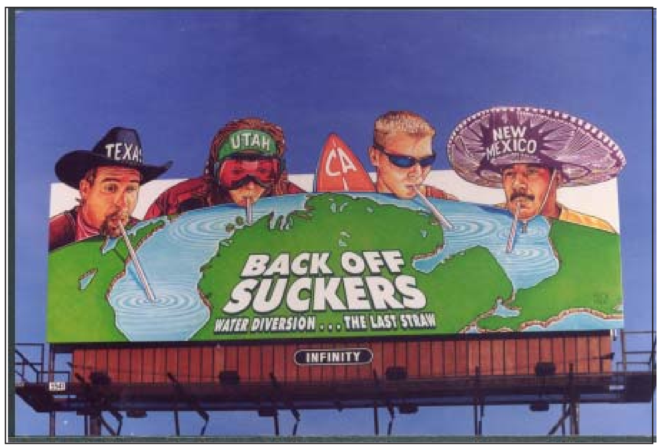
While in-basin demand for Great Lakes water has remained fairly constant over the past decade, uncertainty associated with long-term trends in lake level fluctuations, potential increases in water demand due to population and industrial growth, and regional consequences of global climate change and other factors, has challenged the region to compile and collect the data and information necessary for informed decisionmaking. Policymakers and scientists must also increase their understanding of how small, localized changes to the quality and quantity of Great Lakes water resources impact the larger ecosystem, particularly with regard to long-term and cumulative effects.

One major challenge to scientists and managers is to answer the questions, "how sensitive is the system to impacts associated with cumulative withdrawals?" and "at what level can those impacts be ascertained?" The ability to adequately respond to these questions is complicated by several factors. For example, the system is no longer entirely natural. Changes, primarily for navigation and hydropower production purposes and improvements, have permanently altered the flow regime. Dredging, diversions (both incoming and outgoing) and the construction of locks, dams and controlling works have created changes that are orders of magnitude greater than any changes that might occur from small-scale withdrawal, diversion or export projects. In addition, anthropogenic changes to the natural hydrologic/hydraulic regime have occurred (to a lesser extent) through consumptive uses and related resource demands since settlement began in the region. These issues require scientifically sound data and the formulation of socio-economically viable and environmentally responsible policies. This will be fundamentally important in providing a sustainable future for the region.

Project Background and Scope

In early 2000, in response to the Great Lakes governors' 1999 statement on water management, the Great Lakes Commission and numerous project collaborators were invited to prepare a proposal to the Great Lakes Protection Fund. The proposed project entailed an inventory and assessment of available water resources information, along with related work, that would yield a framework for a Water Resources Management Decision Support System (WRMDSS) for the Great Lakes. The proposal was approved in June 2000.

The focus of the initiative evolved over time, influenced by Annex deliberations that began in late 2001. Additional tasks were subsequently added to the work plan to address issues that include a review/evaluation of consumptive use coefficients; an examination of water conservation programs and associated elements; and an examination of the "resource improvement standard" concept embodied in Annex 2001 and its prospective application.



Billboard off an interstate highway in Michigan shows heightened awareness of the need to manage Great Lakes water resources

This final project report addresses the status and availability of data, information, models and other resources required to support the development of a WRMDSS. It includes an assessment of water resources data compiled to support a water balance for the Great Lakes; water withdrawal, diversion and consumptive use information; and a description of models and resources related to the ecological effects of water withdrawals. Further, state and provincial water resource management programs and practices are characterized and, to the extent possible, evaluated with regard to requirements of the Great Lakes Charter. Report products and information also include an evaluation of data and information gaps and needs, with an eye toward data and information requirements to fully support Annex 2001 implementation.

The project scope addresses the importance of scale (both geographic and temporal) in the assessment of data and information availability, requirements and needs. The ability to discern impacts and the importance of those impacts will vary depending on where a potential withdrawal or diversion is occurring within the system. For example, the data, information requirements and models used to assess the impacts of a water withdrawal from the Great Lakes themselves will vary significantly from the data, information and models required to assess a withdrawal at the sub-watershed level. The way that this issue is presented and addressed varies throughout the report and is a function of the different project element work plans. Some project elements focused on the larger, systemwide data and information requirements, while other elements, such as the ecological impacts component, focus more on the importance of discerning impacts at the sub-watershed level. Any decision support system will likely have to accommodate the different spatial and temporal scales that could be associated with water withdrawal and use.

It is important to note that data and information requirements are just one component of a decision support system. Many other components, such as the legal foundation, decisionmaking process and institutional framework must be addressed as well. Thus, this project represents one very important piece of what is necessary to inform the next step in developing and designing an actual decision support system for Great Lakes-St. Lawrence River water withdrawal projects. It must be augmented by work in other areas as a WRMDSS is designed, tested and implemented.

Project Process and Accomplishments

The Great Lakes Commission and its collaborators are providing the data, information and a needs assessment to assist the governors and premiers in the design and implementation of a WRMDSS. This initiative has also produced several major products, which, singly and collectively, will strengthen water quantity decisionmaking and management processes. Five project elements were pursued as follows:

Detailed Project Design and Infrastructure (Project Element One)

The Great Lakes Commission established a formal project administrative structure, identified management team responsibilities, and defined the role and responsibility of project stakeholders. The administrative structure provided for a Project Management Team (PMT), a Stakeholders Advisory Committee (SAC), a Project Secretariat (Great Lakes Commission staff) and three technical subcommittees (TSCs) (see Figure 1-1). The PMT, with representatives from each of the ten Great Lakes states and provinces and the U.S. and Canadian federal agencies with a major water resources related role or mandate, provided overall leadership and direction in the design and conduct of all project elements. The SAC, comprised of policy and technical experts from other regional and federal agencies as well as citizen, environmental, and industry groups, provided valuable information and

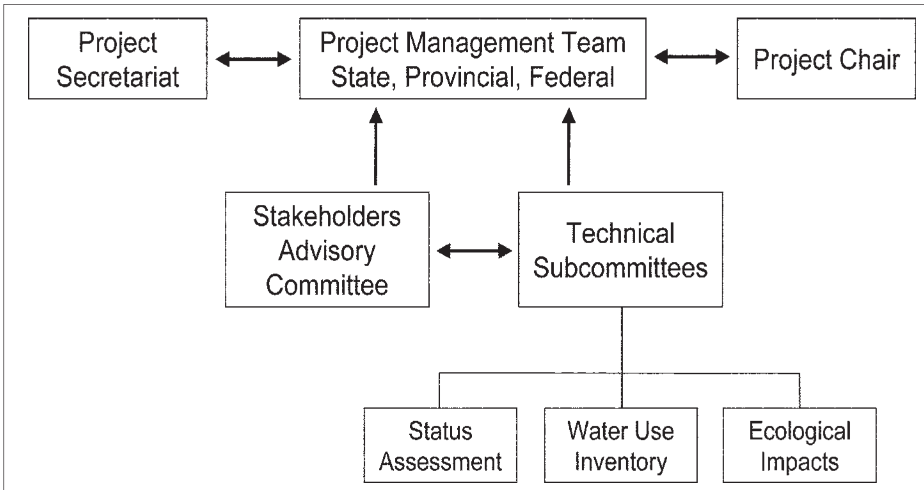


Figure 1-1
Project infrastructure schematic

advice on the project. The TSCs, comprised of experts on topical areas, contributed to work on Project Elements Two through Four: a Status Assessment of Water Resources; an Inventory of Water Withdrawal and Use; and an Inventory of Information on Ecological Impacts.

Status Assessment of Water Resources (Project Element Two)

One of the baseline activities of this effort was the compilation of data and information on the Great Lakes hydrologic system and the completion and update of a water balance. This approach involved assembling data and information associated with both ground and surface water resources based on hydrologic variables such as precipitation, runoff, evaporation, groundwater levels and connecting channel flows. This assessment lays the groundwork for a WRMDSS 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 system. An important component of the work for this element included a series of three flows accounting workshops that examined connecting channel flows, diversions and other inputs and outputs to the Great Lakes system. A critical part of the overall characterization and interpretation of the available hydrologic data was to quantitatively and qualitatively identify uncertainties associated with measures or estimates of the various components of the Great Lakes water balance.

Inventory of Water Withdrawal and Use (Project Element Three)

An understanding of the demand for Great Lakes water resources, such as the amount of water withdrawn and used on a daily, monthly or annual basis, is valuable information for scientists working on the water balance. It is also crucial in developing water budgets at the watershed and sub-watershed level, and vital to the understanding of cumulative impacts associated with increases in demand over time.

Every day, nearly one trillion gallons (about 3.75 trillion liters) of water are withdrawn or used instream for industrial, municipal, agricultural, power generation and other purposes, according to data provided by the Great Lakes states and provinces to a Great Lakes Commission-managed regional water use database. While these numbers inform the discussion of water use activities in the Great Lakes basin in a broad sense, there have been long-standing concerns over the quality, quantity and compatibility of water use data provided by the jurisdictions to the regional database. This lack of high quality, comprehensive and uniform data has contributed to the region's inability to move forward on important activities such as demand forecasting, conducting trend analyses and developing water budgets at the watershed level. Recognizing this area as one of critical need, the project partners have focused significant effort on documenting data gaps and information needs and providing guidance to the states and provinces on ways to improve water use data collection and reporting activities.

With the Great Lakes Regional Water Use Database as a foundation, the Commission staff, with oversight from the Water Withdrawal and Use Technical Subcommittee, assessed the latest available water use data as it relates to withdrawals, instream uses, diversions and consumptive use. Beginning in the late 1980s, the states and provinces, through their Water Resources Management Committee and its Technical Work Group, established parameters for data collection and reporting. Data is compiled by each jurisdiction for nine categories of use and presented in aggregate form on an annual basis, broken down by jurisdiction, lake basin and category of use. Technical subcommittee members used the 1998 water use report process as an opportunity to evaluate data and information needs, methodologies for data collection and reporting, and the database's functionality.

Other significant work products include an evaluation of ways to improve the utility of and access to water use data by decisionmakers and other stakeholders; a detailed state/provincial water use programs report; briefing papers on consumptive use and water conservation; and a scenarios process to evaluate water withdrawal and use data and information needs for decisionmaking. Research on water conservation was pursued to support the Annex's directive for a decisionmaking standard that includes water conservation measures. Although this topic was not part of the original project work plan, the PMT agreed that water conservation can inform the decision support process and, consequently, authorized the additional research.

Inventory of Information on Ecological Impacts (Project Element Four)

The Great Lakes hydrologic system is dynamic and highly complex. Levels and flows within the system constantly fluctuate in response to both natural and human-induced factors, and alterations to this system have an ecological effect that can be cumulative, occurring over space and time. Experts generally agree that demands on Great Lakes water resources are likely to increase and impacts on the Great Lakes basin ecosystem likely will intensify. Enhanced understanding of ecological/biological impacts (local and systemwide) associated with increased water withdrawal and use will be key to formulating scientifically sound resource management decisions.

This project element includes three discrete activities. The scientific literature on the ecological impacts of water use and changes in levels and flows provided information on the status of current knowledge. A descriptive inventory of models with prospective relevance to ecological impacts of water withdrawals complemented information gathered through the literature search. The Commission staff also convened an "Experts Workshop" which brought together U.S. and Canadian scientists with policy and management officials to determine how scientific understanding and modeling capabilities can be incorporated into a decision support system. A third discrete project task involved a focus group approach to determining the potential definitions and application of a "resource improvement standard" that might be applied to water withdrawal and use proposals. A briefing paper and one-day workshop helped inform future discussion on this topic as called for in Directive #3 of the Annex.

Project Synthesis and Next Steps (Project Element Five)

The many individual work products associated with the project have been synthesized and presented in a manner that will ensure immediate use and benefit to the Great Lakes states and provinces and other relevant parties. A comprehensive series of findings and recommendations associated with each of the project elements and their products, as developed by the TSCs and agreed to by the PMT in consultation with the SAC, was the primary focus of project element activity. This included identification of gaps and unmet needs associated with the project work.

Many preliminary findings and recommendations were derived from a project-wide "scenarios workshop" that bridged the work of the technical products by visualizing how water use proposals may be reviewed under decisionmaking mechanisms developed through the Annex process. The workshop also provided an improved understanding of the consequences of cumulative effects over time and space and highlighted the need to address this topic in future decisionmaking strategies.

Report Format

This report provides a description of the results of the work done through the WRMDSS project and presents findings and recommendations that have resulted from that work. These findings and recommendations are explicitly addressed within each chapter, and then are brought together cohesively in Chapter eight.

This written report and the many supporting documents that have resulted from this project provide a wealth of information about the water resources and associated policies related to the Great Lakes-St. Lawrence River basin. Along with the various briefing papers and technical reports, the appendices include background information on Great Lakes regional water resources management, annotated bibliographies, a summary project work plan, and a list of project participants. The project technical reports and various appendices are attached in CD-ROM form and are available at www.glc.org/wateruse/wrmdss/.

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Chapter Two

Status Assessment of Great Lakes-St. Lawrence River Water Resources

Introduction

In June 2001, the governors and premiers of the eight Great Lakes states and two provinces signed an Annex to the 1985 Great Lakes Charter. The Annex calls for, among other items, hydrologic data and information to support a new decision standard regarding proposals to withdraw water from the Great Lakes-St. Lawrence River basin. No current monitoring networks are designed with the specific purpose of providing this decision support.

Great Lakes levels and flows are monitored by many federal, state and provincial agencies, and are done for a number of purposes, including floods, droughts, transportation, and regulatory issues. Monitoring is typically long-term and at the core of agency missions.

This chapter, a product of Project Element Two (Status Assessment of Water Resources), summarizes Great Lakes-St. Lawrence River system hydrology and explains how levels and flows are measured, discusses uncertainty in measurements of levels and flows, and recommends improvements to current monitoring that will provide support for decisionmaking under Annex 2001. More detailed information is available from two other project reports*: The Great Lakes Water Balance: Data Availability and Annotated Bibliography of Selected References* (Neff and Killian, 2003) and Uncertainty in the Great Lakes Water Balance (Neff et al., publication pending). Specific information on flows from 1948 to 1998 can be found in Croley et al. (2001).

This decision support system project was proposed and initiated prior to the signing of the Annex in June 2001. Most of the work on Project Element Two was designed to evaluate the extent, content and accuracy of water resources data and information on a lake-wide or systemwide scale. Publications resulting from Project Element Two focused on levels and flows in the context of net basin supplies to each Great Lake. This chapter builds upon that work and also evaluates water resources data and information in the context of Annex 2001. Emphasis is placed on relating the magnitude of uncertainties associated with levels and flows within the Great Lakes-St. Lawrence River system to those uncertainties associated with cumulative withdrawals and their effects. This status assessment does not address hydrologic conditions beyond the international reach of the St. Lawrence River, even though impacts can occur downstream.

Physical Setting

The Great Lakes-St. Lawrence River system is comprised of: 1) Lakes Superior, Michigan, Huron, Erie and Ontario; 2) their connecting channels, the St. Marys River, St. Clair River, Lake St. Clair, Detroit River and Niagara River; and 3) the St. Lawrence River, which carries the waters of the Great Lakes to the Atlantic Ocean. The system also includes several man-made canals and control structures that either interconnect the Great Lakes or connect the Great Lakes to other river systems.

The Great Lakes basin, including the international section of the St. Lawrence River above Cornwall, Ontario/Massena, New York, covers about 302,000 square miles (782,000 square kilometers). It includes parts of eight states and one province: Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York and Ontario. Fifty-nine percent of the surface area of the Great Lakes basin is in the United States; 41 percent is in Canada. The Great Lakes basin is about 700 miles (1,100 kilometers) long measured north to south and about 900 miles (1,500 kilometers) long measured west to east, at the outlet of Lake Ontario at Cornwall, Ontario/Massena, New York. The St. Lawrence River below Cornwall, Ontario/Massena, New York is about 540 miles (870 kilometers) long and flows through the provinces of Ontario and Québec.

Surface and groundwater flows are significantly affected by the surficial geology and topography of the Great Lakes basin, which is variable. Pre-Cambrian metamorphic and igneous rocks surround most of Lake Superior and northern Lake Huron, in what is known as the Pre-Cambrian Shield physiographic region. This area is very rocky and has little or no overburden. The remainder of the Great Lakes basin is in the Central Lowlands physiographic region and is covered mostly by unconsolidated deposits from glaciers and glacial meltwater. Thickness of the glacial deposits ranges from less than one foot to more than 1000 feet (0.3 to 300 meters). The topography in the Central Lowlands is generally flat and rolling.

In 1990, the population of the Great Lakes basin was about 33 million. About 52 percent of the Great Lakes basin is forested; 35 percent is in agricultural uses; 7 percent is urban/suburban; and 6 percent is in other uses. Major industries in the Great Lakes basin include manufacturing, tourism, and agriculture, valued at about $308 billion, $82 billion, and $48 billion (U.S.) per year, respectively.

Hydrologic Setting

The Great Lakes-St. Lawrence River hydrologic system is complex and highly dynamic. The Lake Superior basin is at the upstream end of the Great Lakes-St. Lawrence River system. Lake Superior discharges into Lake Huron by way of the St. Marys River. The St. Marys River has a long-term average flow of 76,000 cubic feet per second (cfs) (2,150 cubic meters per second (cms)). Lake Superior outflows have been as high as 132,000 cfs (3,740 cms) and as low as 41,000 cfs (1,160 cms) per month. Lakes Huron and Michigan are usually considered as one lake hydraulically, due to their connection at the Straits of Mackinac. Lake Huron is connected to Lake Erie by the St. Clair River, Lake St. Clair and the Detroit River. Lake Erie discharges to Lake Ontario through the Niagara River. A small portion of water from Lake Erie also reaches Lake Ontario by way of the Welland Canal and the DeCew Falls power plant tailrace. Lake Ontario discharges to the St. Lawrence River, which has a long-term average flow of about 242,000 cfs (6,870 cms) at Cornwall, Ontario/Massena, New York. Lake Ontario outflows have been as high as 350,000 cfs (9,910 cms) and as low as 154,000 cfs (4,360 cms).

Dredging, control structures, locks, dams, hydroelectric facilities, canals and diversions have altered the hydrology of the Great Lakes-St. Lawrence River system. Of these, dredging and outflow control have been the most significant. Dredging has had a major permanent impact on water levels on the middle Great Lakes. Dredging in the St. Clair and Detroit rivers began as early as 1855. Further improvements were made incrementally to deepen these navigation channels, with major dredging projects occurring in the 1930s and 1960s. In addition, sand mining occurred in the St. Clair River from 1909 through 1926 to support local manufacturing. From 1880 to 1965, dredging and/or sand mining in the St. Clair River caused a permanent lowering of Lake Michigan-Huron by about 14 inches (35 centimeters).

Outflow control structures at the outlets of Lake Superior and Lake Ontario keep the levels of these lakes regulated within a range that is smaller than the range of levels that would occur under natural outflow conditions. The outflow from Lake Superior has been affected by human modifications beginning in 1822, with subsequent expansions occurring over time. The current outflow control structures have been in place since 1921. Outflows are adjusted monthly under the direction of the International Joint Commission (IJC) with an objective of maintaining the water levels on lakes Superior and Michigan-Huron in relative balance to their long-term seasonal averages. The St. Lawrence Seaway and Power Project, opened in 1960, incorporates outflow control structures to regulate Lake Ontario water levels, maintain hydropower operations, provide adequate depths for commercial navigation, and protect the lower St. Lawrence River from flooding.

The surface area of the Great Lakes, their connecting channels and the St. Lawrence River cover approximately 32 percent of the entire Great Lakes-St. Lawrence River basin above Cornwall, Ontario/Massena, New York. Figure 2-1 provides the volume of each of the Great Lakes as well as the areas of the land and lake components of their individual basins. For example, the total area of the Lake Superior basin is 81,000 square miles (210,000 square kilometers). The surface area of Lake Superior itself is 31,700 square miles (82,100

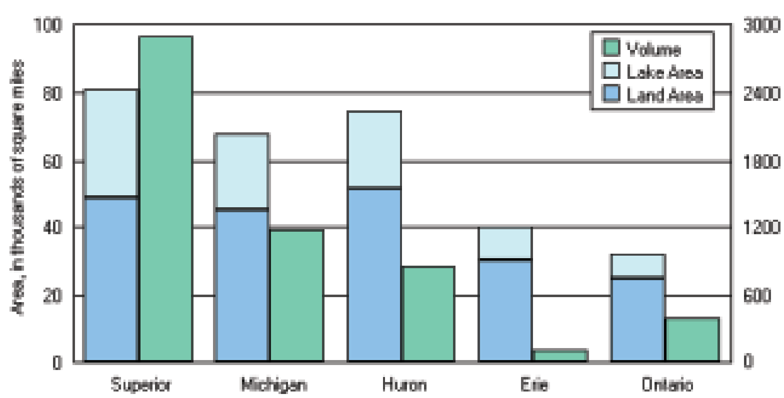

Figure 2-1
Volumes and areas of the Great Lakes

square kilometers), or 39 percent of its entire basin area. In contrast, the surface area of Lake Ontario, 7,340 square miles (18,960 square kilometers), is only 23 percent of the Lake Ontario basin.

Clearly, the proportion of a lake's basin area that is lake surface area directly affects the amount and timing of water that comes into a lake as precipitation directly on the lake's surface and as runoff from its tributary streams. It also affects the amount of water lost through evaporation from its surface.

The Great Lakes basin climate varies widely due to its long north-south extent and the effects of the Great Lakes on nearshore temperatures and precipitation. For instance, the mean January temperature ranges from -2° Fahrenheit (-19° Celsius) in the north to 28° Fahrenheit (-2° Celsius) in the south, and the mean July temperature ranges from 64° Fahrenheit (18° Celsius) in the north to 74° Fahrenheit (23° Celsius) in the south. Precipitation is distributed relatively uniformly throughout the year, but does have variability west to east across the Great Lakes basin, ranging from a mean annual precipitation of 28 inches (71 centimeters) north of Lake Superior to 52 inches (132 centimeters) east of Lake Ontario. Mean annual snowfall is much more variable because of temperature differences from north to south and the snowbelt areas near the east side of each lake. For instance, in the southern areas of the Great Lakes basin, annual snowfall is about 20 inches (51 centimeters) whereas, in snowbelt areas downwind of lakes Superior and Ontario, snowfall can be as high as 140 inches (355 centimeters). Wind is also an important component of the Great Lakes climate. During all seasons, the predominant wind directions have a westerly component. In fall and winter, very strong winds are common on the Great Lakes in nearshore areas due to temperature differences between the lakes and the air moving over them.

Fluctuations in Great Lakes water levels are the result of several natural factors and may also be influenced by human activities. These factors operate on a time scale that varies from hours to years. The levels of the Great Lakes depend on their storage capacity, outflow characteristics of the outlet channels, operating procedures of the regulatory structures, and the amount of water supply received by each lake. The primary natural factors affecting lake levels include precipitation on the lakes, run-off from the drainage basin, evaporation from the lake surface, inflow from upstream lakes, and outflow to the downstream lakes. Man-made factors include diversions into or out of the Great Lakes basin, consumption of water, dredging of outlet channels and regulation of outflows.

Three types of water-level fluctuations occur on the Great Lakes. Long-term (or multi-year) fluctuations result from persistent low or high water supplies. Seasonal (one-year) fluctuations of the Great Lakes levels reflect the annual hydrologic cycle, which is characterized by higher net basin supplies during the spring and early summer, and lower net basin supplies during the remainder of the year. Short-term fluctuations (lasting from less than an hour to several days) occur as water levels set-up (rise) or set-down (fall) due to wind and barometric pressure differences over the lake surface. Set-up is also referred to as storm surge. While all of the Great Lakes are affected by these meteorologic-induced phenomena, Lake Erie is particularly prone to major set-up/set-down events, occasionally causing major water level differences between Buffalo, New York, and Monroe, Michigan, of 12 feet (3.6 meters) or more. Such large events are almost always followed by seiches that can disturb water levels for two to three days. A seiche is the free oscillation of water in a closed or semi-closed basin; it is frequently observed in harbors, bays, lakes, and in almost any distinct basin of moderate size. Wind generated waves are superimposed on all three categories of water-level fluctuations.

Short-term changes in outflows can occur as a result of storm surge or seiches. If water levels increase at the outlet end of the lake, outflows can temporarily increase. Conversely, if levels decline at the outlet end of the lake, outflows will be reduced. The Detroit River descends nearly 3.0 feet (0.9 meters) in the 32 miles (51 kilometers) that it flows from Lake St. Clair to Lake Erie. This makes flows through the Detroit River particularly sensitive to wind set-up and seiche on Lake Erie. During times of wind set-up at the west end of Lake Erie, the flow in the Detroit River slows dramatically. Researchers from the National Oceanic and Atmospheric Administration (NOAA), Great Lakes Environmental Research Laboratory have documented short-term flow reversals under wind set-ups at the western end of Lake Erie.

The flows in the outlet rivers of the lakes during the winter are often constrained by ice formation and occasionally by ice jamming, with the St. Clair and Detroit rivers being most affected. Ice booms deployed upstream of the Niagara River and throughout the St. Lawrence River help stabilize ice cover in these rivers, reducing ice retardation most of the time. Ice conditions are a consequence of prevailing climate conditions, and their severity and exact timing are not predictable for any specific winter. Plant growth in the rivers during the summer also creates flow retardation, and varies from river to river. Plant growth is also variable from year to year, since it is affected by changes in water temperatures.

Over time, water levels throughout the Great Lakes are affected by isostatic rebound, often referred to as crustal movement. Isostatic rebound is the gradual rising of the earth's crust from the removal of the weight of the glaciers that covered the Great Lakes-St. Lawrence River region during the last ice age. The phenomenon of crustal movement was recognized as early as 1869 (Clark and Persoage, 1970). The rate of movement is not uniform throughout the region and results in differential rates of change between specific sites, as shown in Figure 2-2 (USACE and GLC 1999). Generally, the rates around lakes Superior and Ontario are greater than those around lakes Michigan-Huron and Erie.

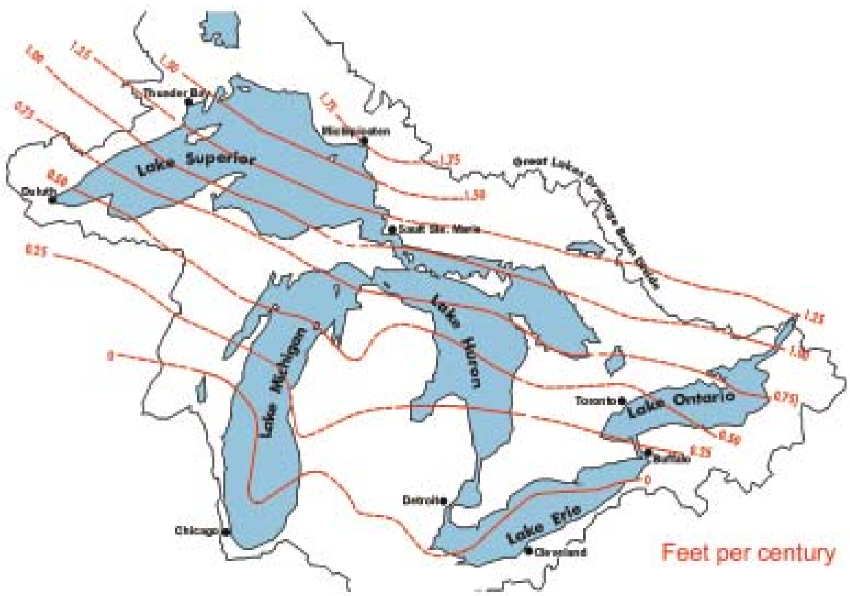

Figure 2-2.
Rates of isostatic rebound

The effects on water levels of differential crustal movement can be visualized if the lakes are considered to be basins that are tilting by a gradual rising of their northeastern rims. Generally, water depths along the southern or western shores relative to the lake's outlet are increasing for a given average lake level as time goes by, while levels along the northern or eastern shores are becoming shallower. On Lake Superior, for example, the axis of mean crustal movement runs from the international border south of Thunder Bay, Ontario, through the lake's outlet at Sault Ste. Marie, Michigan and Ontario. The average land-to-water relationship around the lake remains unaffected by crustal movement under stable natural outlet conditions, but water depths recorded along its shorelines either increase or decrease depending on their location relative to this axis of movement. This discussion is important to the implementation of the Charter Annex because reductions of water levels caused by cumulative withdrawals in one location could be offset or exacerbated by local effects of differential crustal rebound. An example of this situation would be the Cootes Paradise wetland complex on the western end of Lake Ontario. A theoretical 4-inch (10 centimeter) drop in water levels in this area over a 35-year period caused by cumulative withdrawals would be completely offset by an increase in depth of the same magnitude caused by differential crustal rebound.

Levels and Flows

Water levels of the Great Lakes, and flows into and out of the lakes, are measured or calculated at hundreds of locations throughout the Great Lakes basin. Although lake levels are measured directly, most flows are based on estimates or measurements of other parameters and are calculated using simple models. Many agencies conduct the continuous and long-term monitoring necessary for maintaining a current understanding of the Great Lakes-St. Lawrence River system. Funding sources for monitoring are diverse, ranging from federal governments to state, provincial and municipal agencies, and the private sector. For instance, in Canada, the national streamflow-gauging network is funded and operated under cost sharing agreements between the Canadian federal government and the individual provinces and territories. Additional gauges are funded and operated by agencies such as power entities, municipalities and other federal departments. The U.S. streamflow-gauging network has more than 100 different sources of funding. The monitoring is continuous and long-term because levels and flows are highly variable temporally and spatially. Variations in levels and flows can significantly affect navigation, hydroelectric power generation, drinking water intakes, shoreline erosion, and other uses and conditions of the waters of the Great Lakes-St. Lawrence River system.

Levels

The water levels of the Great Lakes and connecting channels are measured for numerous reasons. Instantaneous, daily, monthly and long-term average water levels are used to help meet regulatory requirements, assist with commercial and recreational navigation, operate hydroelectric power stations, predict future water levels, and calculate changes in storage in each lake.

Water levels are measured or gauged at over 100 locations along the shore on the Great Lakes and their connecting channels by NOAA and the U.S. Army Corps of Engineers (USACE) in the United States and by Fisheries and Oceans Canada (DFO). NOAA operates 50 permanent and several seasonal water level gauges along the Great Lakes shoreline, the connecting channels and the St. Lawrence River. The USACE operates 17 water level gauges on the St. Marys, St. Clair, Detroit and Niagara rivers. Similarly, DFO operates 34 permanent water level gauges on the Canadian side of the border as part of its national network. Water levels at both U.S. and Canadian gauges are measured and reported to the nearest millimeter, although the sampling methods used by each agency differ. Daily average levels calculated by each agency, however, are considered equivalent for calculation purposes. Water level data recorded by NOAA, USACE and DFO at their respective gauge stations are available from these agencies via the Internet. Power entities and others operate additional gauges, principally on the Niagara and St. Lawrence rivers, to meet their specific needs.

Great Lakes levels are expressed in two ways, either as: 1) an elevation above sea level or; 2)as an amount above or below Chart Datum on the lake or connecting channel where the gauge is located. Great Lakes water levels are currently referenced to the International Great Lakes Datum of 1985 (IGLD85). The impact of differential crustal movement on Great Lakes water levels requires that this datum be updated every 30 to 35 years. IGLD85 is the second internationally coordinated Great Lakes datum, replacing IGLD55. The IGLD is updated by the Vertical Control-Water Levels Subcommittee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

The USACE and Environment Canada calculate and report lake-wide daily and monthly mean levels for each of the Great Lakes under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. The lake-wide average water levels are calculated from selected NOAA and DFO water level gauges on each lake, which account for short-term water level disturbances and long-term effects of differential crustal movement. The level of lakes Michigan and Huron are reported as a single number due to their hydraulic connection. The daily and monthly lake-wide average levels are reported to the nearest centimeter, which is considered adequate for operational and public information purposes. Information on how to find and obtain lake level data is provided by Neff and Killian (2003).

Flows

Flows into and out of the Great Lakes include tributary streamflow (also referred to as basin runoff), groundwater, precipitation, evaporation, connecting channel and St. Lawrence River flows, diversions and consumptive uses. Consumptive uses are a very small percentage of the total flows and are discussed in Chapter three. Figure 2-3 shows

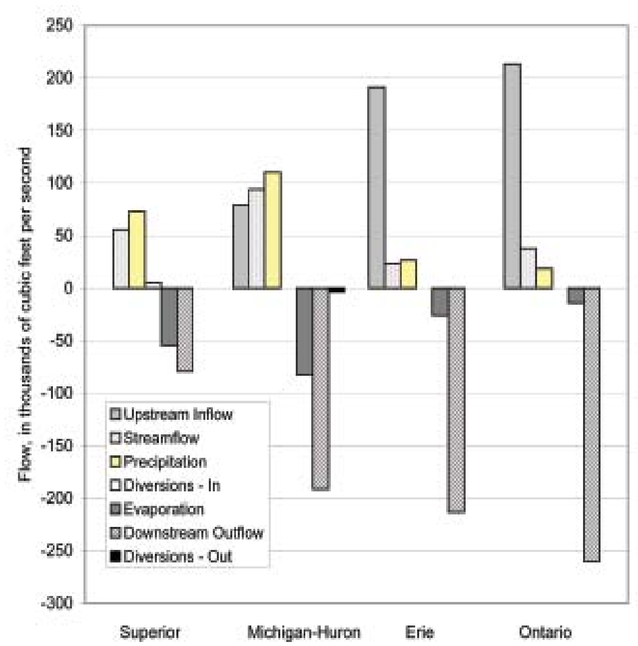

Figure 2-3
Flows into and out of the Great Lakes

the magnitude of each hydrologic component for each of the lakes.

Streamflow

Streamflow is a large part of each Great Lake's inflow, but the percentage varies from one lake to the next. Figure 2-4 depicts the relative role of streamflow for each lake. Excluding inflows from connecting channels, which are discussed separately, streamflow is 46 percent of the inflow to Lake Michigan-Huron and 67 percent of the inflow to Lake Ontario. This variability is primarily a function of the land-to-lake surface ratio in each lake basin.

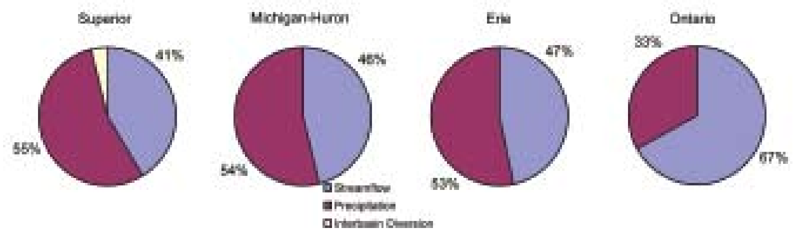

Figure 2-4
Inflows to the Great Lakes (excluding connecting channel inflows)

Tributary streamflow is measured or gauged at several hundred locations throughout the Great Lakes basin. Gauged areas account for about 60 percent of the land area of the Great Lakes watershed. Streamflow in most gauged watersheds is calculated from continuous measurements of water level (or stage) and used to model a stage-discharge relationship. The relationship of stage to discharge is periodically checked and updated by direct measurements of discharge at gauging locations. A few gauging locations are not suitable for generation of a stage-discharge relationship and, at these locations, other types of measurements or models are employed.

Streamflow from ungauged areas is not typically calculated by monitoring agencies. However, NOAA does regularly calculate monthly mean streamflow from ungauged areas for calculations of net basin supply. These calculations use a simple procedure that relates ungauged streamflow to streamflow-drainage area ratios in nearby gauged watersheds.

Historical and current streamflow data can be obtained from agencies that collect, publish and archive the data. The two principal sources of data are the U.S. Geological Survey (USGS) and Environment Canada. Information on how to find and obtain streamflow data is provided by Neff and Killian (2003).

Groundwater

The amount of groundwater that discharges directly into the Great Lakes, their connecting channels and the St. Lawrence River is small relative to other flows into the Great Lakes and is not measured. For these reasons, direct groundwater discharge is typically ignored in water-balance computations and discussions of flows into and out of the Great Lakes. A summary of the available literature on this topic is included in Neff and Killian (2003). Locally, direct groundwater discharge to the Great Lakes may be important to aquatic ecosystems. However, a literature search did not yield information on the relation of groundwater to aquatic ecosystems in the Great Lakes proper, their connecting channels or the St. Lawrence River.

Groundwater also discharges to the Great Lakes, their connecting channels and the St. Lawrence River indirectly by way of tributary streams. From the perspective of long-term water-balance calculations for the Great Lakes proper, this indirect groundwater discharge can be ignored because it is a part of streamflow computations. From a water management perspective, however, indirect groundwater discharge must be calculated because it supports instream ecosystems by maintaining base flows and moderating water temperatures. It also allows for computation of allowable point discharges during periods of low flow. In some cases, groundwater discharge may be a significant source of nonpoint source pollution in streams.

In much of the Great Lakes basin, indirect groundwater discharge is a large percentage of the total amount of streamflow, as shown in Figure 2-5. The percentage of streamflow attributable to groundwater is typically calculated by use of long-term streamflow records and application of baseflow-separation models. However, these calculations are reliable only in areas where human factors such as flow regulation and wastewater discharge are minimal. Binational efforts are currently underway to expand, and improve upon, earlier calculations by Holtschlag and Nicholas (1998).

Each aquifer that contributes groundwater to the Great Lakes or their tributary streams has a "potentiometric surface," which is a measure of the static head of groundwater in an encased well. This potentiometric surface is similar to the earth's surface in that it has groundwater divides that are analogous to surface watershed divides. Unlike surface water divides, groundwater divides are not static and may vary in response to groundwater withdrawals. Groundwater on one side of the divide flows toward the Great Lakes; groundwater on the other side flows away from the Great Lakes. Only a part of the Great Lakes region and only some of the aquifers have mapped potentiometric surfaces and groundwater divides. In the remainder of the region, the area that contributes groundwater to the Great Lakes is unknown.

Precipitation

Precipitation directly on the Great Lakes basin is a large part of each Great Lake's inflow as shown in Figure 2-4. The percentage varies from one lake to another, and is largely a function of the land-to-lake surface ratio in each lake basin.

Precipitation is measured or gauged at hundreds of locations in the Great Lakes basin. All of these gauges are on land; precipitation over the lake surface is calculated by interpolation of data from these gauges. Modern radar technologies are deployed in the United States and Canada to calculate precipitation over land masses. These systems have the potential for estimating precipitation over lake surfaces as well but, heretofore, have not been exploited for this application.

Historical and current precipitation data from gauges can be obtained from agencies that collect, publish and archive the data. The two principal sources of data are the National Climate Data Center, in the United States and the National Archives and Data Management Branch, Atmospheric Monitoring and Water Survey Directorate, Meteorological Service of Canada. Historical monthly over-lake precipitation calculations for each lake are available in Croley et al. (2001). Information regarding how to find and obtain precipitation data is discussed by Neff and Killian (2003).

Evaporation

Evaporation from the surface of the Great Lakes is a large part of each Great Lake's outflow as shown in Figure 2-6. The percentage varies from one lake to another depending primarily upon the area of the lake surface as compared to the area of the watershed draining to the lake. Much of the seasonal decline the lakes experience each fall and early winter is due to the increase in evaporation from their surfaces when cool, dry air passes over the relatively warm water of the lakes.

Evaporation is not measured directly; it is calculated using a computer model developed by Croley (1989). Most parameters used to calculate evaporation (e.g., air temperature, wind speed, relative humidity) are measured at on-shore locations. Since the early 1990s, satellite imagery and other remote sensing techniques have been used to calculate surface water temperatures. Historical monthly evaporation calculations for each lake are available in Croley et al. (2001).

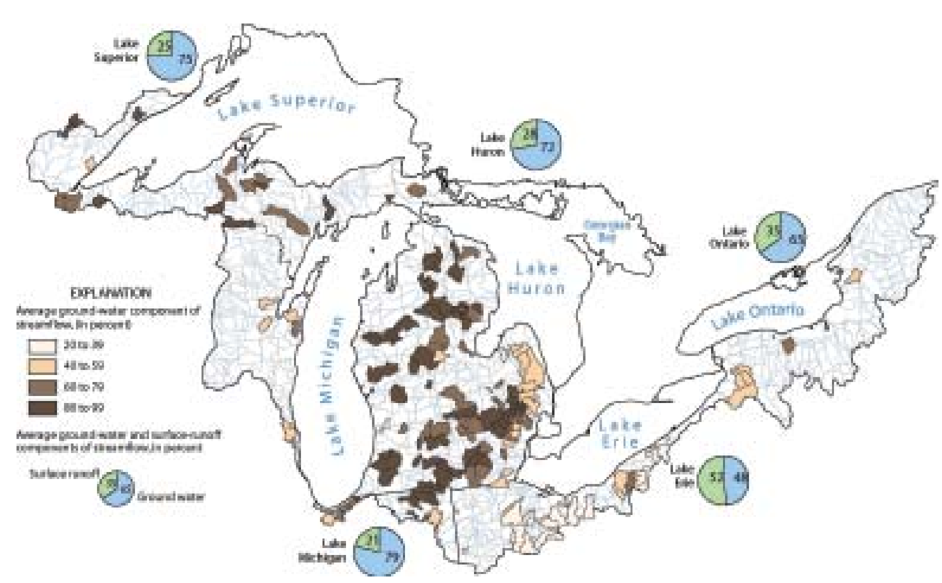

Figure 2-5
Average groundwater and surface-runoff components of streamflow in the United States portion of the Great Lakes basin

Connecting Channels and the St. Lawrence River

Connecting channel flows are a large part of each Great Lake's outflow. The percentage increases downstream through the Great Lakes as shown in Figure 2-6. Increased discharges are due to the additional overland and over-lake water supplies to the immediate upstream lake.

Flows in all of the connecting channels and the St. Lawrence

River have been altered by human activities since 1855. Some of these flow modifications have not been compensated for, effectively causing a permanent change in hydraulic conditions (higher or lower water levels) upstream of their locations. Major hydraulic regime changes occurred throughout the system when the navigation channels were deepened to 25 feet in 1933-1936 and to 27 feet in 1960-1962.

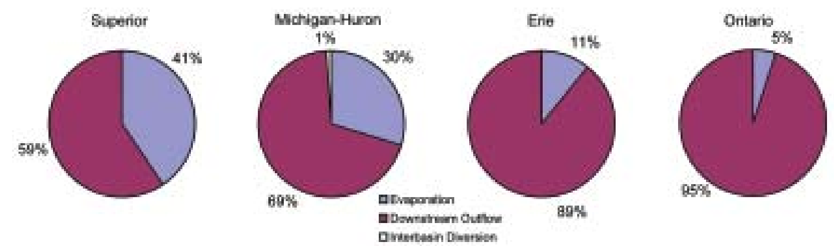

Figure 2-6.
Outflows from the Great Lakes (Note: Intrabasin diversions are included in outflows)

Connecting channel and St. Lawrence River flows are measured or calculated using a variety of methods specific to each. Flows in the St. Marys River, Niagara River and St. Lawrence River are calculated as the sum of flows through power plants, selected river sections, shipping locks, and other structures. A stage-discharge relationship is also available for the upper Niagara River that is used for operational and modeling purposes. Flows in the St. Clair and Detroit rivers are calculated from measurements of stage using a set of stage-fall-discharge relationships. These relationships accommodate the range of vegetative growth and ice conditions that can occur in the St. Clair-Detroit rivers system. Periodic discharge measurements are used to verify and update stage-fall-discharge relations and power plant or control structure rating curves.

Historical connecting channel flows can be obtained from the agencies that collect, publish and archive the data. The Hydraulic Subcommittee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data regularly meets to discuss and agree upon binationally accepted flow values. Binationally coordinated data from this subcommittee are calculated and published, typically in response to a reference from the IJC. Information regarding how to find and obtain connecting channel flow data is discussed by Neff and Killian (2003).

Diversions

Diversions account for only a small portion of total Great Lakes flows. Diversions are either interbasin, transferring water into or out of the Great Lakes basin, or intrabasin, transferring water from one Great Lake to another.

There are three major and five minor interbasin diversions, listed in Figure 2-7, which uses a logarithmic scale so that diversions of different orders of magnitude can be compared. The Long Lac and Ogoki diversions are major diversions that transfer water from the Hudson Bay watershed to Lake Superior. The Lake Michigan Diversion at Chicago, Illinois, is a major diversion that transfers water from Lake Michigan to the Illinois River watershed. Minor interbasin diversions are Forestport, New York (out of Lake Ontario), Portage Canal, Indiana (into Lake Michigan), Pleasant Prairie, Wisconsin (out of Lake Michigan), Ohio & Erie Canal (into Lake Erie) and Akron, Ohio (out of and into Lake Erie).

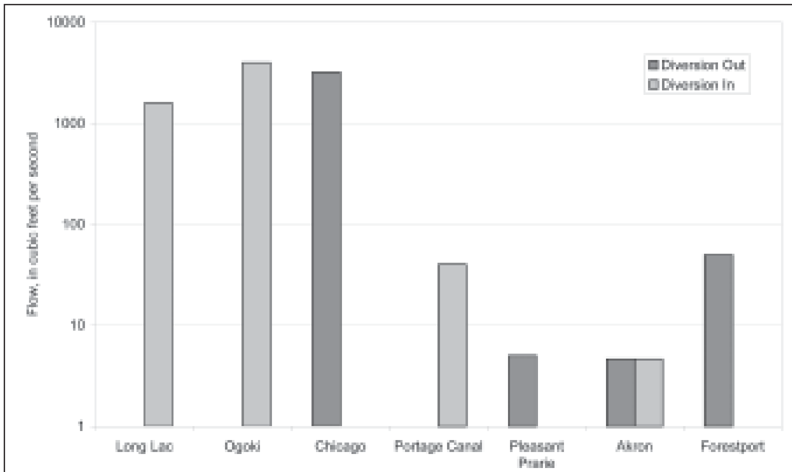

Figure 2-7
Interbasin diversions (logarithmic scale)

Some intrabasin diversions – the Welland Canal, the New York State Barge Canal and the Raisin River Diversion – are measured and accounted for as part of the outflow of their respective Great Lake. The remaining intrabasin diversions – Detroit, London and Haldimand – are generally ignored in water-balance computations because they are relatively small compared to other flows as shown in Figure 2-8, which also uses a logarithmic scale.

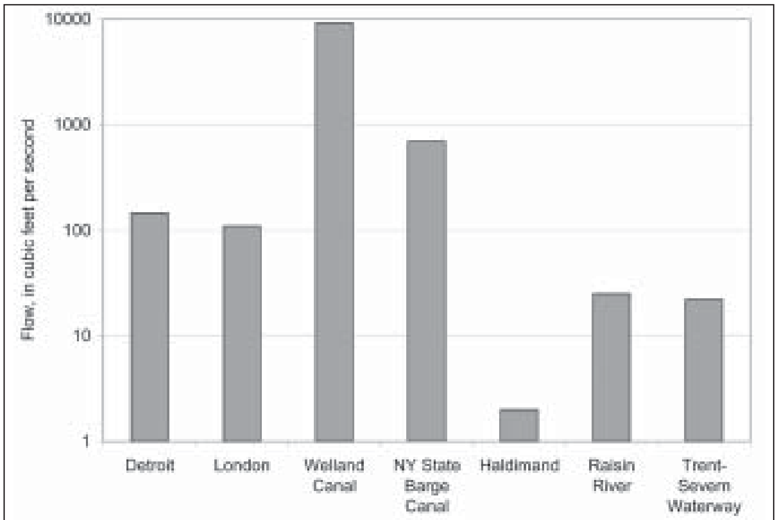

Figure 2-8
Intrabasin diversions (logarithmic scale)

Diversions are measured or calculated using a variety of methods specific to each diversion. Information on how to find and obtain flow data for diversions is provided by Neff and Killian (2003).

Variability of Levels and Flows

Levels and flows in the Great Lakes basin are highly variable, suggesting the need for continuous, long-term monitoring. Factors affecting levels and flows are variations in climate, diversions and outflow regulation. Variation in climate, both temporal and spatial, is the major factor affecting levels and flows, dwarfing the other two factors.

Long-term variability in water levels results from persistent low or high water supplies. Such variability caused extremely low levels on some lakes in 1926, the mid-1930s and mid-1960s, and extremely high levels in years such as 1952, 1973, 1985-86 and 1997. The intervals between periods of high and low levels, and the length of such periods, can vary widely over a number of years and only some of the lakes may be affected. The ranges of levels on lakes Michigan-Huron, Erie and Ontario reflect not only the fluctuation in supplies from their own basins, but also the fluctuations of the inflow from upstream lakes.

The historical record for levels of Lake Superior from 1860-1999 is shown in Figure 2-9. This plot demonstrates the long-term variability of water levels primarily affected by climate variability. Lake levels derived from the geologic record over the last five thousand years indicate that levels can be more variable than those of the past 140 years of historical record.

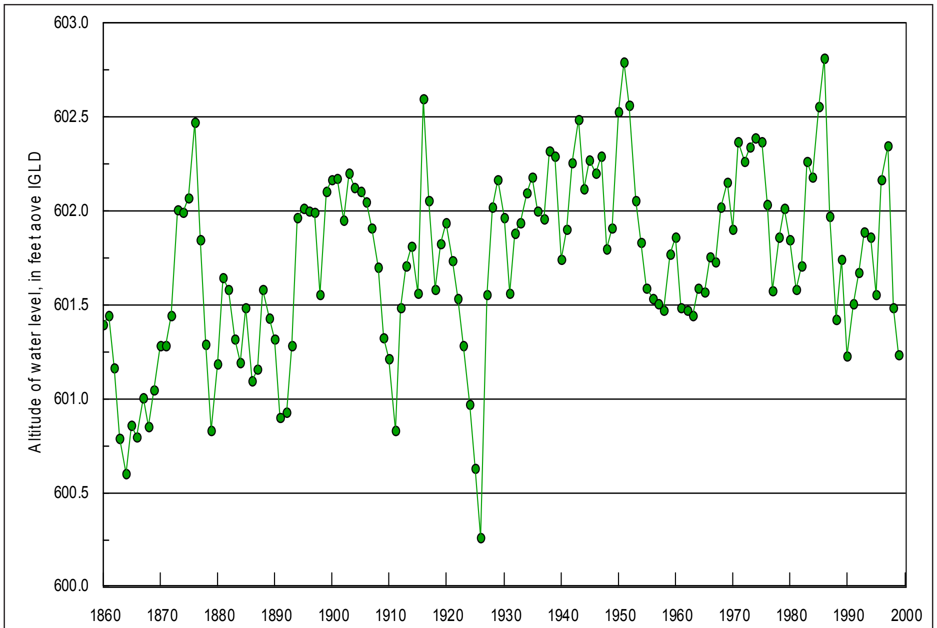

Figure 2-9
Lake Superior water level, 1860-1999

Seasonal variability in water levels reflects the annual hydrologic cycle, which is characterized by higher net basin supplies during the spring and early summer and lower net basin supplies during the remainder of the year. The maximum lake level usually occurs in June on lakes Ontario and Erie, in July on Lake Michigan-Huron, and in August on Lake Superior. The minimum lake level usually occurs in December on

Lake Ontario, in February on lakes Erie and Michigan-Huron, and in March on Lake Superior. Based on the monthly average water levels, the magnitudes of seasonal fluctuations are relatively small, averaging about 1.3 feet (0.4 meters) on lakes Superior, Michigan and Huron, about 1.6 feet (0.5 meters) on Lake Erie, and about 2.0 feet (0.6 meters) on Lake Ontario. However, in any one season it has varied from less than 0.7 feet (0.2 meters) to more than 2.0 feet (0.6 meters) on lakes Superior and Michigan-Huron, from less than 1.0 foot (0.3 meters) to more than 2.6 feet (0.8 meters) on Lake Erie, and from 0.7 feet (0.2 meters) to 3.6 feet (1.1 meters) on Lake Ontario.

Seasonal variability in flows can be very large. For instance, long-term evaporation from Lake Superior is about -300 cfs (-8.5 cms) in June and about 10,000 cfs (280 cms) in January and December, as shown in Figure 2-10. Cold winter temperatures in the northern Great Lakes also cause reduced winter streamflow and substantial spring runoff from melting snow and ice.

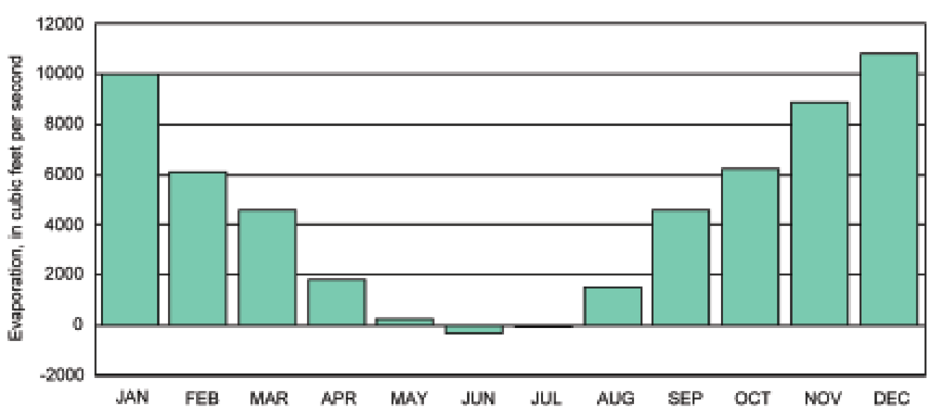

Figure 2-10
Long-term average monthly evaporation from Lake Superior

Short-term variability in water levels, lasting from less than an hour to several days, is caused by meteorological conditions. The effect of wind and differences in barometric pressure over the lake surface create temporary imbalances in the water level at various locations. Storm surges are largest at the ends of an elongated basin, particularly when the long axis of the basin is aligned with the wind. In deep lakes such as Lake Ontario, the water level surge rarely exceeds 1.5 feet (0.5 meters) but, in shallow Lake Erie, water level differences from one end of the lake to the other of more than 16 feet (4.9 meters) have been observed, followed by major seiches causing water levels to oscillate and diminish for several days. The range of fluctuations may be large, but only minor changes occur in the volume of water in the lake because, as the water levels rise at one end, they generally fall at the opposite end.

Generally, a lake's outflow depends on its water level; the higher the level, the higher the outflow. Accordingly, low lake levels are characterized by low outflows. This self-regulating feature helps keep levels on the lake within standard ranges, as long as unremediated dredging or other factors do not modify outflow channels. Due to the size of the Great Lakes and the limited discharge capacity of their outflow rivers, extremely high or low levels and flows can persist for a considerable time after the factors that caused them have changed. Thus, many years can pass before the effect of changes in flows in the upper lakes reaches Lake Ontario.

Great Lakes water level data must be used appropriately, or analyses will be misleading. This is particularly true where the long-term impact of differential crustal movement on local water levels may be important. While appropriate for water-balance calculations, using a lake-wide average level to analyze changes over time in wetland areas around a lake would lead to erroneous results. For this example, more appropriate data would come from water level gauges close to the study sites that are adjusted for local isostatic rebound. Similarly, use of monthly lake-wide average levels would be inappropriate for most flood and erosion studies.

In contrast to the effects of climate on levels and flows, the effects of diversions and outflow regulation are generally small. For instance, from 1970 through 1990, the Lake Michigan Diversion at Chicago, Illinois, ranged between 2934 cfs and 4055 cfs (83 cms and 115 cms), a difference of 1121 cfs (32 cms) as seen in Figure 2-11. The difference between the impact of a long-term withdrawal of 2934 cfs and 4055 cfs through the diversion, theoretically, is a 0.07-foot (2 centimeter) change in the water level of lakes Michigan-Huron and a 0.6 percent change in the average flow of the St. Clair River. The regulation of outflows from Lake Superior reduces the natural variability of water levels on lakes Superior and Michigan-Huron. Outflow controls in the St. Lawrence River likewise reduce the natural variability of water levels on Lake Ontario.

Figure 2-11 shows the non-certified and certified outflows through the Lake Michigan Diversion. Local authorities computed diversion flows prior through 1980 but, after that water year, diversion outflows were computed and certified by the USACE, in accordance with U.S. Supreme Court directives.

may be reduced by additional monitoring or by the application of more advanced instrumentation and estimation methods. The degree of uncertainty can vary as a function of the magnitude of the physical process being measured, computed or estimated. For example, uncertainties may be greater or lesser at higher outflows than at average outflows for a natural system.

Uncertainty in calculations of levels and flows is closely linked to Charter Annex issues. If part of the system is poorly understood (i.e., has high uncertainty), then it will be difficult to predict the effects of a proposed withdrawal on levels and flows, and on the ecosystem. Conversely, if part of the system is well understood, then the effects of a withdrawal on levels or flows may be easier to predict and could be used to evaluate ecological impacts.

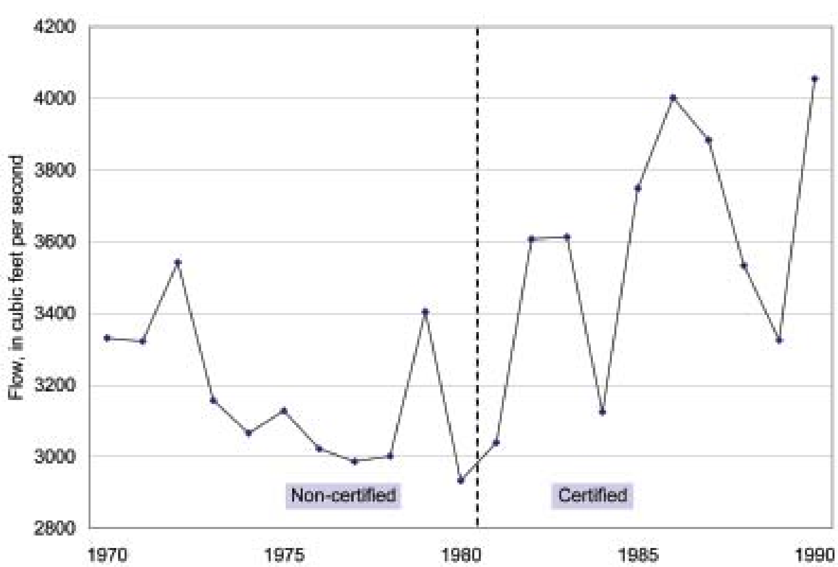

Figure 2-11
Lake Michigan Diversion at Chicago, Illinois, 1970 to 1990

There are no published uncertainty calculations associated with any of the levels and flows of the Great Lakes. The Status Assessment of Water Resources Technical Subcommittee, therefore, used its best professional judgment to estimate ranges of uncertainty for levels and flows. These ranges are presented in this section for the purpose of illustrating how well the hydrology of the Great Lakes-St. Lawrence River system is understood and to provide background for recommendations. For consistency in comparisons, uncertainties for each type of level and flow are related to: 1) the average outflow through the Lake Michigan Diversion at Chicago, Illinois; 2) the level of Lake Michigan-Huron; and 3) the average flow of the St. Clair River. Comparison between flows assumes identical time periods (instantaneous, hourly, weekly, monthly, etc.). Comparison with levels on Lake Michigan-Huron assumes persistence over an indeterminate time to achieve equilibrium throughout the system. For additional detail regarding uncertainty in levels and flows see Neff et al. (publication pending).

Uncertainty in Calculations of Levels and Flows

All measurements and calculations have uncertainty associated with them. The term "uncertainty" is used within this chapter, not in a formal statistical manner, but as a means for quantifying errors and biases associated with measurements, calculations and estimates. In some cases, uncertainty in a measurement or calculation may reflect the level of accuracy of state-of-the-art instrumentation or estimation methods used. In other cases, uncertainty

Levels

Uncertainty in the calculation of lake level fluctuations derives primarily from adequacy of the gauge network, accuracy of gauge datum and accuracy of recording equipment. An additional consideration is the proper selection and averaging of water levels recorded at individual water level gauges for calculation of lake-wide water level values. These calculations must also account for the impact of short-term weather conditions and the long-term impact of differential crustal movement.

A robust network of water level gauges is maintained throughout the Great Lakes and their connecting channels. NOAA, USACE and DFO operate more than 100 gauging stations throughout the Great Lakes-St. Lawrence River system. Instantaneous and hourly water levels at individual gauges are available to both the public and water managers on a real or near-real time basis through the use of voice announcing gauges, the Internet or phone interrogation. Daily and longer period lake-wide average levels are calculated based on selected gauge networks. Reductions in the network have occurred or been considered in the recent past; it must be adequately maintained and enhanced as needed, to address current and anticipated data requirements.

Water level data are referenced to an internationally coordinated Great Lakes datum, which is updated periodically to compensate for the impact of differential crustal movement throughout the system. This work is completed by United States and Canadian federal agencies participating in the Coordinating Committee on Great Lakes Basic Hydrologic and Hydraulic Data. Water levels are measured accurately, despite technical differences in the sampling methods used by NOAA, USACE and DFO to generate hourly water level values.

The NOAA and DFO hourly observations are considered equivalent for calculation of lake-wide daily, monthly, yearly and long-term mean water levels. While hourly values generated at an individual gauge are reported to the nearest millimeter, the lake-wide daily, monthly, yearly and long-term period of record levels are generally reported to the nearest centimeter only. Since the lake mean water levels are adjusted averages of many individual stations, they have significantly greater accuracy.

Uncertainty in Great Lakes levels may range from 0.002 to 0.011 feet (0.06 to 0.03 centimeters). If the uncertainty for levels is 0.006 feet for each lake, for example, then the amount of lake storage associated with this uncertainty is 5.3, 7.5, 1.7 and 1.2 billion cubic feet (0.15, 0.21, 0.05 and 0.03 billion cubic meters), for lakes Superior, Michigan-Huron, Erie, and Ontario, respectively. The uncertainty and storage figures for Lake Michigan-Huron equate to an inflow of 2,900 cfs (80 cms), assuming a 30-day month. This is about 90 percent of the Lake Michigan Diversion and about 1.5 percent of the average St. Clair River flow.

Gauged Streamflow

As noted above, streamflows are generally determined by measuring water level elevations at a stream gauge site, and then converting these levels to flows using a stage-discharge relationship established at the site based on field measurements. Uncertainty in gauged streamflow derives primarily from the stage discharge relationship. Periodic field measurements are used to verify or update this relationship, which is used in the computation of continuous, daily and annual flows. Some gauging locations have a stable stage discharge relationship, whereas others do not. The accuracy of the relationship is dependent upon natural factors that cannot be altered, such as channel stability, and ones that vary seasonally, such as vegetation and ice. Since the stage-discharge relationships are established based on instream flow measurement, the accuracy of the relationship is generally lower during periods of very high or very low flows and when ice is present.

Uncertainty in gauged streamflow can range from 5 percent to 15 percent. For an average-size stream that has a long-term annual mean flow of 200 cfs, a period-of-record peak flow of 5,500 cfs, a period-of-record low flow of 3 cfs, and an uncertainty of 10 percent, these flows may have uncertainties of 20 cfs, 550 cfs, and 0.3 cfs, respectively.

Total gauged annual mean streamflow to Lake Michigan is about 30,000 cfs (850 cms). An uncertainty of 10 percent results in a potential uncertainty of 3,000 cfs (85 cms). This is about 94 percent of the average outflow of the Lake Michigan Diversion and about 1.6 percent of the average St. Clair River flow. A flow of 3,000 cfs results in a change of 0.18 feet (5.5 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Ungauged Streamflow

Uncertainty in ungauged streamflow derives primarily from differences between rainfall-runoff characteristics in a gauged watershed and an adjacent ungauged watershed. This uncertainty can be reduced by employing an estimation method that incorporates watershed characteristics, rather than relying upon simple drainage area-runoff relationships. There is also uncertainty in using the streamflow of the gauged watershed to calculate streamflow in the ungauged watershed.

Uncertainty in ungauged streamflow cannot be computed with precision, but exceeds the uncertainty of gauged streamflow. For an average-size ungauged stream with a drainage area of 350 square miles (910 square kilometers), a long-term annual mean flow of 200 cfs (5.7 cms), and an uncertainty of 15 percent, this flow may have an uncertainty of 30 cfs (0.9 cms).

Total ungauged streamflow to Lake Michigan is about 9,000 cfs (255 cms). An uncertainty of 15 percent results in a potential uncertainty of 1,350 cfs (38 cms). This is about 40 percent of the average outflow of the Lake Michigan Diversion and about 0.7 percent of the average St. Clair River flow. A flow of 1,350 cfs results in a change of 0.08 feet (2.5 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Groundwater

The amount of groundwater that discharges directly into the Great Lakes and connecting channels has not been calculated and is unknown. In fact, the subsurface areas that contribute groundwater flow to the Great Lakes or their tributary streams have not been delineated. However, the amount of groundwater that discharges directly to the Great Lakes is likely a small percentage of the total inflows for each lake.

Grannemann and Weaver (1999) roughly estimated groundwater discharge to Lake Michigan to be about 2700 cfs (75 cms), or 3 percent of the lake's inflows. A groundwater discharge to Lake Michigan of 2700 cfs is about 84 percent of the average for Lake Michigan-Huron after equilibrium is achieved.

Groundwater that discharges to tributary streams – indirect groundwater discharge to the Great Lakes – is accounted for in streamflow calculations. Therefore, it is not necessary to discuss the relationship of uncertainty to lake-wide levels and flows. For predicting the effects of proposed groundwater withdrawals on streamflow, however, the magnitude, timing and uncertainty of indirect groundwater discharge, also called baseflow, must be understood.

Uncertainties in baseflow calculations have not been quantified; this is an area of ongoing research. Assuming that the uncertainty in the baseflow component of streamflow is greater than the uncertainty of streamflow, it may range from 10 percent to 20 percent for a gauged stream. An average-size stream that has a flow of 200 cfs (6 cms), of which 70 percent is baseflow, will have a potential uncertainty in baseflow of 14 cfs to 28 cfs (0.4 cms to 0.8 cms). For comparison, a typical domestic well has a capacity of 0.002 cfs, a municipal or irrigation well has a capacity of 1 cfs, and a medium-sized community withdraws 10 cfs. Note that these withdrawal amounts are smaller than the uncertainty associated with the flow of an average-size stream.

Precipitation

Uncertainty in precipitation over the Great Lakes derives from: 1) measurement uncertainty at rain gauges; 2) differences between precipitation over the lakes and over the land, where rain gauges are located; and 3) the interpolation method used to calculate precipitation over the lakes. Potentially, the use of weather radar (NEXRAD in the U.S. and the MSC radar network in Canada) to calculate precipitation over the lakes would do away with the latter two sources of uncertainty, but introduces new ones inherent to the weather radar technology.

Uncertainty in precipitation over the Great Lakes is generally believed to range from 15 percent to 60 percent. If the uncertainty for precipitation on lakes Superior, Michigan, Huron, Erie and Ontario is 40 percent, then uncertainties would be 28,500 cfs, 20,600 cfs, 22,000 cfs, 10,200 cfs and 7,210 cfs (810 cms, 585 cms, 625 cms, 290 cms and 205 cms), respectively.

Precipitation on Lake Michigan is calculated to average 51,600 cfs (1,460 cms). An uncertainty of 40 percent results in a potential uncertainty of 20,600 cfs (585 cms). This is about 6.4 times the average outflow of the Lake Michigan Diversion and about 11 percent of the average St. Clair River flow. A flow of 20,600 cfs results in a change of 1.3 feet (40 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Evaporation

Uncertainty in evaporation from the Great Lakes derives primarily from: 1) measurement uncertainties in the parameters used to calculate evaporation – lake-surface temperature, air temperature, wind speed, and relative humidity; 2) the thermodynamic model used to calculate evaporation; 3) unaccounted for lake-surface-area variations caused by waves; and 4) spatial averaging of parameters and model calculations. The recent use of remote sensing to measure lake-surface temperatures reduces the uncertainty of this measurement and the uncertainty associated with its spatial averaging.

Uncertainty in evaporation from the Great Lakes is generally believed to range from 15 percent to 60 percent. If the uncertainty for evaporation from lakes Superior, Michigan, Huron, Erie and Ontario is 40 percent, then uncertainties may be 21,600 cfs, 16,500 cfs, 16,600 cfs, 10,300 cfs and 5580 cfs (610 cms, 465 cms, 470 cms, 290 cms and 160 cms), respectively.

Evaporation from Lake Michigan averages 41,200 cfs (1,165 cms). An uncertainty of 40 percent results in a potential uncertainty of 16,500 cfs (465 cms). This is about 5.2 times the average outflow from the Lake Michigan Diversion and about 8.8 percent of the average St. Clair River flow. A flow of 16,500 cfs results in a change of 1.0 foot (30 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Niagara Falls

Connecting Channels

Uncertainty in connecting channel flows derives from the various methods used to compute different flows, including stage-fall-discharge relationships, water-control structure ratings, turbine ratings at hydroelectric facilities, and lock use and leakage through these structures. The uncertainty of stage-fall- discharge relationships depends upon accurate stage measurements, sufficient fall of the stage over the reach for which discharge is being calculated, and periodic measurements of discharge to update and verify the relationship. Since stage-discharge relationships are developed for open-water, ice-free, vegetation-free conditions, flow estimates must be adjusted to account for these factors, whenever appropriate. The uncertainty of flows through turbines depends upon the accuracy of the turbine rating and the availability of flow measurements to update and verify the ratings. Generally, newer turbines can be assumed to have a more accurate rating than older turbines. The uncertainty of flow through locks by use or leakage depends upon the accuracy of the calculation of lock volume, the amount of use, and the frequency and accuracy of field measurements of lock leakage. Sources of uncertainty in the flows of the connecting channels and St. Lawrence River are discussed by Gauthier et al. (2003).

The uncertainty of connecting channel flows has not been rigorously calculated for all connecting channels. Uncertainties for the St. Marys River, St. Clair River, Niagara River, and Lake Ontario average outflows may be 10 percent, 10 percent, 5 percent and 3 percent, respectively. Potential uncertainties for average flows of these connecting channels, therefore, may be 7,600 cfs, 18,200 cfs, 10,300 cfs and 7,390 cfs (215 cms, 535 cms, 290 cms and 210 cms), respectively.

The average outflow from Lake Michigan-Huron by way of the St. Clair River is 182,000 cfs (5,155 cms). During extreme conditions, flows have been recorded as high as 232,000 cfs (6,570 cms) and as low as 106,000 cfs (3,000 cms) per month. An uncertainty of 10 percent in computing the average St. Clair River flows results in a potential uncertainty of 18,200 cfs (515 cms). This is about 5.9 times the average outflow of the Lake Michigan Diversion. A flow of 18,200 cfs results in a change of 1.2 feet (36 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Diversions

Uncertainty in diversions derives from the various methods to compute flows. Sources of uncertainty in the flows of the Lake Michigan, Long Lac and Ogoki diversions are discussed below. Sources of uncertainty in the flows of the remaining diversions are discussed by Gauthier et al. (2003).

Lake Michigan Diversion at Chicago, Illinois

Water has been diverted from Lake Michigan at Chicago, Illinois, since 1848, with subsequent changes in the flow volume, control structures and accounting procedures. Since 1981, the diversion outflow has been managed in accordance with a U.S. Supreme Court Decree that limits flows to 3,200 cfs (90.6 cms), averaged over a 40-year period. Uncertainty in the Lake Michigan Diversion derives mostly from: 1) the accuracy of the acoustic flow meters placed in the system; 2) velocity-discharge relationships; 3) the rainfall-runoff models; and 4) calculations of groundwater return flow.

The uncertainty of the Lake Michigan Diversion may range from 5 percent to 15 percent.

An uncertainty of 10 percent results in a potential uncertainty of 340 cfs (10 cms), which is about 0.2 percent of the average St. Clair River flow. A flow of 340 cfs results in a change of 0.02 feet (6 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Long Lac Diversion

The Long Lac Diversion connects the headwaters of the Kenogami River (which originally drained north through the Kenogami and Albany Rivers into James Bay) with the Aguasabon River, which naturally discharges into Lake Superior. As a result, it diverts the runoff from about 1690 square miles (4375 square kilometers) directly into Lake Superior. The volumes of the Long Lac Diversion are measured and reported by Ontario Power Generation Inc. (OPG). Discharges through the Long Lake Control Dam to the Aguasabon River are determined based on the current sluice-rating table for the structure. OPG verifies and updates the sluice-rating table on a periodic basis using accepted engineering practices.

The uncertainty of the Long Lac Diversion is similar to that of gauged streamflow and may range from 5 percent to 15 percent, but is most likely closer to the lower value. An uncertainty of 10 percent results in a potential uncertainty of 140 cfs (4 cms), which is about 0.09 percent of the average St. Clair River flow. A flow of 140 cfs results in a change of less than 0.01 feet (0.3 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Ogoki Diversion

The Ogoki Diversion connects the upper portion of the Ogoki River (which originally drained through the Albany River into James Bay) with the headwaters of the Little Jack River, which flows into Lake Nipigon and, from there, through the Nipigon River into Lake Superior. The Waboose Dam on the Ogoki River impounds water that would normally flow northward in the Ogoki reservoir and redirects it southward into Lake Nipigon. The Summit Dam controls the rate of the diversion from the Ogoki reservoir into Lake Nipigon. Although the long-term average outflow from the Ogoki reservoir into Lake Nipigon has been about 4020 cfs (115 cms), monthly diversions have varied from 0 cfs to 15,000 cfs (0 cms to 425 cms).

The quantity of water diverted from the Ogoki River in any month is not necessarily representative of the quantity reaching Lake Superior for the same month. This is due to the water being stored in Lake Nipigon for later release through the power plants during fall and winter months when inflows are lower. Therefore, uncertainties related to the Ogoki Diversion must be viewed in two ways: 1) uncertainty in the amount of water diverted from the Ogoki River into Lake Nipigon, which represents the short- and long-term diversions to the Great Lakes basin; and 2) the amount of water diverted to Lake Superior on a monthly basis.

A question is occasionally raised as to whether or not all of the water diverted into Lake Nipigon from the Ogoki River reaches Lake Superior. While a precise answer is not available, it is believed that, if losses do occur, they are likely within the quantitatively identified measurement accuracy. Discharges from the Ogoki reservoir to Lake Nipigon are determined based on a stage-discharge relationship. OPG verifies and updates the stage-discharge relationship though periodic field measurement to accepted standards. The stage-discharge relationship used for the Ogoki diversion has remained stable over time. Therefore, the uncertainty for both the daily and monthly flow values reported for the diversion from the Ogoki River to Lake Nipigon, and the resulting long-term average diversion into Lake Superior, is similar to any other gauged streamflow site, ranging from 5 percent to 15 percent, but very likely closer to the lower value. An uncertainty of 10 percent results in a potential uncertainty of 400 cfs (11 cms), which is about 0.2 percent of the average St. Clair River flow. A flow of 400 cfs results in a change of 0.03 feet (0.9 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved.

Discussion

Potential uncertainties associated with different components of the hydrologic cycle translate into large quantities of water, some much larger than others. For instance, uncertainties in precipitation on Lake Michigan-Huron are estimated to be plus or minus 40,000 cfs (1,130 cms), whereas uncertainties in the Lake Michigan Diversion are estimated to be plus or minus 300 cfs (8 cms), as shown in Figure 2-12.

When considering flows on a systemwide scale, diversions are very small. Clearly they are much smaller than the magnitude of major hydrologic

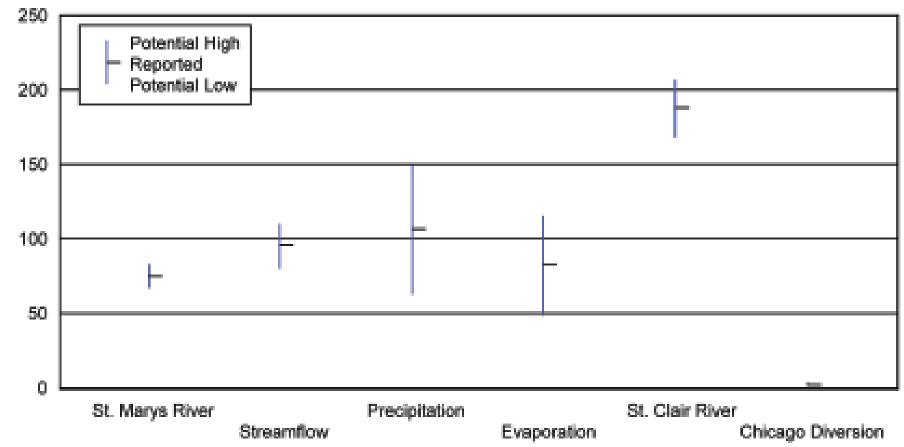

Figure 2-12
Potential uncertainties in flows to and from lakes Michigan-Huron

components, including streamflow, precipitation, evaporation and connecting channel and St. Lawrence River outflows shown in Figure 2-13.

On a lake-wide or systemwide scale, potential uncertainties are much larger than any current withdrawal. Even the flow impacts of large, new withdrawals, for example, likely would not be detected by measurement of a connecting channel flow or a lake level because of natural variability in the system and potential uncertainties in measuring or computing flows. However, while this effect is unlikely to be detected by direct measurement, the impact of removing water from the system can be predicted to some extent. Current hydrologic models of the Great Lakes system can predict how withdrawals will change supplies to each of the lakes, and thus, lower lake levels, reduce connecting channel flows, or reduce hydroelectric generation. The accuracy of the predicted effect of a withdrawal is limited only by the accuracy with which the model simulates the physical system.

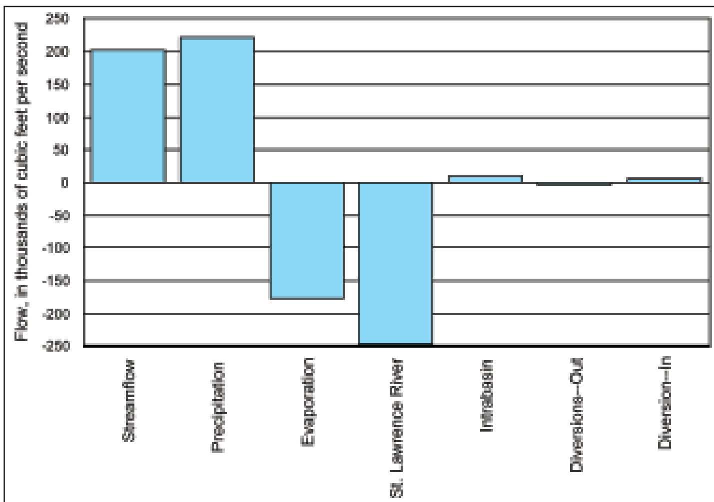

Figure 2-13
Flows into and from the Great Lakes

Findings and Recommendations

The many findings and recommendations in this section have four cross-cutting themes. First, a binational coordination framework needs to be established for collecting, analyzing, reporting and accessing Great Lakes hydrologic and hydraulic data. Second, uncertainties in levels and flows have not been quantified. Third, a formal and robust evaluation of current monitoring should be undertaken with the goals of quantifying data gaps and making specific recommendations to reduce uncertainties. Fourth, all recommendations assume an increased quantity and quality of monitoring and reporting. The need for resources to carry out this work is implicit.

Findings

Although a significant amount of hydrologic monitoring occurs in the Great Lakes basin, current efforts target specific needs that do 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, data are not available for all flows on a binational basis; coordination between U.S. and Canadian jurisdictions on 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.

Decisionmakers do not always understand or 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 systemwide 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.

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.**

   The evaluation should include specific additions to or modifications of current networks, as well as changes to operating and reporting methods.

2. **Secure agency commitments to core, long-term, geographically distributed hydrologic/hydraulic monitoring that will be needed to implement the decisionmaking standard.**

   Sustained investment in hydrologic/hydraulic monitoring networks and programs is crucial to assessing cumulative impacts of withdrawals. Continual records of levels and flows throughout the system have long-term strategic value for protection of the resource and, as such, their availability needs to be factored into the design of a decision support system.

3. **Support the continued maintenance and enhancement of the Great Lakes water level gauging network, and quantify and report uncertainties.**

   Substantial improvements have been made to instrumentation and reporting methods from U.S. water level gauging stations over the last few years, but not all data are collected and distributed uniformly or in a timely manner. Analysis should be conducted to quantify and report on uncertainties related to instrumentation accuracies, sampling methodologies, and reporting between U.S. and Canadian sites, with the objective of reducing differences and uncertainties.

4. **Develop coordinated binational methods for evaluating groundwater flow directly and indirectly to the Great Lakes-St. Lawrence River system using common data standards and models.**

   A conceptual model of groundwater flow and associated mapping tools for the Great Lakes basin should be developed that includes known groundwater divides, identifies and prioritizes data needs, and identifies locations and quantities of groundwater discharge directly to the Great Lakes. Research should be focused on developing relationships between direct groundwater discharge and adjacent nearshore aquatic ecosystems. Standardized methods should be developed between countries for computing indirect groundwater discharge to tributary streams and coordinate results.

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.**

   The assessment of the adequacy of existing streamflow gauging networks should include quantification of uncertainties, identification of optimum gauging locations, and recommendations of core networks to meet Annex needs. Determination of streamflow for ungauged watersheds should be based upon coordinated methods between countries that make maximum use of known surface runoff characteristics and flow processes, including calculations of associated uncertainties.

6. **Develop coordinated binational methods, with measures of uncertainty, for calculating over-lake precipitation and evaporation processes using existing remote sensing techniques.**

   Over-lake precipitation can be estimated from ground-based radar systems in the United States and Canada. This will require a significant commitment of funds for applied research. Improvements in evaporation estimates are also possible, using satellite observations of water surface temperatures, ambient air temperatures and other related meteorologic parameters, as input to new-generation thermo-dynamic models.

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.**

   These may include use of hydrodynamic flow models, permanent installation of acoustic flow meters, and/or more frequent direct measurements of flow to support calculations. Since instrumentation and models are subject to frequent changes in technology, the efficiency and accuracy of accepted methods need to be periodically evaluated. The standards need to be flexible enough to be adapted to all hydraulic situations, particularly since channel modifications can occur through natural physical processes or human intervention. Flows in diversion canals also can be affected by changes in maintenance over time.

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.**

   Complex hydrologic/hydraulic processes can be simplified via computer modeling, while providing substantial visualization abilities. Computer models should be accessible via the Internet, with model inputs and outputs well documented and readily available for wide application.

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.**

   Data and information should be coordinated regularly so that it is current. The collection and coordination of hydrologic data and information relevant to the Annex should be carried out by agencies under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

10. **Ensure easy access to hydraulic/hydrologic data for decisionmakers and other interested parties via clearinghouse services, and conventional and electronic communications technology.**

    Access can be enhanced by development of a comprehensive Internet clearinghouse, coordination of web pages from primary data sources, and promotion of consistent data and metadata that can be used in a geographic information system (GIS). Metadata is descriptive information about data that typically addresses its lineage, quality, condition, or characteristic. Sensitive information (proprietary, personal and security) will need to be protected and managed accordingly.

Information Use

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

The uncertainty and variability of levels and flows assessed on a Great Lakes basin-wide scale will differ significantly from those assessed at a sub-watershed or individual stream basis. A withdrawal from an individual watershed should not therefore be assessed based on information compiled at the Great Lakes basin level. Data, information and measures of uncertainties at the appropriate temporal and spatial scale are extremely important to the decisionmaking process.

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Chapter Three

Inventory of Water Withdrawal and Use Data and Information

Introduction

An inventory of water withdrawal and use data and information in the Great Lakes-St. Lawrence River basin is a key component of the Water Resources Management Decision Support System project. This effort included an assessment of the latest available water use data as it relates to withdrawals, in-stream uses, diversions and consumptive use. A Water Withdrawal and Use Technical Subcommittee was established to provide guidance and oversight to Great Lakes Commission staff in the conduct of this project element. This chapter describes the outcomes of its work by focusing on the background and history of regional water use data collection and reporting activities; describing state and provincial programs for water withdrawal data collection, consumptive use and demand forecasting; and examining how the states and provinces have addressed commitments embodied in the Great Lakes Charter.

Background and History of Water Use Data Collection and Reporting

States, provinces and municipalities of the Great Lakes-St. Lawrence River region have a long history of water resources management, with a primary focus on manipulating freshwater supplies to meet the growing and ever-evolving needs of residents, businesses and other water use sectors.

Increasingly, across North America, many existing sources of water are being depleted or otherwise stressed by withdrawals from aquifers, lakes, rivers and reservoirs to meet these needs. While the Great Lakes-St. Lawrence River region has been largely immune from serious systemwide water shortages, conflicts and supply problems, individual watersheds are increasingly seeing such problems (on a short-term or extended basis) and the attendant ecological, economic and quality of life impacts.

To generate a sense of how water resources are used, the U.S. Geological Survey (USGS) has compiled and disseminated estimates of water use for the United States at five-year intervals since 1950. In 1977, the U. S. Congress expanded USGS water use activities by establishing a National Water-Use Information Program which, in cooperation with the states, collects reliable and uniform nationwide information on the sources, uses and management of water (see Figure 3-1).

The Great Lakes states work closely with the USGS through its National Water-Use Information Program. However, the concept of a region-

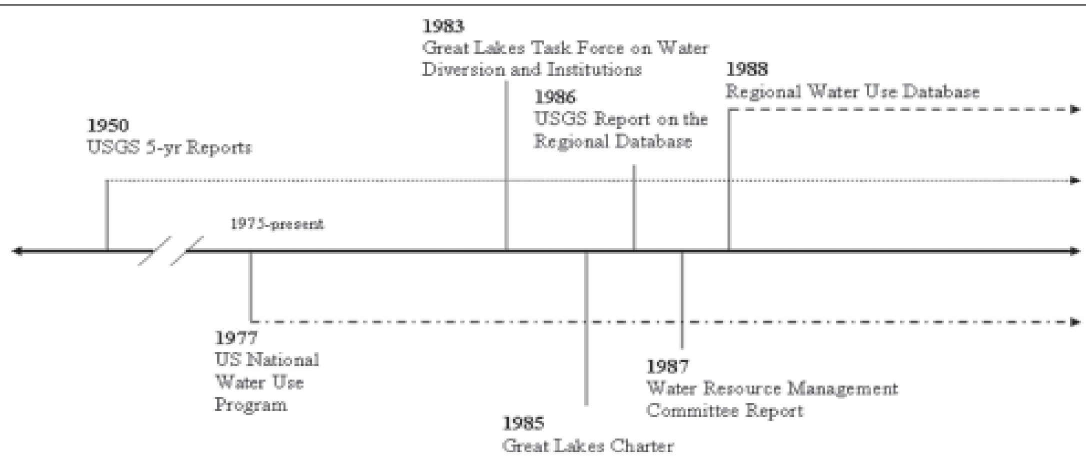

Figure 3-1
Timeline of Great Lakes water use data collection and reporting

specific, binational data system on water withdrawals, diversions and consumptive use has long been of interest to the region's policymakers, managers and scientists.

This interest was heightened in the early 1980s with growing concerns about the vulnerability of the Great Lakes-St. Lawrence River system to harmful large-scale out-of-basin diversions. To address this growing concern, the Great Lakes governors and premiers appointed a Task Force on Water Diversion and Great Lakes Institutions in 1983 to study the issue and offer recommendations. Its report, submitted in January 1985, spoke to the need to protect the water resources of the Great Lakes-St. Lawrence River system by enhancing program and institutional capabilities. The task force was particularly concerned over the state of technical information on water withdrawal and use, stating that "the kind of reliable, comparable water use data needed to accurately project future needs or to forecast 'significant impacts' are not available now."

The centerpiece of the task force's efforts was the development of the Great Lakes Charter, signed by the Great Lakes governors and premiers in 1985. A non-binding "good faith" agreement, the Charter provides the principles and framework for strengthening water management activities in the binational Great Lakes-St. Lawrence River system. Among other items, it calls for the establishment of a regional water use database and arrangements for exchanging and comparing water use data and information.

Coinciding with Charter development and implementation were other state/provincial efforts to describe and document their individual water use data collection and reporting programs and to explore opportunities to establish a consistent regional approach to water management. In 1985, for example, the Great Lakes Commission formed a Water Data Collection Task Force to evaluate regional data collection efforts. Through a survey process, this task force determined the extent of withdrawal, return flow and water consumption data in the states and provinces, and also assessed the compatibility of the data. The results were published in an October 1985 report by the Great Lakes Commission titled *Survey and Preliminary Evaluation of the Existing Water Use Data Collection Systems in the Great Lakes States and Provinces.*

Further, in an extensive 1985-86 study undertaken with input from the Council of Great Lakes Governors' Water Resources Management Committee, the USGS examined and compared Great Lakes state and provincial data for nine water use categories. A December 1986 report titled *Water Use Data Collection Programs and Regional Data Base in the Great Lakes-St. Lawrence River Basin States and Provinces* influenced the subsequent design of the Great Lakes Regional Water Use Database.

Following the signing of the Great Lakes Charter, a Water Resources Management Committee (WRMC) was established through the Council of Great Lakes Governors to achieve the objectives of the Charter. In a February 1987 report to the governors and premiers, the WRMC recommended that the Great Lakes Commission serve as the repository for a regional water use database to store, aggregate, manipulate and display state/provincial water withdrawal, diversion and consumptive use data for multiple categories of use.

The Great Lakes Regional Water Use Database became operational in mid-1988. Database maintenance and operation has been provided by the Great Lakes Commission since that time in partial fulfillment of Great Lakes Charter obligations.

Charter Minimum Requirements for Water Use Programs and Data Reporting

The Great Lakes Charter of 1985 provides a regional framework for water resources management with the intent of protecting the Great Lakes region from ill-advised diversion and consumptive use proposals and their deleterious impacts on the region's ecological and economic health. It presents a series of five water management principles along with general guidelines for their implementation. Among others, an important recommendation provided for the development and maintenance of a regional water use database and the minimum requirements under which the database should operate. These guidelines were reaffirmed and expanded upon in the 1987 WRMC report, titled *Managing the Waters of the Great Lakes Basin.*

The Charter describes, in general terms, the types of data and information to be collected and exchanged among jurisdictions and a compliance mechanism to ensure jurisdictional participation. Under the "Implementation of Principles" section, the Charter presents three components to a common base of data.

1. *Each State and Province will collect and maintain, in comparable form, data regarding the location, type, and qualities of water use, diversion, and consumptive use, and information*

regarding projections of current and future needs.

2. *In order to provide accurate information as a basis for future water resources planning and management, each State and Province will establish and maintain a system for the collection of data on major water uses, diversions, and consumptive uses in the Basin. The States and Provinces, in cooperation with the Federal Governments of Canada and the United States and the International Joint Commission, will seek appropriate vehicles and institutions to assure responsibility for coordinated collation, analysis, and dissemination of data and information.*

3. *The Great Lakes States and Provinces will exchange on a regular basis plans, data, and other information on water use, conservation, and development, and will consult with each other in the development of programs and plans to carry out these provisions.*

Under the "Progress Toward Implementation" section, the Charter specifies a sequence of steps to be taken to implement the Charter and develop a Basin Water Resources Management Program. Among these are basic requirements in water use data collection and exchange activities that jurisdictions must complete in order to participate in the prior notice and consultation process.

> *The prior notice and consultation process will be formally initiated following the development of procedures by the Water Resources Management Committee and approval of those procedures by the Governors and Premiers. Any State or Province may voluntarily undertake additional notice and consultation procedures, as it deems appropriate. However, the right of any individual State or Province to participate in the prior notice and consultation process, either before or after approval of formal procedures by the Governors and Premiers, is contingent upon its ability to provide accurate and comparable information on water withdrawals in excess of 100,000 gallons (380,000 litres) per day average in any 30-day period and its authority to manage and regulate water withdrawals involving a total diversion or consumptive use of Great Lakes Basin water resources in excess of 2,000,000 gallons (7,600,000 litres) per day average in any 30-day period.*

Charter Objectives for a Regional Water Use Database

The Great Lakes Charter calls for development of a common, regional database as a principal tool for regional water resources management. In its 1987 report, the WRMC presented recommendations for data collection and management, laying out the objectives of a regional information system:

> *The establishment of a regional water-use database will assist management efforts by providing:*
>
> - *the states and provinces, and federal and international agencies with better basic information that can be applied to development of a water budget for the Great Lakes Basin;*
> - *a more accurate base of data on present in-basin uses from which to project future in-basin demands;*
> - *consistent, and, to the extent possible uniform regional water-use data so that the uses and needs of individual jurisdictions may be compared and evaluated;*
> - *a better understanding of the extent to which the cumulative effects of small-scale diversions and consumptive uses of Great Lakes water may affect lake levels and flows;*
> - *information on which to base regional decisions relating to consumptive uses; and*
> - *more accurate data to be applied to future research of the relationship between levels and flows and water use in the Basin.*

In its present form, the Great Lakes Regional Water Use Database meets most, but not all objectives. Among others, limitations of data as well as the lack of a scientific basis to perform such necessary analyses, compromise its utility.

Lake Michigan dunes with power plant in background

Water Resources Management Programs Related to Water Withdrawal and Use

Many state and provincial water resources management programs in the Great Lakes-St. Lawrence River region trace their origin to the 1985 Great Lakes Charter. However, for many years prior, the states and provinces have maintained a variety of independent water use data collection, storage and retrieval systems that have been adapted to meet Charter reporting requirements for withdrawals, uses, and diversions.

Progress Made on Charter Data Reporting Processes

The Charter commits the states and provinces to collect data on all water withdrawals in excess of 100,000 gallons (380,000 litres) per day in the interest of supporting its prior notice and consultation process. In practice, however, this requirement has not been emphasized, with a resultant lack of consistency among jurisdictions in Charter implementation.

Table 3-1 presents an assessment of jurisdictional efforts to fulfill Charter commitments for water use data collection programs. This information was collected by surveying members of the Water Withdrawal and Use Technical Subcommittee, who were asked to rate how well their jurisdictions have met their commitments to two key Charter requirements: 1) collect accurate and comparable information for withdrawals in excess of 100,000 gallons (380,000 litres) per day average in any 30-day period and 2) report collected data for the agreed-to categories of use to the Regional Water Use Database Repository annually.[1] The members rated their jurisdictions' fulfillment of Charter commitments according to the legislative and/or regulatory authority to cover water withdrawals within the water use category (legislative/regulatory fulfillment scale) and the implementation effort to provide the required water use data collection and reporting commitments for the water use category (implementation fulfillment scale). Ratings are based on a conventional five-point scale, from "0" meaning no legislative/regulatory authority or implementation effort to "4" meaning full legislative/regulatory authority or implementation effort. This information, while somewhat subjective, is helpful in identifying water withdrawal and use data gaps and information needs.

Several conclusions may be drawn from survey results. About half of the members indicate that their jurisdiction is presently able to fulfill Charter commitments in both legislative/regulatory authority and implementation effort for almost all water use categories. The balance indicate that their jurisdiction is presently able to partially fulfill commitments through legislative/regulatory authority or implementation effort. In most instances, constraints are found in implementation efforts, suggesting inadequate resources to carry out the reporting. Among all jurisdictions, the weakest water use categories for data collection appear to be self-supply domestic, irrigation and livestock.

Technical subcommittee members expressed some difficulty in rating their jurisdictions' performance for the hydroelectric power category due to several unique considerations. Major hydroelectric uses along the St. Lawrence and Niagara Rivers, where most of the quantity of hydroelectric water use occurs, are monitored much more closely than many of the smaller operations, and jurisdictions can generally use federal data for the regional database. For smaller hydroelectric uses, some states, such as Indiana, use electricity generation data collected from the U.S. Federal Energy Regulatory Commission to calculate water use. New York, on the other hand, does not make these calculations because it has more small hydroelectric users and the process would be more time consuming.

States and provinces also report differently on instream hydroelectric uses. Ohio does not report instream uses because it considers them to be incidental uses, while some other jurisdictions do include these uses in their data reports. All states and provinces report offstream uses, which involve temporary storage of water so electricity can be generated to meet peak loads, but not many jurisdictions have these uses. Other water use categories have unique considerations that point to a general need for clarifying water use category definitions and determining whether categories should be reclassified.

[1] This second requirement is not stated explicitly in the 1985 Great Lakes Charter. The Charter mandated the formation of a Water Resources Management Committee to develop and design a system for the collection and exchange of comparable water resources management data. The Water Resource Management Committee recommended, in its 1987 report to the governors and premiers, that the jurisdictions provide collected data to the regional database repository annually. In return, the centralized repository would develop annual reports.

Table 3-1
Fulfilling Data Collection Commitments Under the Great Lakes Charter
~Self Assessment by Jurisdiction~

Water Use Category	Illinois		Indiana		Michigan		Minnesota		New York		Ohio		Ontario		Pennsylvania		Quebec		Wisconsin	
	L	I	L	I	L	I	L	I	L	I	L	I	L	I	L	I	L	I	L	I
Public Supply	4[1]	4	4	4	4	4	4	4	4	1	4	4	4	3	4	4	4	0	4	4
Domestic	1	4	4	4	0	0	4	4	4	1	4	4	4	3	2	2	4	0	4	0
Irrigation	N	N	4	4	1[3]	4	4	4	4	1	4	4	4	3[4]	4	2	4	0	4	0
Livestock	N	N	4	4	0	0	4	4	4	1	4	4	0	3[4]	4	0	4	0	4	0
Industrial	4	4	4	4	4	4	4	4	4	2	4	4	4	3[4]	4	4	4	0	4	3
Fossil Fuel	4	4	4	4	4	4	4	4	4	3	4	4	4	4	N	N	4	4[5]	4	4
Nuclear	4	4	N	N	4	4	N	N	4	4	4	4	4	4	N	N	4	N	4	4
Hydroelectric	N	N	0	4[2]	0	0	4	4	4	3	N	N	4	3	N	N	4	4[5]	4	4
Other	4	4	3	4	N	N	4	4	4	1	4	4	4	3	4	4	4	0	4	0

1. Illinois' watershed drains to Lake Michigan and covers a relatively small area. Most of it is served by established public water supplies and, therefore, there are very few self-suppliers.
2. Indiana does not have the regulatory authority to require water usage reporting from hydroelectric power plants, but has provided the information voluntarily. Some of the data is also available online from the Energy Information Administration of the U.S. Department of Energy.
3. Michigan's water use reporting law requires annual reports from irrigated golf courses but not irrigated farms. For agricultural irrigation, the law directs the state to develop an estimation model. That model is now used to calculate agricultural irrigation water withdrawals on an annual basis – based upon irrigated acreage and crop type data reported every five years in the federal Census of Agriculture.
4. Ontario provides water use estimates based on census data (1991, 1996 and 2001) for irrigation, livestock and industrial water use. These categories are being reviewed to establish methodologies for more regular reporting.
5. For Québec, all data are available for self-supply thermoelectric and hydroelectric power but are not reported to the regional water use database annually.

Codes for Self Assessment of Data Collection and Reporting Programs
L - Legislative/Regulatory Fulfillment Scale
I - Implementation Fulfillment Scale
N - No water use occurs in this category within the Great Lakes-St. Lawrence River basin
4 - Covers total quantity of water withdrawals for the required data collection and reporting programs
3 - Covers approximately 2/3 or more of the total water withdrawal quantity for the required data collection and reporting programs
2 - Covers approximately 1/3 to 2/3 of the total water withdrawal quantity for the required data collection and reporting programs
1 - Covers approximately 1/3 or less of the total water withdrawal quantity for the required data collection and reporting programs
0 - No legislative/regulatory authority within this water use category

Chicago shoreline, looking at the Chicago River Lock and Controlling Works – a component of the Lake Michigan Diversion

State and Provincial Programs, Regulations, Statutes and Authorities

A survey of state/provincial water resources management programs shows that, while jurisdictional water use data collection and reporting programs are similar in some ways, they have evolved differently and are unique in their development and function. (See project report titled, *Report on State and Provincial Water Use and Conservation Programs in the Great Lakes-St. Lawrence Basin.)* Most jurisdictions use either a water withdrawal registration approach or a permitting system that allows for data collection for facilities in many water use categories that withdraw or have the capacity to withdraw 100,000 gallons (380,000 litres) of water per day averaged over a 30-day period. A few jurisdictions also collect data or have requirements at lower withdrawal rates.

Survey information compiled under the project suggests that the region is moving in the right direction, albeit slowly, in developing coordinated programs for water use data collection and reporting. According to a USGS report (Snavely, 1986), data collection programs in the mid-1980s relied primarily on estimated data, and the states and provinces used different water use categories. Significant progress has been made since that time. Currently, annual data submitted by jurisdiction to the Great Lakes Regional Water Use Database fit within prescribed categories of public supply, self-supply domestic, self-supply irrigation, self-supply livestock, self-supply industrial, self-supply thermoelectric (fossil fuel), self-supply nuclear, hydroelectric and "other." A summary of the state and provincial programs (and associated authorization) is presented below. Tables 3-2 and 3-3 also provide summary program information.

Illinois

The state's Level of Lake Michigan Act (615 ILCS 50) allows the Illinois Department of Natural Resources (DNR), Lake Michigan Management Section to allocate Lake Michigan withdrawals allowed under a 1967 U.S. Supreme Court Decree. The DNR's administrative code, which outlines the process involved in issuing these permits, is found in Title 17 Chapter I (h) Part 3730, "Allocation of Water from Lake Michigan." The Lake Michigan Management Section receives monthly data from the 21 facilities that take water directly from Lake Michigan. The 200 permittees that use the water must report metered annual water use. No allocation permits are required for water coming from non-Lake Michigan sources, but the Illinois State Water Survey conducts annual surveys of public water suppliers and industrial facilities using more than 70 gallons per minute (100,800 gallons, or 381,500 litres, per day). Water use data is available from a combination of facility reports and estimates.

Indiana

Indiana's Water Resource Management Act (Indiana Code 14-25-7), enacted in 1983, requires registration of facilities with a withdrawal capacity of more than 100,000 gallons (380,000 litres) per day. The Indiana Department of Natural Resources (DNR), Division of Water collects annual data for all water use categories. Authority for data collection comes from Indiana Code 14-25-7 for all of the categories but hydroelectric power generation. Indiana's four hydroelectric facilities voluntarily provide data; the state has no nuclear facilities. Facilities estimate their total water use for the categories of public supply, self-supply irrigation, self-supply thermoelectric (fossil fuel), and hydroelectric. Facilities measure and estimate data for the self-supply industrial and "other" categories, and the state estimates the majority of the data for self-supply domestic and self-supply livestock uses.

Michigan

Water use reporting occurs through the Michigan Department of Environmental Quality's (MDEQ) Drinking Water and Radiological Protection Division. Under Public Act 451 of 1994, Part 327, industrial, power generation, and non-agricultural irrigation facilities that have the capacity to withdraw over 100,000 gallons (380,000 litres) of water in a 30-day period are required to register water withdrawals. As directed in Act 451, the MDEQ and state Department of Agriculture use a model to estimate agricultural irrigation water use. Public Act 399 of 1976, Part 15,

Table 3-2
Summary of Water Use Reporting Programs by Jurisdiction *

Jurisdiction	Agencies Involved (lead agency in bold)	Authorizing Laws/Regulations	Permit/ Registration (all water sources unless specified)	Public Participation in Permit Process	Total Principal Facilities	Percent Principal Facilities Reporting	Data Reporting Frequency	Data Compilation Methods	Consumptive Use Compilation Methods	Specificity of Primary Data to G.L Basin	Funding	Staffing
Illinois	**Department of Natural Resources**; State Water Survey	Level of Lake Michigan Act; Regulation Title 17 Chapter I (h), Part 3730; Voluntary Survey	Permits for Lake Michigan allocations (surface water)	Public hearings held for applications	33	N/A	Annual/ Monthly	Facility measured	N/A (all water consumed)	Yes	$80,000 (70 DNR, 10 Survey) (G.L Basin)	1.35 FTEs (1 DNR, 0.35 Survey) (G.L. Basin)
Indiana	**Department of Natural Resources**	Indiana Code 14-25-7: Water Resource Management Act	Registration for more than 100,000 g/day capacity	None	540	100	Annual	Facility/state measured or estimated	State estimated	No	$10,000 (estimate) (G.L. Basin)	0.2 FTEs (G.L. Basin)
Michigan	**Department of Environmental Quality**	Public Act 451 of 1994, Part 327 Public Act 399 of 1976, Part 15	Registration for public supply, some 100,000 g/day capacity	None	2,221	Nearly 100	Annual	Facility/state measured or estimated	Facility/state estimated	Yes	$53,000 (annual fees) (G.L. Basin)	0.9 FTEs (G.L. Basin)
Minnesota	**Department of Natural Resources**	Statute 103G.265 to 103G.315; Rules 6115.0600 to 6115.0810	Permits for use of more than 10,000 g/day or 1 million g/year	Local units given 30 days for comments	118	Nearly 100	Annual with monthly data	Facility measured	State estimated	No	From State General Fund	0.4 FTEs (G.L. Basin)
New York	**NYS Department of Environmental Conservation**; USGS; ACOE; NYSDOH	NYSECL 15-1609 and 15-1501, NYCRR Parts 675 and 601	Reg. for more than 100,000 g/day use; public supply permits	Water Supply Permit Program only	641	N/A	Annual/ Biennial	Measured or estimated	Measured or estimated	Partially	$35,367 (G.L. Basin)	0.65 FTEs (G.L Basin)
Ohio	**Department of Natural Resources, Division of Water**	Ohio Revised Code Sections 1521.15 and 1521.16	Registration for more than 100,000 g/day capacity	None	262	100	Annual	Measured and estimated	State estimated and facility measured	No	$19,410 (G.L. Basin)	0.3 FTEs (G.L. Basin)
Ontario	**Ministry of Natural Resources;** Ministry of Environment and Energy; Env't Canada	Ont. Water Res. Act: Sect. 34; Water Transfer and Taking Reg. 285/99. Other regs. may influence takings.	Permits for use of more than 50,000 L/day	Applications web posted for 30 days. Public can appeal decisions.	2,827	N/A	N/A	Measured and estimated	Province est. and facility measured (industrial)	Partially	No specific, stable funding	1 FTE (G.L. Basin)
Pennsylvania	**Department of Env'tal Protection's Bureau of Watershed Management**	Chapter 109.701 (b) Rules and Regulations; Administrative Code Section 1904-A(3)	Surface withdrawal permits for public supply	Public comment for public supply	26	N/A	Annual	Facility estimated or measured	State estimated/ fac. est. or measured	Yes	$6,700 (G.L. Basin)	0.1 FTEs (G.L. Basin)
Québec	Municipalities; Ministry of Agriculture and Fisheries; Industry; Hydro-Québec	Ministry of the Environment; Watercourses Act; Environment Quality Act; other ministries	Permit needed for public supply	Municipality gives public supply comments	171	70-100	When requested	Facility measured (industrial, electric only)	N/A (no systematic mechanism)	Only for hydro	$0	0 FTEs
Wisconsin	**Department of Natural Resources**	State Statute 281.35; Natural Resources 142, Administrative Code	Registration for more than 100,000 g/day use	None	414	100	Annual	Facility measured or estimated	Facility estimated	Yes	$14,000 (state-wide)	0.2 FTEs (state-wide)

*Based on status in 1998

Table 3-3
Summary Characterization of Water Use Permitting, Registration and Reporting Programs

<table>
<tr><th rowspan="2">Jurisdiction</th><th rowspan="2">Characteristic</th><th colspan="9">Water Use Category</th></tr>
<tr><th>Public Supply</th><th>Self-Supply Domestic</th><th>Self-Supply Irrigation</th><th>Self-Supply Livestock</th><th>Self-Supply Industrial</th><th>Self-Supply Thermoelectric</th><th>Self-Supply Nuclear</th><th>Hydroelectric</th><th>Other</th></tr>
<tr><td rowspan="6">Illinois</td><td>Permit/Reg.</td><td>Permit</td><td colspan="3">N/A</td><td>Permit</td><td colspan="3">N/A</td><td>Permit</td></tr>
<tr><td>Water Source</td><td>Surface</td><td colspan="3">-</td><td>Surface</td><td colspan="3">-</td><td>Surface</td></tr>
<tr><td>Threshold</td><td>All</td><td colspan="3">-</td><td>All</td><td colspan="3">-</td><td>All</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td colspan="3">-</td><td>All</td><td colspan="3">-</td><td>All</td></tr>
<tr><td>Req'd Reporting</td><td>Yes</td><td colspan="3">-</td><td>Yes</td><td colspan="3">-</td><td>Yes</td></tr>
<tr><td>Data Source</td><td>Permit program</td><td colspan="3">No existing uses</td><td>Permit program</td><td colspan="3">No existing uses</td><td>Permit program</td></tr>
<tr><td rowspan="6">Indiana</td><td>Permit/Reg.</td><td colspan="6">Registration</td><td>N/A</td><td>None</td><td>Registration</td></tr>
<tr><td>Water Source</td><td colspan="6">All</td><td>-</td><td>-</td><td>All</td></tr>
<tr><td>Threshold</td><td colspan="6">100,000 g/day</td><td>-</td><td>-</td><td>100,000 g/day</td></tr>
<tr><td>Capacity/Use</td><td colspan="6">Facility capacity</td><td>-</td><td>-</td><td>Facility capacity</td></tr>
<tr><td>Req'd Reporting</td><td colspan="6">Yes</td><td>-</td><td>-</td><td>Yes</td></tr>
<tr><td>Data Source</td><td colspan="6">Registration program</td><td>No existing uses</td><td>Volunt. reporting</td><td>Reg. program</td></tr>
<tr><td rowspan="6">Michigan</td><td>Permit/Reg.</td><td>Registration</td><td>None</td><td>None</td><td>None</td><td colspan="3">Registration</td><td colspan="2">None</td></tr>
<tr><td>Water Source</td><td>All</td><td>-</td><td>-</td><td>-</td><td colspan="3">All</td><td colspan="2">-</td></tr>
<tr><td>Threshold</td><td>All</td><td>-</td><td>-</td><td>-</td><td colspan="3">100,000 g/day</td><td colspan="2">-</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td>-</td><td>-</td><td>-</td><td colspan="3">Facility capacity</td><td colspan="2">-</td></tr>
<tr><td>Req'd Reporting</td><td>Yes</td><td>-</td><td>-</td><td>-</td><td colspan="3">Yes</td><td colspan="2">-</td></tr>
<tr><td>Data Source</td><td>Reg. program</td><td>Not reported</td><td>Modelling</td><td>Not reported</td><td colspan="3">Registration program</td><td colspan="2">Not reported</td></tr>
<tr><td rowspan="6">Minnesota</td><td>Permit/Reg.</td><td colspan="9">Permit[1]</td></tr>
<tr><td>Water Source</td><td colspan="9">All</td></tr>
<tr><td>Threshold</td><td colspan="9">10,000 g/day or 1 million g/yr.</td></tr>
<tr><td>Capacity/Use</td><td colspan="9">Actual use</td></tr>
<tr><td>Req'd Reporting</td><td colspan="9">Yes</td></tr>
<tr><td>Data Source</td><td colspan="9">Permit program</td></tr>
<tr><td rowspan="6">New York</td><td>Permit/Reg.</td><td>Permit</td><td colspan="6">Registration</td><td>None</td><td>Registration</td></tr>
<tr><td>Water Source</td><td>All</td><td colspan="6">All</td><td>-</td><td>All</td></tr>
<tr><td>Threshold</td><td>All</td><td colspan="6">100,000 g/day</td><td>-</td><td>100,000 g/day</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td colspan="6">Actual use</td><td>-</td><td>Actual use</td></tr>
<tr><td>Req'd Reporting</td><td>No</td><td colspan="6">Yes</td><td>-</td><td>Yes</td></tr>
<tr><td>Data Source</td><td>Est. with permits</td><td colspan="6">Registration program</td><td>Power agencies</td><td>Reg. program</td></tr>
<tr><td rowspan="6">Ohio</td><td>Permit/Reg.</td><td colspan="9">Registration</td></tr>
<tr><td>Water Source</td><td colspan="9">All</td></tr>
<tr><td>Threshold</td><td colspan="9">100,000 g/day</td></tr>
<tr><td>Capacity/Use</td><td colspan="9">Facility capacity</td></tr>
<tr><td>Req'd Reporting</td><td colspan="9">Yes</td></tr>
<tr><td>Data Source</td><td colspan="9">Registration program</td></tr>
<tr><td rowspan="6">Ontario</td><td>Permit/Reg.</td><td>Permit</td><td colspan="2">Permit[2]</td><td>None</td><td>Permit</td><td colspan="4">Permit</td></tr>
<tr><td>Water Source</td><td>All</td><td colspan="2">All</td><td>-</td><td>All</td><td colspan="4">All</td></tr>
<tr><td>Threshold</td><td>50,000 L/day</td><td colspan="2">50,000 L/day</td><td>-</td><td>50,000 L/day</td><td colspan="4">50,000 L/day</td></tr>
<tr><td>Capacity/Use</td><td>Allowable use</td><td colspan="2">Allowable use</td><td>-</td><td>Allowable use</td><td colspan="4">Allowable use</td></tr>
<tr><td>Req'd Reporting</td><td>No</td><td colspan="2">No</td><td>-</td><td>No</td><td colspan="4">No</td></tr>
<tr><td>Data Source</td><td>Federal survey</td><td colspan="2">Federal census</td><td>Federal census</td><td>Federal survey</td><td colspan="4">Voluntary reporting</td></tr>
<tr><td rowspan="6">Pennsylvania</td><td>Permit/Reg.</td><td>Permit</td><td>None</td><td>None</td><td>None</td><td>None</td><td colspan="3">N/A</td><td>None</td></tr>
<tr><td>Water Source</td><td>Surface</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="3">-</td><td>-</td></tr>
<tr><td>Threshold</td><td>All</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="3">-</td><td>-</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="3">-</td><td>-</td></tr>
<tr><td>Req'd Reporting</td><td>Yes</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="3">-</td><td>-</td></tr>
<tr><td>Data Source</td><td>Permit program</td><td>State estimated</td><td>Volunt. reporting</td><td>Not reported</td><td>Volunt. reporting</td><td colspan="3">No existing uses</td><td>Not reported</td></tr>
<tr><td rowspan="6">Quebec</td><td>Permit/Reg.</td><td>Permit</td><td colspan="3">None</td><td>None</td><td>None</td><td>N/A</td><td>None</td><td>N/A</td></tr>
<tr><td>Water Source</td><td>All</td><td colspan="3">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Threshold</td><td>All</td><td colspan="3">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td colspan="3">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Req'd Reporting</td><td>No</td><td colspan="3">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Data Source</td><td>Prov. estimated</td><td colspan="3">Province estimated</td><td>Env. Canada</td><td>Hydro-Quebec</td><td>No existing uses</td><td>Hydro-Quebec</td><td>No existing uses</td></tr>
<tr><td rowspan="6">Wisconsin</td><td>Permit/Reg.</td><td>Approval[3]</td><td>Approval/Reg.[3]</td><td>App/Reg | Permit</td><td colspan="6">Approval/Registration[3]</td></tr>
<tr><td>Water Source</td><td>All</td><td>All</td><td>gwater | swater</td><td colspan="6">All</td></tr>
<tr><td>Threshold</td><td>All</td><td>100,000 g/day</td><td>100,000 | All</td><td colspan="6">100,000 g/day</td></tr>
<tr><td>Capacity/Use</td><td>All</td><td>Facility capacity</td><td>Fac. cap | All</td><td colspan="6">Facility capacity</td></tr>
<tr><td>Req'd Reporting</td><td>Yes</td><td>Yes</td><td>Yes | No</td><td colspan="6">Yes</td></tr>
<tr><td>Data Source</td><td>Approval</td><td>Approval/Reg.</td><td>App/Reg | Volunt.</td><td colspan="6">Approval/Registration</td></tr>
</table>

NOTES

1 The hydropower category of Minnesota's water use permitting program only covers facilities that divert water out of the river channel. Currently, all Minnesota hydroelectric water uses in the Great Lakes watershed are in the river channel.
2 Permits for the self-supply domestic category do not include individual residential use.
3 Wisconsin has an approval process for many water uses that goes beyond registration but not a complete permitting process.

KEY TO TABLE 3-3 CHARACTERISTICS

Permit/Reg.: Does the jurisdiction have a water use permitting or registration program? If neither, the box for the category is marked "None" for no program or "N/A" for no existing uses and the next four categories are left blank.
Water Source: What water sources (i.e., groundwater, surface water, all) are included in the program?
Threshold: What is the use threshold for inclusion in the program?
Capacity/Use: Does the threshold apply to facility capacity, actual use, or allowable use? If the threshold applies to all uses, "All" is repeated.
Req'd Reporting: Is water use reporting required under the permit or registration program?
Data Source: What is the source of water use data for the 1998 Great Lakes Regional Water Use Data Base?

requires public suppliers to register. The MDEQ has no authority to collect data (and voluntary data is not provided) for the categories of self-supply domestic, self-supply livestock, hydroelectric, and "other." Facilities measure their water use for the categories of public supply, self-supply thermoelectric (fossil fuel), and self-supply nuclear. Self-supply industrial data is available from facility measurements and estimates. Golf course irrigation data is based on facility measurements and estimates.

Minnesota

A water appropriation permit from the Department of Natural Resources' Waters Division (DNR Waters) is required for all water withdrawals exceeding 10,000 gallons (37,900 litres) per day or 1 million gallons (3.79 million litres) per year. Minnesota Statutes 103G.255 to 103G.315, and Minnesota Rules 6115.0600 to 6115.0810, provide for implementation of the Water Appropriation Permit Program. Water data is collected for the nine Great Lakes Regional Water Use Database categories. Registered facilities report on all categories but hydroelectric. Hydroelectric water use where water remains in the waterway (run of the river) is not considered a water use in the state, and all current basin hydroelectric uses are of this type. Hydroelectric data has been derived from U.S. Geological Survey five-year reports, and future reports will use Federal Energy Regulatory Commission data. Minnesota has no nuclear facilities in its portion of the basin. Data for all categories are measured by facilities for all categories.

New York

New York Codes, Rules and Regulations, Part 675 requires registration of Great Lakes basin withdrawals greater than 100,000 gallons (380,000 litres) per day in a 30-day period. Public water suppliers are exempt but, based on the authority of NYCRR Part 601, the Department of Environmental Conservation (DEC) issues permits to public water suppliers and uses permit quantities to estimate water use. The DEC collects water use data for all water use categories except for hydroelectric. The New York Power Authority and International Niagara Committee provide measurements of the state's two largest hydropower facilities, and the DEC, Federal Energy Regulatory Commission and Army Corps of Engineers are involved in other hydroelectric data collection. Most information is reported every other year, but reports occur annually for self-supply irrigation. All facilities registered in the categories of self-supply industrial, self-supply thermoelectric (fossil fuel), and self-supply nuclear make the required reports with partially measured data. Estimates are more frequently used for public supply and self-supply livestock data.

Ohio

Sections 1521.15 and 1521.16 of the Ohio Revised Code require facilities with the capacity to withdraw more than 100,000 gallons (380,000 litres) of water per day to register with the Ohio Department of Natural Resources (DNR). The DNR's Division of Water collects annual data on all nine water use categories in the Great Lakes Regional Water Use Database, and all registered facilities file reports. The state estimates data for the categories of self-supply domestic and hydroelectric. Facilities measure data for the public supply, self-supply irrigation, self-supply thermoelectric (fossil fuel), and self-supply nuclear categories. Facilities estimate data for the self-supply livestock category. Data for the self-supply industrial and "other" categories combine facility measurements and estimates.

Ontario

Ontario's Ministry of the Environment (MOE) regulates all types of water withdrawals with the Permit to Take Water (PTTW) program under Section 34 of the Ontario Water Resources Act (OWRA) of 1963. Withdrawals in excess of 50,000 litres (13,200 gallons) per day, or that significantly interfere with other users, require permits which define maximum allowable water takings. The Ministry of Natural Resources (MNR) is responsible for reporting to the Great Lakes Regional Water Use Database, but relies on voluntary reporting because it lacks the authority to require reporting. The MOE can require reporting under the PTTW program, but does not presently exercise this authority. Environment Canada and Statistics Canada collect water use data every two to three years for municipal users and every five years for industrial users. A 1996 Rural Water Use Survey conducted by the University of Guelph provides data for the self-supply domestic, self-supply livestock and self-supply irrigation categories. MNR contacts station operators to collect power generation water use data. Navigation data from the National Canal survey makes up the bulk of water use for the "other" category.

Pennsylvania

Under the Water Rights Act of 1939, public supply agencies must obtain a permit before withdrawing surface waters, but no rules and regulations govern the water allocation process. The Pennsylvania Department of Environmental Protection's (DEP) Bureau of Watershed Management is responsible for water allocations and the Annual Water Supply Report. Chapter 109.701 (b) Rules and Regulations, administered by the DEP's Bureau of Water Supply and Waste Water Management, provides authority for collection of surface water public supply water use information. Administrative Code Section 1904-A (3) provides for data collection for "other" uses. Data is collected for facilities using 100,000 gallons (380,000 litres) per day or more but the DEP lacks statutory power to gather data for non-public supply categories. Water use data is collected for all public supply facilities, and at least 80 percent of principal facilities in other categories. Data is compiled through facility measurements and estimates.

Québec

The Ministry of the Environment (MOE) oversees most of the water use in Québec (i.e., quality, hydrology), but several other ministries, agencies and municipalities share responsibilities. Under the Environment Quality Act, Québec has several regulations addressing water use, primarily related to environmental and water quality impacts. The act requires a certificate of authorization (permit) from the Environment Minister before a variety of activities can occur on water bodies, including operation of a public water facility. The 1999 Water Resources Preservation Act prohibits the transport of water outside Québec in most cases. Although the MOE has the legislative authority to collect and report on water use, it has not implemented any mandatory program and no resources are formally dedicated for that purpose. To fulfill the provisions of the Great Lakes Charter, MOE initiated, in 1994, the collection of available data from other ministries and agencies.

Wisconsin

Wisconsin's Act 60, passed in 1985, provides for regulation of water withdrawals, diversions, and consumptive use. A water withdrawal must be registered if it will average more than 100,000 gallons (380,000 litres) per day in any 30-day period. Wisconsin diversions resulting in a loss of more than 2 million gallons (7.57 million litres) in a 30-day period require approval under Wisconsin State Statute 30.18. The state Department of Natural Resources (DNR) collects water use data based on the authority in Wisconsin State Statute 281.35 and the associated rules in Natural Resources 142, Wisconsin Administrative Code. Wisconsin receives information that is either measured or estimated by facilities on an annual basis for all water use categories.

Water Use Database

The Great Lakes Regional Water Use Database provides a common base of data and information on water use in the Great Lakes basin as called for in the Great Lakes Charter of 1985. It was envisioned to be a primary vehicle to support water withdrawal decisions.

Housed at Great Lakes Commission offices, the database uses a modified Microsoft Access7 software package using Visual Basic for Applications. The customized program was designed in 1987 by Acres International, Ltd. and revised in 1999/2000 by Eastern Michigan University's Center for Environmental Information, Technology and Application. It performs routine database operations and includes standard data entry, retrieval and report generation options.

The nine categories of use included in the Great Lakes Regional Water Use Database are outlined in the previous section. Figure 3-2 depicts water withdrawals by category. Each water use category includes three types of withdrawal/discharge

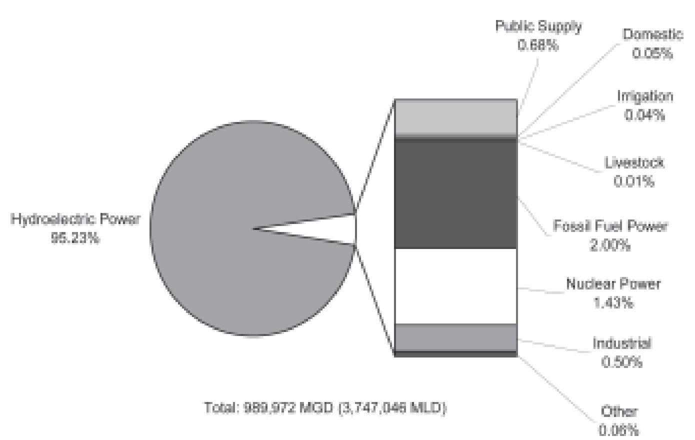

Figure 3-2
1998 water withdrawals by category

records: Great Lakes Surface Water (GLSW); Other Surface Water (OSW); and Groundwater (GW).

The system includes six drainage basins (Lake Superior; Lake Michigan; Lake Huron; Lake Erie; Lake Ontario; and the St. Lawrence River) which are numerically coded in the database. All states and provinces submit water use data to the database repository by basin of withdrawal. There are 22 possible combinations of the six basins and ten jurisdictions. Each jurisdiction's set of sub-basin records is comprised of nine sets of water use category records which, in turn, are comprised of three sets of withdrawal/discharge type records. Figure 3-3 shows water withdrawals by jurisdiction.

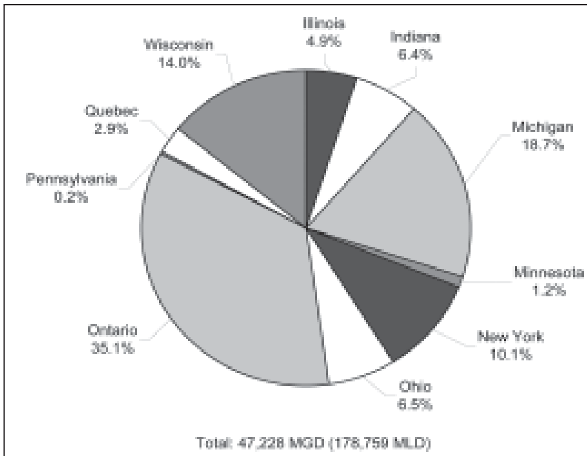

Figure 3-3
1998 water withdrawals by jurisdiction (not including hydroelectric power)

Data submitted to the Regional Water Use Database is provided in either million gallons per day (U.S.) (mgd) or million litres per day (mld). There are also two measures of the quality of data provided for each record: level of accuracy and level of aggregation. The accuracy level indicates whether the withdrawals are 100 percent measured, more than 50 percent measured, or estimated. The level of aggregation indicates whether the withdrawal data originate from site-specific sources or from higher-level aggregate sources such as county or census databases.

Discussion

Great Lakes jurisdictions have, over time, made significant progress in developing coordinated programs for water use data collection and reporting. Much work, however, lies ahead. 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 able to fulfill Charter data collection and reporting requirements in both legislative/regulatory authority and implementation effort for almost all water use categories. The balance believe that their jurisdiction has relatively strong legislative/regulatory authority but weak implementation efforts.

Even jurisdictions with more formal data collection and reporting programs are constrained by the lack of high-quality data at the sector or facility level, inadequate enforcement, and/or limited resources to implement programs. Jurisdictions where multiple agencies are involved in the data collection and reporting process face additional coordination challenges. Jurisdictions with mandatory reporting requirements appear to be more effective than those lacking them, given the more stringent requirements for water users and the availability of enforcement mechanisms. Currently, many jurisdictions lack the appropriate statutory or regulatory authority to implement mandatory reporting and/or permitting programs.

Progress has been made since the Great Lakes Regional Water Use Database became operational in 1988, but the database has limited utility as a management tool because it does not include site-specific data, and constraints in data collection and reporting programs at the state/provincial level have been experienced. Consequently, it lacks the high data quality needed to inform activities such as trend analysis, demand forecasting and water resources planning in general.

The database presently lacks four years of data from most jurisdictions (1994-1997) and, consequently, it has limited utility in identifying trends in water use, such as changes in demand at the systemwide, jurisdictional and water use category levels. Trend analysis would provide a valuable planning tool, allowing, among many other functions, projection of possible cumulative effects of water use.

The states and provinces released the 1998 annual database report in mid-2002. Water use data for 1999 and 2000 were recently submitted by most jurisdictions, and reports for these years will be prepared in 2003. As resources permit, data from 1994 to 1997 will be gathered and incorporated into the database.

If the utility of the database as a planning tool is not improved, the annual data collection and reporting becomes little more than an administrative exercise with limited value for the jurisdictions. Under such a scenario, jurisdictions are likely to encounter difficulties in securing funding and other resources for their individual data collection and reporting programs, and the region will remain unable to identify water use trends accurately.

A leading obstacle to improving the utility of the database is that most jurisdictions are unable to collect and report water use data on an annual basis for at least one water use category. At one extreme, due to staffing and other program constraints, Pennsylvania and Quebec relied upon 1993 and 1994 data for all water use categories in the 1998 Regional Water Use Database Report.

Overall, the Great Lakes Regional Water Use Database is characterized by the following limitations:

- Measured or metered data is lacking and the use of measurements or estimates to collect data varies by jurisdiction;
- The reported level of accuracy (i.e., overall quality) of water use data varies significantly by jurisdiction;
- Measurement accuracy levels are not well documented in the database, limiting the usefulness of data in analyses;
- Each jurisdiction follows its own schedule and protocols in data collection and reporting; and
- Programs differ from one jurisdiction to another and suffer from lack of funding support and authority to fully develop and implement programs consistent with the Great Lakes Charter.

Accuracy, of course, is a key consideration in database utility, but the database only indicates whether data is based on estimated use or site-specific metering and direct measurements. Measured data, however, is not presently available for many of the water use categories. Clarification of category definitions, including prospective reclassification, would also enhance database utility. A prime example is the need to track self-supply domestic separately from self-supply commercial water use.

Data submitted to the database is aggregated for multiple facilities, estimated in many cases, reported at an annual interval and, in some jurisdictions, focused solely on surface water. This level of data quality is inadequate for identifying impacts from specific withdrawals and annual/seasonal trends of water use. In addition, aggregate data may not be useful to support the decisionmaking standard currently being developed under Annex 2001 to the Great Lakes Charter, particularly for withdrawals from tributaries shared by multiple jurisdictions. Site-specific data is needed if the hydrological and ecological impacts of a prospective withdrawal are to be accurately assessed.

The data reported by most jurisdictions for most water use categories is an aggregation of data collected for specific withdrawals. Therefore, reporting data in a less aggregated format should be possible without a prohibitive increase in the level of the data collection effort. One inherent problem associated with more specific withdrawal data should be noted; as the level of withdrawal data aggregation decreases, the degree of accuracy also decreases (i.e., the tendency for instances of over-reporting and under-reporting to cancel each other out decreases as the data become more "localized").

Consumptive Use of Great Lakes Water

Definitions and Calculations

Consumptive use, as defined by the Great Lakes Regional Water Use Database, is "that portion of water withdrawn or withheld from the Great Lakes basin and assumed to be lost or otherwise not returned to the Great Lakes basin due to evapotranspiration, incorporation into products, or other processes."[2] Consumptive use is one of several factors that affect the amount of water in lakes and other water bodies. In the Great Lakes Charter, the Great Lakes states and provinces agreed, "that new or increased diversions and consumptive uses of Great Lakes basin water resources are of serious concern." The International Joint Commission (IJC), in its 2000 report to the Governments of Canada and the United States, recommended that federal, state, and provincial governments should exercise caution with regard to consumptive use of

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

Great Lakes basin waters. Within the Great Lakes Charter, the governors and premiers set forth provisions for notifying and consulting each other on proposed diversions or consumptive uses of more than 5 million gallons (19 million litres) per day and call for increased and improved data collection on water use, diversion and consumptive use.[3]

Conceptualizing consumptive water use is difficult because the amount of water lost to the system is not easily determined, and means are not readily available to measure all water withdrawal and use processes. For instance, if water is "consumed" through evapotranspiration, the water may or may not remain within the basin depending upon where it returns to the earth's surface as rain or snowfall. Similarly, water incorporated into food or beverage products may or may not remain in the basin depending upon where it is consumed. Additionally, calculated or measured consumptive uses need to consider the quality of return flows, which may be altered through chemical or thermal processes. The return flow of water may be so severely degraded as to render it unusable, in which case the water is – in one sense – lost to the watershed.

Two primary methods of calculating consumptive use are currently employed in the Great Lakes region: subtracting return flows from overall withdrawals and multiplying withdrawal quantities by a coefficient that reflects the percentage of water loss. This latter method is the one predominantly used in the Great Lakes-St. Lawrence River basin. Greater cooperation and coordination on the part of the Great Lakes states and provinces is needed to establish a workable methodology for calculating, measuring or estimating consumptive use. A common definition, along with common and consistently applied coefficients, will be an important first step.

Data Collection

All consumptive use figures contained in Great Lakes Regional Water Use Database reports are provided by individual jurisdictions. Table 3-4 presents the coefficients used by each in calculating consumptive uses. Most of these coefficients originated with the USGS or the Technical Work Group of the Water Resources Management Committee. This group was established in 1988 to develop the protocols and methodology for data submittals to the water use database, including establishing uniform water withdrawal and consumptive use estimation procedures. Despite the lack of an overriding scientific basis for the consumptive use coefficients, state and provincial officials generally believe that their application is useful to provide a general sense of consumptive losses by water use category.

Most Great Lakes states and provinces estimate consumptive use at the jurisdictional level, but Wisconsin and Michigan have basic legislative authority to require consumptive use reporting by facilities. Prompted by the Great Lakes Charter of 1985, Wisconsin passed legislation in the late 1980s that requires consumptive use reporting for seven water use categories: irrigation, livestock, thermoelectric power, commercial, industrial, mining, and public water systems. Michigan requires consumptive use reporting for the self-supply thermoelectric (fossil fuel) and self-supply industrial categories only.

Voluntary facility consumptive use reporting occurs in Indiana, New York, Ohio and Pennsylvania through water use registration forms or reports for facilities that use or have the capacity to withdraw 100,000 gallons (380,000 litres) of water per day. New York and Ohio request return flow data from registered facilities in withdrawal reports, and Indiana collects return flow data in initial registration forms. In Pennsylvania, the reporting of withdrawals and return flows is only requested for thermoelectric (fossil fuel and nuclear) and industrial (not including mining). Pennsylvania uses this data to calculate consumptive use, but Indiana, New York and Ohio rely on established coefficients due to concerns over its accuracy. Ontario also has some voluntary reporting by industrial facilities, and this data is used for database submissions. Table 3-5 describes the facility consumptive use reporting processes and applications.

The following is a description of the consumptive use coefficients used by Great Lakes states and provinces to estimate consumptive use for the nine water use categories included in the Great Lakes Regional Water Use Database. Figure 3-4 shows the percentage of water consumed by each category of use.

Public Supply

All Great Lakes jurisdictions use between 10 percent and 15 percent as the coefficient to estimate consumptive use for this category. For

[3] The IJC's report, Protection of the Waters of the Great Lakes: Final Report to the Governments of Canada and the United States. (2000. p. 37) notes that the Mud Creek irrigation project in Michigan is the only consumptive use proposal to date large enough to trigger Charter requirements. The proposal "went forward even though there were objections by some Great Lakes jurisdictions. … Consequently, the Charter has not yet provided the impetus for an ongoing conversation among the jurisdictions on the subject of consumptive uses."

Table 3-4
Consumptive Use Coefficients by Water Use Category (Great Lakes Jurisdictions and USGS)*

Water Use Category	Illinois	Indiana	Michigan	Minnesota	New York	Ohio	Ontario	Pennsylvania	Quebec	Wisconsin	USGS 1995
Public Supply	10-15%	15%**	10-15%	10-15%	10%**	10-15%	10-15%	10%**	10-15%	10-15%	N/A
Self-Supply Domestic	10-15%	15%**	10-15%	10-15%	10%**	10-15%	10-15%	10%**	10-15%	10-15%	10-15% of withdrawals and deliveries
Self-Supply Irrigation	90%	90%	90%	90%	90%	90%	78%	90%	90%	70%	40-100% of withdrawals and theoretical crop requirements
Self-Supply Livestock	80%	80%	80%	80%	90%**	80%	80%	80%	80%	90%**	10-100% of withdrawals
Self-Supply Industrial	For both mfg. & mining varies by plant and SIC code	6%	10-15%**	For both mfg. & mining varies by plant and SIC code	25%**	10%; except salt mining is 90%*	Facility measured; varies by plant and facility*	For both mfg. & mining varies by plant and SIC code	10% for pulp and paper industry	10.2% for both mfg. and mining	10-40 % depending on type of industry
Self-Supply Thermoelectric (Fossil Fuel)	Varies by individual plant; est. using makeup water for each system.	2%	1-2% for plants using once-through cooling; plant by plant analysis for wet cooling towers**	2%**	2%**	Negligible; estimates based on indiv. plant reports of withdrawals, return flows.	0.9% based on reports of increased local lake evaporation due to discharge of heated water to lakes.	N/A	10%; estimates obtained from USGS report	0.5% - 1%	1-100% varies greatly depending on type of plant and cooling process
Self-Supply Thermoelectric (Nuclear)	Varies by individual plant; est. using makeup water for each system.	N/A	1-2% for plants using once-through cooling; plant by plant analysis for wet cooling towers.**	N/A	5%**	14%; based on reports of increased local lake evaporation due to discharge of heated water to lakes.	0.9% based on reports of increased local lake evaporation due to discharge of heated water to lakes.	N/A	N/A	0.5% - 1%	1-100% varies greatly depending on type of plant and cooling process
Hydroelectric	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other	Varies based on use	12%	Varies based on use	Varies based on use	Varies based on use	Varies based on use	Varies based on use	Varies based on use	Varies based on use	Varies based on use	N/A (category not used)

* Based on Great Lakes Commission survey, Spring 2002

** Denotes change from Great Lakes Regional Water Use Data Base Repository representing 1993 data

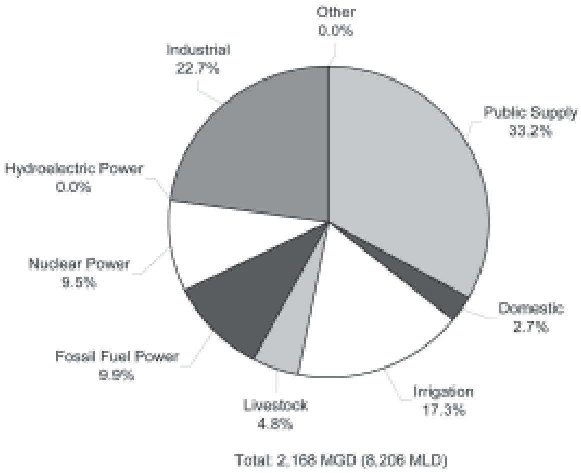

Figure 3-4
1998 consumptive water use by category

Illinois, the coefficient does not apply to the Great Lakes basin because all public supply water is diverted from Lake Michigan and entirely consumed.

Self-Supply Domestic

The database defines self-supply domestic use as "water used for normal household purposes" or "residential water use." The category includes a multitude of uses that do not neatly fit into any of the other water use categories, such as commercial and institutional uses. Many users are rural or unregulated, and, in those instances, water use is estimated at 75 gallons (284 litres) per capita per day. The Great Lakes states and provinces use a coefficient between 10 percent and 15 percent of withdrawals to estimate consumptive use.

Self-Supply Irrigation

Eight of the ten Great Lakes jurisdictions use a 90 percent consumptive use coefficient for irrigation. The exceptions are Ontario, which uses 78 percent, and Wisconsin, which uses 70 percent. Many irrigation experts and water resources managers prefer using evapotranspiration (ET) rates to estimate consumptive use instead of using what they believe to be an inflated consumptive use coefficient. In the field, ET rates are calculated for particular crops and locales using accepted formulas that consider factors such as the water holding capacity of the soil, the crop root zone and climate.

Self-Supply Livestock

This category includes water for livestock, feedlots, dairies, and other on-farm needs. Great Lakes jurisdictions use an 80 percent consump-

Table 3-5
Measured Processes for Consumptive Use Reporting by Facilities

Jurisdiction	Description	Application
Mandatory Reporting		
Michigan	Required for self-supply fossil fuel and self-supply industrial only	Submitted for database reports
Wisconsin	Required for all water use categories	Submitted for database reports
Voluntary Reporting		
Indiana	Return flow data for all facilities with the capacity of more than 100,000 gal/day included in initial registration form	Not used (concerns over accuracy)
New York	Consumption data for facilities using more than 100,000 gal/day included in withdrawal reports (public supply not included)	Not used (concerns over accuracy)
Ohio	Return flow data for self supply fossil fuel and self-supply nuclear facilities with capacity of more than 100,000 gal/day	Not used (concerns over accuracy)*
Ontario	Many industrial facilities provide data	Submitted for database reports
Pennsylvania	Return flow data included in withdrawal reports for self-supply categories of fossil fuel, nuclear and non-mining industrial	Submitted for database reports

* Although Ohio does not use this data, consumptive use for the self-supply fossil fuel category is reported by facilities, which base their calculations on withdrawal and return flow data.

tive use coefficient for livestock except for New York and Wisconsin, which use 90 percent.

Self-Supply Industrial

This category includes industrial and mining activities, and coefficients range from 6 percent in Indiana to 25 percent in New York. Several jurisdictions use the type of industrial facility and the Standard Industrial Classification (SIC) code to estimate industry-specific consumptive use, which averages between 10 percent and 15 percent. Michigan and Wisconsin are the only Great Lakes jurisdictions that mandate consumptive use reporting by facilities. Michigan does not provide coefficients or technical guidance to assist facilities with their estimations, and only about 30 percent of facilities comply with reporting requirements. In Wisconsin, consumptive use reporting by facilities is virtually non-existent due to program weaknesses and lack of enforcement.

Self-Supply Thermoelectric (fossil fuel and nuclear-powered facilities)

This category is reported as two distinct categories in the database, but most Great Lakes jurisdictions use the same coefficient for both nuclear and fossil fuel-powered facilities. In most Great Lakes jurisdictions, facilities measure withdrawals and provide that data to the state or province. Since the water is used for cooling purposes, but is not incorporated into products, consumptive use is generally reported to be between 1 percent and 2 percent. However, Wisconsin uses a low of 0.5 percent to 1 percent and Ohio uses a high of 14 percent for nuclear. Ohio estimates fossil fuel consumptive use based on individual plant withdrawals and return flows while Illinois and Pennsylvania thermoelectric coefficients relate to cooling processes. Variable water cooling and discharge techniques and evaporation rate issues bring uncertainty into consumptive use calculations for this category.

Hydroelectric

Hydroelectric power generation occurs when gravity causes water to fall and drive turbines. This category includes both “instream”(water remains within the water channel) and “offstream” (pumping and storage) uses. Evaporation in hydroelectric power generation is minimal, and consumptive use is assumed to be zero.

Other

This water category was created to accommodate all water uses not included in other categories. Examples include withdrawals for fish/wildlife, recreation, navigation and water quality purposes. All jurisdictions except Indiana report that the coefficient varies depending on the use. Indiana uses a coefficient of 12 percent, although the basis for this coefficient is unclear.

Discussion

Accurate and reliable water withdrawal and use data are essential in generating meaningful and defensible consumptive use figures. Currently, such data is generated by multiplying the aggregate withdrawal quantity for each use category by a category-specific coefficient. While the use of coefficients does provide valuable information, confidence in their application is often limited. For example, coefficient-calculated consumptive use data may not be accurate at a site-specific level and is more useful at a larger scale. Consumptive use data are most reliable when they are based on measured, location-specific withdrawals and return flows. Obtaining credible, location-specific consumptive use data will require substantial commitments of time and resources in all Great Lakes jurisdictions.

Where actual measurements of withdrawals or return flows/discharges are not feasible, such as for irrigation, livestock and rural uses, other reliable methods for calculating or estimating consumptive uses can be applied. Current consumptive use coefficients cannot be validated by existing data and information and, due to the variance in use of coefficients among Great Lakes jurisdictions, data comparability can be problematic.

Wisconsin’s experience illustrates this point. Consistent with the intent of the 1985 Great Lakes Charter, Wisconsin codified a consumptive use reporting program that requires coefficients for seven water withdrawal categories. Given the questionable validity of coefficients, and the fact that withdrawal data is largely estimated, the program has serious limitations.

Some of the larger water withdrawal categories use the same coefficients for many types of distinct activities that, in reality, have very different consumption characteristics. Similarly, there is great variability among the types of uses in the self-supply domestic and livestock categories, suggesting that a single coefficient for each category may be inadequate in determining actual consumptive use.

Demand Forecasting

Water demand forecasting is an essential tool in reducing uncertainty associated with the future status and use of Great Lakes water resources. The Great Lakes Charter acknowledges the need for such assessments to guide future development, management and water conservation activities in the Great Lakes basin. The Charter recognizes that a key element of a Great Lakes basin water resources program is:

> *Identification and assessment of existing and future demands for diversions, into as well as out of the Basin, withdrawals, and consumptive uses for municipal, domestic, agricultural, manufacturing, mining, navigation, power production, recreation, fish and wildlife, and other uses and ecological considerations.*

Demand forecasting has also been acknowledged as an important planning tool in any decision support system – a key outcome of a Scenario Evaluation Workshop conducted in May 2002. (Refer to the Scenario Evaluation Workshop Summary Proceedings in the Appendix).

Recent Demand Forecasting Efforts

Five of ten Great Lakes jurisdictions (Illinois, Minnesota, Ohio, Ontario and Pennsylvania) presently employ demand forecasting in their water management programs. Table 3-6 below describes the status of demand forecasts within these five jurisdictions.

Developing an appropriate demand forecasting methodology is a complicated undertaking, and methods of water demand forecasts will vary according to the scale and scope of the study area. In 1999, the IJC commissioned Donald Tate and Jeff Harris of GeoEconomics Associates to develop water demand forecasts for the United States and Canadian portions of the Great Lakes basin. These water demand forecasts focused on five water use categories: agriculture, mineral extraction, manufacturing, thermal power, and municipal. Their study uses five main parameters to forecast water demand:

1. *Total water intake* – the total amount of water added to the water system of a given facility, including amounts withdrawn from various sources and for various purposes, or end uses.
2. *Recirculated water* – water used at least twice in an industrial plant, and applied mainly to manufacturing and mineral extraction activities.
3. *Gross water use* – the total amount of water used.
4. *Water consumption* – water that is lost during use or in a production process.
5. *Wastewater discharge* – water that is returned to the environment in the form of water.

To better understand future water demand in Ontario, the Ministry of Natural Resources undertook a demand forecasting project with the assistance of GeoEconomics Associates in early 2002. The project was co-funded by Ontario with a matching grant from the Great Lakes Protection Fund.

Table 3-6
Jurisdiction Demand Forecasting Efforts

Jurisdiction	Demand Forecasting Efforts
Illinois	The DNR does demand forecasting every 8 to 10 years, at which time the long-term demands of all permittees is reevaluated for a 20 to 40 year period.
Minnesota	Demand forecasting is done for the Twin Cities Metro Area, but not statewide. Projections of water demands are required for new permit requests.
Ohio	The state periodically produces regional water plans that include water use demand forecasting. The most recent forecasts were done in 1988 for northeast Ohio and 1986 for northwest Ohio. Other forecasts were done in the 1970s.
Ontario	Currently, MNR, MOE, Conservation Authorities and Environment Canada are involved in a multi-year study on water use and supply in the Ontario portion of the Great Lakes basin. This study includes demand forecasting. Previous demand forecasting has been undertaken at irregular intervals by the federal government.
Pennsylvania	Demand forecasting is done for public water supply systems on a five to ten year basis with 50-year projections. The last demand forecasts were made in 1995 using the 1990 U.S. Census. With the assistance of the Pennsylvania State Data Center, the Division of Water Use Planning projects municipal populations for counties, which are applied to public water supply service areas with a system per capita usage.

The methodology used for water demand forecasting is based on the application of category-specific (e.g., public water use) water use coefficients to water use drivers (e.g., population served by public water supply) where the growth of those drivers is expected to correlate with that of water use. Forecasting was carried out at the sub-basin level for the years 2001, 2011, and 2021 projected from the base year of 1996.

In contrast to large-scale water demand analysis, small-scale studies with a narrower focus may take a different approach. An example is found with a water demand analysis of communities in northeastern Illinois. The Illinois Department of Natural Resources – Office of Water Resources contracted with Harza Consulting Engineers and Scientists to develop water demand forecasts of domestic, commercial and industrial water use under the Lake Michigan Allocation Program. The program allocates water to approximately 200 permittees located in four counties in northeastern Illinois. Water demand projections were developed for all permittees based on historic water use data and local demographic projections. The development of population, housing and employment projections was used for the demand forecast analysis. Additionally, the analysis used adjustment factors to account for system-specific conditions that cause water usage to vary among similar communities. The specific purpose of this demand forecasting effort is to review the current allocations and revise them to better reflect expected water use trends.

Complexity of Forecasts

Regardless of methodology, future economic activity, population growth, technological advances and climate change are examples of factors influencing the outcomes of demand forecasts.

Lake Ontario, Toronto's skyline in winter

Climate change is a leading example of an influential factor for which the future impacts in the Great Lakes basin are not well known and widely debated among experts. Predicting climate change impacts in a specific geographic location is particularly difficult given the current uncertainty associated with the state of the science. However, Donald Tate drew several general conclusions in a 2002 report commissioned by the province of Ontario. For example, climate change will enhance natural climatic variability, average temperatures in North America will rise between 1 to 4 degrees Centigrade (2 to 7 degrees Fahrenheit), and changes in the atmosphere are beginning to affect the hydrologic cycle. Collaborative research with Environment Canada and the U.S. National Oceanic and Atmospheric Administration shows a lowering of lake levels of up to one meter (3.28 feet) by the end of the century, which may result in serious social, economic and environmental impacts. Climate change is a slow process and may have long-term adverse effects on water availability. Scientific understanding of global climate change must therefore be integrated in long-term water demand forecasts.

The weaknesses of demand forecasts must also be recognized in the interest of assessing their applicability to water resource management. Influential factors inject an element of uncertainty that constrains the accuracy of any demand forecast. In demand forecasting, uncertainty is reflected in high and low projections and by running the model through various future scenarios. Uncertainty increases in developing long-term projections, and most conventional economic forecasts project no more then ten years into the future. This presents a challenge to water managers who handle projects with planning horizons beyond ten years. More sophisticated forecasting approaches need to be developed to reduce uncertainty.

Discussion

Demand forecasting is an essential tool for informing water resources planning and management activities at the state/provincial, regional, and local levels. Forecasts provide important information on where water demand is likely to increase and where financial and other resources may need to be directed to address priority areas.

The limitations and weaknesses of demand forecasting need to be recognized, understood and addressed. As forecasting methodology is improved and refined, and water use data become more reliable and accurate, the ability to project water demand with greater certainty over longer planning horizons will be enhanced. The foundation of any comprehensive water demand forecast is reliable and accurate water use data.

Findings and Recommendations

Findings

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 is 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 state that their jurisdiction has relatively strong legislative/regulatory authority but weak implementation efforts. 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, focus 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.

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.**

   All jurisdictions would benefit from increased authority and resources to better fulfill commitments they made in the Great Lakes Charter and its Annex. At a minimum, all states and provinces should ensure they are able to provide accurate and comparable information for withdrawals that exceed 100,000 gallons per day average in any 30-day period for all water use categories. To ensure that all jurisdictions comply with their commitments, enforcement mechanisms should be reviewed, including the conditions for participation in the prior notice and consultation process.

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.**

   Data collection must match the needs of the decisionmaking process. The current database should be evaluated to determine elements that need to be strengthened. This includes determining whether the current water use categories are appropriate and provide the means to process and use data. The use of aggregate data should be refined, particularly for sub-watersheds that are shared by jurisdictions. A finer resolution of data is needed to assess ecological impacts, particularly at the sub-watershed and nearshore scale, while respecting the prospective need for confidentiality of site-specific data. Data accuracy and confidence levels need to be improved to better inform the decisionmaking process. Further. states and provinces must strive for comprehensiveness, consistency and collaboration in developing a regional water management program.

The Regional Water Use Database should become a more viable tool to assist in regional water resources management and planning activities, including developing detailed demand forecasts, creating a water budget, analyzing water use by jurisdiction, understanding cumulative effects, and recommending (on an ongoing basis) means to enhance database utility. More reliable and accurate data and information by water use category will be valuable to decisionmakers as they are faced with proposals for new or increased withdrawals or diversions. Data need to be collected at the scale that is appropriate for decisionmaking, and these needs may change over time. Some basic steps that will increase the utility of the database are improving software capabilities (see Table 3-7), establishing and honoring agreed-to data submittal schedules, preparing annual reports on a regular schedule and in a timely manner, continuing the process of reviewing data submittal requirements and methodologies by water use category, and refining and expanding the metadata for the database.

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.**

   Jurisdictions should work together to determine the appropriate level of data accuracy and consistency of withdrawal and consumptive use data within each water use category. The ten jurisdictions should work toward providing water use and consumptive use data that are site specific, accurate with high confidence levels (metered, measured or highly accurate estimations), collected at monthly intervals, and inclusive of all water sources. This will ensure that data for all jurisdictions are comparable, accurate and applicable to a regional decision support system. Each water use category may have specific data collection needs that can be addressed by determining which type of data generation process is most effective. The states and provinces should regularly review water use data availability, collection and reporting on a category-by-category basis to recommend ways to improve this sector specific information.

4. **Develop reporting requirements for incorporation into state/provincial water use data collection and reporting programs.**

   Reporting requirements instituted through statutory or regulatory powers help ensure that facilities – and state/provincial agencies – provide necessary reports in a timely manner. The data collection process outlined in the Great Lakes Charter does not assert that the states and provinces must require reporting, but those jurisdictions that have been most successful in collecting good data have reporting requirements that are attached to compliance mechanisms, such as those within a permitting program.

5. **Improve state/provincial consumptive use reporting processes to ensure reliable and accurate data.**

   Measured consumptive use data would provide much more accurate detail about how much water is actually consumed (i.e., lost from the basin) from the various processes of water withdrawal and use. Where measured data is not feasible, research-driven improvements in the accuracy of estimates should be pursued. This would provide information to decisionmakers that would help in evaluation of future water withdrawal or diversion proposals.

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.**

   Measured consumptive use data are not likely to be available in the near future for many water use sectors until new technologies are developed or current technologies become more economical. Establishing consumptive use reporting programs in jurisdictions where they do not currently exist will also take time, resources and political commitment. With this in mind, current reliance on consumptive use coefficients should be continued, but those currently in use must be refined to be scientifically credible and uniformly adopted and applied. For certain categories such as self-supply industrial, subcategories should be established to provide for a more accurate application of the coefficients. Where facility-supplied consumptive use data are available (either measured, calculated or estimated), states/provinces should provide this information to the Regional Water Use Database. This would allow for comparison of this data with the agreed-upon coefficients and new research.

7. **Develop and regularly pursue a uniform regional approach to demand forecasting in the interest of strengthening jurisdictional and regional planning processes.**

   Demand forecasting methodology developed at the regional level should be refined to address the need for longer planning horizons and uncertainty related to economic trends, demographic changes, climate change impacts, technological developments and sector improvements in water efficiency. Research and development of demand forecasting methodologies should be pursued among academic institutions around the Great Lakes-St. Lawrence Region. States and provinces should keep in mind the regional approach when performing demand forecasts at the watershed and sub-watershed level.

   New water demand forecasts need to be developed on a regular basis (e.g., every five years) with a timeframe of at least 20 years. These forecasts should be an integral component of water resources management activities. Each jurisdiction should conduct demand forecasts at a small scale, such as the major watershed or sub-watershed level, so projected changes in water demand and associated effects can be more easily identified for decisionmakers. Dedicated, long-term financial and technical support for demand forecasting is needed at the state and provincial level and should feed into regional demand forecasts.

Table 3-7
Software Needs and Recommendations

Presentation of interbasin diversion data: The software presently used for the Great Lakes Regional Water Use Database reports total interbasin diversions (the amount of water transferred from the Great Lakes basin into another watershed or vice versa) using a water-balance approach. Diversion totals for each water use category, jurisdiction, lake basin or Great Lakes basin are presented as the sum of incoming and outgoing diversions. A more useful way of presenting this information is to present these data separately.

Presentation of intrabasin diversion data: Intrabasin diversion totals (water flowing from one lake into another, but not leaving the Great Lakes Basin) should also be georeferenced and presented so that the user may view the data separately rather than as an additive fixed total.

Incorporation of an advanced graphics program into the database: The current database allows production of very simple pie charts reflecting total withdrawals by jurisdiction. Advanced graphics capabilities will allow users to display and print complex and detailed data in multiple graphic styles. As data quality improves, graphics that display trends over years would be crucial in analyzing water demand.

GIS Applications: Geographical information system (GIS) applications, tools, and spatial displays of water use would contribute to the analysis of regional water demand and localized environmental effects.

Table 3-7
Software Needs and Recommendations (cont.)

Data submission: Annual data should be submitted quickly and efficiently, and at the click of a button. Enhancement of the software would allow this type of timely, and almost immediate, electronic submittal.

Refined table formatting: Jurisdictional users accumulate and submit the number of principal facilities, which are represented by a composite withdrawal figure for each water use category and withdrawal type. However, the actual number of principal facilities contributing to a particular value has not been incorporated into reports to date. Such an enhancement would increase the utility and value of the reports. For reasons of confidentiality, some data must remain aggregate.

Table accuracy: The 1998 water use tables have blank fields where data is not available. Future reports should have a non-numeric figure, rather than a blank, to indicate a lack of credible data for a particular field.

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Chapter Four

Water Conservation in the Great Lakes-St. Lawrence River Region

Introduction

Annex 2001 of the Great Lakes Charter calls for a decisionmaking standard that includes water conservation measures. Although this topic was not part of the original project work plan, the Project Management Team agreed that water conservation can inform the decision support process and, consequently, authorized additional research. The information in this chapter outlines these research efforts, which were based on a survey of state and provincial water use and conservation programs and supplemented with information on conservation best management practices. The focus of the survey effort was limited to water conservation at the state and provincial scale. Additional research on local water conservation efforts undertaken by entities such as municipalities and agricultural districts would be extremely useful to more fully support Annex requirements. Additional information on existing programs and guidelines is found in the Appendix.

A Case for Water Conservation

The states and provinces of the binational Great Lakes-St. Lawrence River region are blessed with an abundance of high quality fresh surface water. Collectively, the Great Lakes and their connecting channels comprise the world's largest body of fresh surface water. They contain 6.5 quadrillion gallons (24.6 quadrillion litres) of fresh surface water, 20 percent of the world's supply and 95 percent of the supply in the United States. Due to this seemingly inexhaustible supply of fresh surface water, decisionmakers in the Great Lakes region have historically had minimal concern with water supply management issues such as water conservation. These concerns have heightened in recent decades, however, with the increasing frequency of localized water management conflicts and the broader realization of the Great Lakes system as a large, yet finite, supply of freshwater.

Reliable water supplies continue to be readily available to the majority of the basin's population and, in most cases, these supplies will be adequate to accommodate growth in demand. However, in some localized cases, water conservation and other responsible water use practices are needed to provide a viable solution to current shortages or to provide protection to ecologically and hydrologically sensitive areas. Several cases in Michigan are illustrative of water management issues throughout the basin. Monroe County, located in the southeast corner of the state, relies on groundwater for drinking water and irrigation, but aquifers have been depleted due to quarry operations (Behnan, 2002). Oakland and Macomb counties, also in the southeastern portion of the state, likewise have recently experienced aquifer depletion due to low rainfall, higher than normal temperatures and rapid residential development (Patterson and Garrett, 2002). In Saginaw County, similar climatic conditions, along with increases in groundwater-based agricultural and golf course irrigation, have resulted in a loss of residential well water pressure for extended periods during the summer months (Saginaw County Dept. of Health, 2002). Developing additional infrastructure can provide for long-term dependable surface water supplies, but the potential cost savings from water conservation measures will likely be more economical.

Ecological benefits also result from water conservation because less water is removed from the source (e.g., lake, river, aquifer), thus reducing alterations to natural levels and flows and associated ecosystem disruptions.

Even in areas that currently have abundant sources of water, conservation measures may increase efficiencies and lead to lower operating costs. A public water supplier that implements an effective water conservation program can forego, delay and otherwise better manage system and plant expansion. The city of Barrie, Ontario, for example, uses water conservation to reduce wastewater flows, easing the need for supply and wastewater infrastructure while providing savings to customers (Ontario MOE, 1998). Saginaw, Michigan, has successfully used a similar conservation approach (Peters, 2002). Savings can also be realized in other sectors such as industry and agriculture. All communities should reassess the economic benefits of water conservation, and revisit their belief that conservation reduces water-related revenue.

Based on the potential benefits of water conservation, support for a regional water conservation approach has arisen in recent years. In its February 2000 report to the governments of the United States and Canada, the International Joint Commission (IJC) observes, "Because of a possible downward trend in net Basin (water) supply in the 21st century, water-conservation and demand-management practices should become increasingly important components of any overall sustainable use strategy." The report suggests, "Implementation of the Basin Water Resources Management Program – to which the states and provinces are committed under the Great Lakes Charter – could provide the opportunity to launch a water-conservation initiative." Through the Great Lakes Charter Annex, the region further committed itself to the pursuit of responsible water management through a new decisionmaking standard that includes water conservation.

Water Conservation Within a Decision Support System Framework

In Directive #3 of the Great Lakes Charter Annex, the Great Lakes governors and premiers agreed that a new decisionmaking standard on proposals for new or increased water withdrawals should be based on four principles. The first of these is "preventing or minimizing Basin water loss through return flow and implementation of environmentally sound and economically feasible water conservation measures." Clearly, a commitment to water conservation will be an essential consideration as a decision support system is designed and implemented. In addition to economic efficiencies, such measures can lower consumptive use and reduce individual and cumulative ecologic impacts of withdrawals.

Implementing water conservation measures within the basin also provides the region's decisionmakers with a basis to insist on such measures by prospective out-of-basin users.

The General Agreement on Tariffs and Trade, as well as World Trade Organization agreements that have been signed by the United States and Canada, "severely restrict the ability of the Great Lakes States and Provinces to arbitrarily or unilaterally limit the export of Great Lakes water" (Lochhead et al., 1999). The U.S. Constitution's interstate commerce clause also limits the ability of the states to restrict interstate water transfers. Water conservation for all prospective users is important and, by providing a measurement of how effectively the water resource will be used and protected, can determine the merits of a proposed use.

State/Provincial Water Conservation Programs and Drought Contingency Plans

While Great Lakes-St. Lawrence River states and provinces typically have the authority to implement water conservation programs, the relative absence of severe water shortages has limited the impetus for exercising that authority. Where they do exist, state and provincial water conservation programs vary widely in scope and content and are usually components of drought contingency plans.

Below is a summary of state and provincial water conservation programs and drought contingency plans. The conservation efforts detailed here focus largely on the public supply sector, a reflection of the fact that the state and provincial agencies surveyed are most closely involved with that level sector. (See Table 4-1.)

Illinois

Illinois has water conservation requirements in effect for the entire year for Lake Michigan water, and outdoor water use rules apply during the growing season (May 15-September 15). The state's water conservation program requires conservation by the end user and the owners of water distribution systems. Requirements for end users include metering of all new services, low-flow plumbing fixtures, lawn sprinkling restrictions and recycling on automatic car wash facilities. All of the municipal permittees have adopted the required ordinances and building codes pertaining to water conservation, so there is no direct monitoring of these conservation efforts by the state. Distribution

Table 4-1
State/Provincial Water Conservation Programs and Drought Contingency Plans (as of January 1998)

Jurisdiction	Conservation Program	Local Conservation Efforts	Drought Contingency Plan
Illinois	For Lake Michigan water, conservation required and outdoor rules apply during growing season. System owners and end users both required to conserve. Promotion through printed materials. Permittees cannot exceed unaccounted-for-flow of 8 percent.	Municipal permittees have adopted ordinances and building codes requiring conservation.	None, but individual plans encouraged for permitted users. Governor's Drought Task Force discusses drought conditions.
Indiana	None, except during drought.	Local governments support conservation efforts during drought.	Three water shortage phases used with recommendations for action. First phases use voluntary reductions and public outreach. Phase III uses mandatory restrictions. Water Shortage Task Force can be formed to advise the governor.
Michigan	None	Individual municipalities and local governments use drought measures as necessary.	None, but ad hoc interdepartmental task forces have been formed.
Minnesota	Permits require all users to be efficient. Public water suppliers and agricultural irrigators must have conservation plans.	Local demand management measures are required to obtain approvals for new municipal wells or increases in authorized water volumes.	Current plan specific to Mississippi River, but being updated to whole state. Public suppliers and surface water users must have contingency plans. Drought plan includes mandatory restrictions. Multi-agency/stakeholder task force implements the plan.
New York	Water suppliers required to have conservation programs. Goal to maintain unaccounted-for water below 15 percent. Publicity and consumer education efforts required.	Local entities may provide additional support.	State Drought Management Task Force recommends four different drought stages. The first two stages focus on voluntary reductions. The final two stages use mandatory restrictions.
Ohio	None, except during drought.	Local entities may provide additional support.	Four phases of drought are used. The second two phases use voluntary conservation and public education; phase four uses mandatory restrictions after governor declaration. Drought Executive Committee is activated in phase three.
Ontario	Building code and planning laws require low-flow plumbing and other conservation measures. Education initiatives promote conservation. Provincial Water Use Strategy guides efforts.	Municipal levels have regulations and are involved in education during low water conditions. Communities receive federal money to reduce public use.	Three drought indicator levels used. Level 1 is voluntary, Level 2 is regulatory and Level 3 is mandatory. Ontario Low Water Response Plan guides partnerships between local and provincial agencies. Local Water Response Teams develop conservation plans.
Pennsylvania	Public water suppliers using surface water required to have conservation program. Various conservation efforts are used.	Local entities may provide additional support.	Three drought stages used. The first two stages have voluntary restrictions of various levels. The third stage may also include mandatory restrictions. Water suppliers and commercial and industrial users required to have drought plans.
Québec	None, but provincial ministries provide financial support to local efforts and NGOs. The organization RÉSEAU-Environment promotes conservation through a variety of methods.	A range of conservation occurs at local scale, including infrastructure replacement, restrictions on water use, and education programs.	None
Wisconsin	None, but conservation plans recommended as part of wellhead protection plans (required for municipal wells). System losses regulated by Public Service Commission. Plumbing flows regulated by Department of Commerce.	Local entities may provide additional support.	Declaration determines the presence of drought emergency. Formal plan, stages not used. Mandatory restrictions imposed with declaration of drought emergency.

system owners, or permittees, report annually the amount of Lake Michigan water used along with the amount lost due to unaccounted-for-flow. If a permittee's unaccounted-for-flow exceeds 8 percent, a plan of action for meeting the 8 percent standard must be submitted. Water conservation is also promoted by a variety of pamphlets and booklets the Department of Natural Resources makes readily available.

The state has no drought contingency plan, but the Department of Natural Resources encourages permittee emergency water conservation plans in case of temporary water supply failure. A Governor's Drought Task Force makes recommendations on drought situations.

Indiana

Indiana has no formal water conservation program. The Indiana Water Shortage Plan provides criteria for determining the severity of a drought and recommends actions that should be taken during three water shortage phases. The plan recommends approaches for individuals, utilities, and local and state governments to conserve water during different stages of drought and establishes priorities for water use. Phase I and Phase II occur through a joint declaration of the Department of Natural Resources and the State Emergency Management Agency. These phases focus on voluntary water use reductions and public outreach. Phase III involves an emergency declaration by the governor and mandatory restrictions on certain water uses. Also, a governor's advisory Water Shortage Task Force can be formed with representatives from several agencies.

Michigan

Michigan has no formal statewide water conservation program or drought management plan. In the past, interdepartmental task forces have been formed to address drought conditions. Individual municipalities or local governments implement drought management measures as necessary.

Belle Isle fountain, Detroit, Mich.

Minnesota

Minnesota's water conservation program includes both planning and permitting requirements. The state requires all permittees to use water efficiently and meet certain permit conditions. The state Department of Natural Resources coordinates conservation requirements with the state Department of Health for well construction approvals, Drinking Water Revolving Fund requests and wellhead protection efforts. Approaches to water conservation include planning, education, conservation rate structures, metering, leak detection and repair, retrofitting programs, local regulations, and elimination of wasteful use.

Minnesota statutes specifically require conservation plans for public water suppliers and agricultural irrigators. Public water suppliers must implement demand reduction measures before requesting approvals for construction of new municipal wells and increases in permitted water withdrawals. Public water suppliers must have unaccounted-for water volumes below 20 percent as a condition of their permit. Irrigation permit applicants must obtain approval from the county soil and water conservation district, which may impose site-specific conservation requirements.

The state's drought contingency plan is specific to the Mississippi River, but is being updated to reflect all state resources. As part of the drought plan, public water suppliers serving more than 1,000 people must have an approved water emergency and conservation plan that is updated every 10 years. These plans are required for wellhead protection plans and applications for the state's Drinking Water Revolving Fund. All surface water appropriators must have an approved contingency plan. As the plan goes into effect, statutory water use priorities determine which water uses are suspended. An agency and stakeholder task force helps implement the plan.

New York

The Department of Environmental Conservation's Public Water Supply Permit Program (PWSPP) requires new water supply permit applicants to have water conservation programs. The water supplier holds responsibility for implementing the program, and the PWSPP monitors compliance with the programs. The PWSPP requires permittees to develop and implement long-term water conservation measures such as metering, meter replacement/calibration, system water audits and leak detection and repair. The goal of each program is to keep unaccounted-for water to 15 percent or less. The PWSPP also requires publicity and consumer education efforts.

The State Drought Management Task Force, comprised of several state agencies, evaluates drought conditions and recommends to the governor and State Disaster Preparedness Commission which drought stages should be announced. During "Watch" and "Warning" stages, conservation recommendations focus on outdoor use and there are no mandatory statewide restrictions. The governor can declare an "Emergency" stage and require water conservation measures. In the "Disaster" stage, restrictions can be stricter and the governor may request federal assistance. The state Department of Health (DOH) also requires community water supply systems with more than $125,000 in annual gross operating revenues to have a Water Supply Emergency Plan. Local water suppliers are responsible for implementation, and the DOH monitors compliance.

Ohio

Ohio has no formal water conservation program. Ohio's Drought Response Plan has four phases, with increasing amounts of water conservation. Various levels of voluntary water conservation measures are requested during Phase Two and Phase Three Drought Alerts. At these levels, public water suppliers, their customers, and private withdrawers are asked to voluntarily reduce their water use. A Phase Four Drought Emergency, which involves mandatory water use restrictions, occurs by the governor's declaration when water supplies will not meet projected demands and the Palmer Drought Severity Index reaches 4.0 or lower. The Ohio Emergency Management Agency heads Ohio's drought response team and enforces water use restrictions. The Drought Executive Committee is activated during Phase Three and includes relevant agencies and interest groups that assist in monitoring water use to identify non-compliance.

Ontario

Ontario has no formal water conservation program, but federal, provincial and local governments employ a variety of conservation strategies. Many communities restrict outdoor water use, require meter installations and require conservation plans, while the federal government supports water conservation through research, information sharing and funding local conservation efforts.

At the provincial level, a number of regulations impact water conservation. The Ministry of Environment (MOE) "Permit to Take Water" program requires a permit for withdrawals greater than 50,000 litres (13,200 gallons) per day and gives priority to natural ecosystem function protections. Water conservation is required for permit applications in the Greater Toronto Area. Provincial building codes require low-flow plumbing fixtures, retrofits, education programs and support for municipal conservation efforts. The Provincial Planning Act requires consideration of water conservation during planning. The MOE undertakes provincial water conservation education initiatives and the Ministry of Agriculture and Food promotes agricultural best management practices for agriculture.

Drought is managed through the Ontario Low Water Response Plan, which uses partnerships between local and provincial agencies. A local water response team is comprised of stakeholders who work with provincial ministries to find ways to reduce demand. The plan relies on existing legislation to ensure provincial preparedness and to support and coordinate local response. For example, the Ontario Water Resources Act allows the Minister of Environment to limit water withdrawals for permitted uses. The plan includes three drought indicator levels. Level I seeks a voluntary 10 percent reduction in water use. Level II seeks a voluntary 20 percent reduction, and municipal bylaws may be enacted to restrict non-essential uses. Level III includes mandatory water use restrictions and allocation priority recommendations.

Pennsylvania

In Pennsylvania, public water supply agencies withdrawing or using surface water are required to develop a water conservation program. The Department of Environmental Protection (DEP) provides its Drought Information Center guidelines to assist in program development, and a Permit Compliance Report process ensures that a variety of conservation efforts occur. The state investigates public water supply systems that do not have water use that falls between 40 and 70 gallons (150 and 265 litres) per capita per day. The last comprehensive study indicated a statewide average usage of 62 gallons (235 litres) per capita per day for metered systems. The state also investigates unaccounted-for-flows that exceed 20 percent by looking at domestic connection per capita usage.

Streamflow, groundwater levels, reservoir storage, precipitation, and the Palmer index are all used to determine one of three stages of drought. Levels of reduced water use are targeted within each stage: 5 percent in Drought Warning, 10 percent to 15 percent in Drought Watch and at least 15 percent in Drought Emergency. The third stage may also include mandatory restrictions. Water suppliers in a drought emergency area can ration water during the emergency stage with approval from the Commonwealth Drought Coordinator. The state's drought regulations require water supply systems with more than 50 connections to provide the DEP with drought contingency plans. Industrial and commercial water users that use more than 100,000 gallons (380,000 litres) per day in any 30-day period must also have a drought plan.

Québec

Québec has no mandatory water conservation program or drought contingency plan. Conservation efforts occur at the local level, and provincial ministries provide financial support to some non-governmental organizations, such as RÉSEAU Environment, which promotes water conservation through publications, conferences, publicity campaigns and a website (www.reseau-environnement.com). Québec also provides financial support to small municipalities for replacement or improvement of drinking and wastewater infrastructure. Municipalities implement conservation measures (e.g., limiting hours when lawns can be watered) and work with other organizations to provide education and incentive programs. Some municipalities and organizations, such as the Montreal Urban Community, have education programs in schools and awards for institutions that improve their water management.

Wisconsin

Wisconsin has no required formal water conservation program, but the state recommends water conservation plans as part of wellhead protection plans that are required for all new municipal wells. The Department of Natural Resources regulates supply sources and users, such as community water supplies and hydroelectric facilities. The Public Service Commission regulates water rates, pressure standards and system losses, and the Department of Commerce regulates water use standards for new plumbing fixtures.

The statewide drought contingency plan takes effect when the governor declares an Emergency Executive Order. This plan can include mandatory water conservation measures that occur as a drought increases in severity, but there are no compliance provisions. A statewide technical advisory committee has given consideration to the criteria for determining the stages of a drought, but no statute or rule has been adopted.

Summary Analysis

A variety of water conservation efforts are occurring at the state/provincial level, but further progress is needed. Current water conservation practices that some jurisdictions require or encourage include: use of low-flow plumbing fixtures; metering; outdoor water use restrictions; reports on water use and unaccounted-for flow; publicity and consumer education; rate structures; wellhead protection plans; and leak detection and repair.

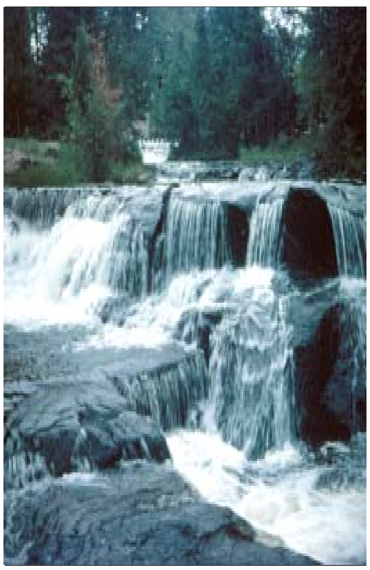
These practices provided initial guidance in developing the 15 recommended conservation measures in the following section of this chapter. Many of the above-mentioned conservation practices are implemented at the municipal/local level, where they are most effective, and further research is needed to assess the extent to which these water conservation efforts are presently employed. Research is also needed to determine the level of water conservation occurring in other water use sectors, such as industry and agriculture.

Several of the water conservation programs currently in place provide elements that should be considered in development of a regional initiative. Illinois' water conservation program is noteworthy for the fact that it provides specific conservation requirements and implements a year-round program. Knowledge gained and lessons learned from Illinois' program, as well as Minnesota's and Ontario's permit-related water efficiency requirements, New York's and Pennsylvania's water supplier conservation program requirements, and elements of the various drought plans, should be considered when assembling guidance for basin-wide water conservation. These programs focus primarily on the public supply sector; other elements will need to be integrated into a regional water conservation approach based on the outcomes of future research on other water use sectors. Jurisdictions without any water conservation program have a clear need to devote time and resources to plan and implement a program.

Existing drought contingency plans appear to provide an appropriate process for addressing emerging water shortage situations and are generally adaptable to varying needs over the course of the year. Jurisdictions without drought contingency plans, including states, provinces and municipalities, should move expeditiously to develop them.

Developing Coordinated Conservation Programs

Water conservation programs and practices at the individual state, provincial and municipal levels suggest a growing awareness of water management needs as well as current/prospective water use conflicts in the region. Such measures, however, are limited in scope and geographic coverage, and are generally not coordinated with other jurisdictions. Consequently, the region lacks a basin-wide framework or over-arching plan, compromising the effectiveness of individual efforts and the region's ability to effectively demonstrate responsible use of its water resources.


Tahquamenon Falls, Michigan

The rationale for a coordinated approach to water conservation is compelling, and is found in the International Joint Commission's February 2000 report, *Protection of the Waters of the Great Lakes*, and the June 2001 Great Lakes Charter Annex. The IJC report recommends that: "Sharing of conservation experiences among basin jurisdictions should be an integral part of the overall approach to conservation programs and practices. Jurisdictions may wish to adopt some common approaches, as appropriate, in their water conservation plans, including incentives to encourage water demand-management initiatives and the installation of best practicable water-saving technology." In Directive #6 of the Great Lakes Charter Annex, the governors and premiers agree to "develop guidelines regarding the implementation of mutually agreed upon measures to promote the efficient use and conservation of the Waters of the Great Lakes Basin within their jurisdictions." Based on this provision and Directive #3, which stipulates that water conservation will be part of the decisionmaking standard, water withdrawal proposals will need to demonstrate appropriate water conservation efforts.

A challenge in implementing these directives will be developing guidance that recognizes the unique hydrologic and ecological characteristics associated with each prospective water withdrawal location and use.

Basic Guidance for Regional Water Conservation

Great Lakes states and provinces will benefit from guidance in developing regionally consistent and coordinated water conservation programs. Basic guidance focusing on public water suppliers is provided in this section; additional research is needed to provide more comprehensive guidance for other water use sectors.

As outlined in the section on state and provincial water use programs, several basin jurisdictions currently require or encourage water suppliers to pursue specific water conservation practices. These should be a foundation in the development of any model programs or guidance to be considered at the regional level. Based on these practices and other reference materials,[1] Table 4-2 has been compiled to present 15 water conservation measures that can be implemented by state, provincial and regional decisionmakers as well as municipalities, water suppliers and other water users. Measures are categorized as Financial, Programmatic, Technological and Informational.

Financial

In the residential water use sector, programs offering financial incentives can be used to encourage water conservation. Some of the most common entail paying for, or subsidizing, retrofits and replacement of older plumbing fixtures, measures that provide instant reductions in water use. Also, metering and submetering allow for the establishment of rate structures with incentives for reduced water use and give end users the ability to track such use. Similarly, industrial facilities can install their own meters to monitor water use at various points in a production process so that potential conservation savings can be identified.

[1] See, in References section, AWWA, 1969, AWWA, 1991; AWWA, 1995; CUWCC, 2002; 17 Ill. Adm. Code 3730; 42 USC 13385; USEPA, 1998; Vickers, 2001.

Table 4-2
Fifteen Suggested Water Conservations Measures

	Water Conservation Measure
Financial	• Incentives to improve water conservation, including retrofits • Conservation pricing/rate structures • Metering and submetering for industrial uses • Universal metering/submetering with commodity rates for public supply water
Programmatic	• Reports on water use and unaccounted-for flow • Leak detection and repair; reductions for water utility operations • Integrated resource planning • Water system pressure management to reduce volume of water used • Water recirculation and reuse in industrial processes
Technological	• Low-flow plumbing fixtures and other water-efficient appliances • Efficient equipment for industrial/commercial facilities and agriculture
Informational	• Promoting efficient practices in industrial/commercial facilities and agriculture • Encouraging efficient water use and equipment for landscapes, including graywater • Public information and school education programs • Advocating use of native and drought-tolerant turf and plants

Programatic

Many conservation measures implemented by a water supplier or large end user require extensively planned and executed programs. Reliable information and regularly scheduled reports on water use and unaccounted-for flow help identify areas for system improvement, and can prompt follow-up action, such as system maintenance or repair. Public water suppliers may initiate other internal conservation programs that reduce water used for operations, such as mains flushing and filtration plant backflushing (Ellison, 2002). Integrated resource planning employs a comprehensive process to consider supply alternatives and to ensure that the most efficient water supply approach is implemented. Other programmatic approaches include altering water system pressure to control water volumes and recirculating and reusing water in industrial processes.

Technological

Technological advances create new options for increased efficiency. In the public water supply sector this can be accomplished through the increased use of low-flow plumbing fixtures and appliances. Industrial, commercial, and agricultural equipment can also be made more efficient through technological improvements. The choice of technology largely depends on the needs of the individual water user, but can be as simple as replacing an older toilet with a low-flow model. For example, the U.S. Energy Policy Act of 1992 requires a maximum manufacturing standard of 1.6 gallons (6 litres) per flush for toilets.

Informational

Information campaigns targeting all sectors of the basin community can be effective in promoting water conservation practices. For example, domestic users can turn off faucets when they are not in use and agricultural users can monitor climate and temperature to irrigate with a goal toward reduced losses to evapotranspiration. Appropriate adoption and use of landscape equipment also can reduce water use, as can planting of native and drought-tolerant vegetation. Industrial and commercial facilities can often find ways to alter operations or procedures to reduce unnecessary water consumption.

Findings and Recommendations

Findings

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 it can responsibily 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 can 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 of reducing costs and providing 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-St. Lawrence 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.

Based on current programs and several consulted guidelines, a list of 15 water conservation practices ranging from financial incentives to improvements is provided in Table 4-2 of this chapter as basic guidance.

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."**

   A coordinated regional approach to water conservation needs to be developed and implemented to demonstrate the region's commitment to responsible water management. The region, including each state and province, must remain committed to a new "environmentally sound and economically feasible" water conservation standard. This will avert potential water shortages while providing economic and technical efficiencies and ecological benefits. Regional goals could be developed for "environmentally sound and economically feasible" water conservation by water use sector.

   Development of models at the basin level based on jurisdiction conservation experiences will assist the states and provinces in developing their own programs and contributing to basin-wide initiatives. Elements of current state and provincial water conservation programs, including the list of 15 best management practices in this chapter, should be used in conjunction with other research to provide this guidance. The Great Lakes Commission's water conservation project, funded by the Great Lakes Protection Fund in 2002-03, will help in developing these models.

2. **Establish an information clearinghouse to publicize best management practices pertaining to individual sectors of water use.**

   Information within this chapter, including the list of 15 suggested water conservation measures, needs to be followed with more research: surveys of water suppliers (largely at the local level) that provide profiles of existing programs; case studies of effective programs in other regions of North America and beyond; and identification of appropriate measures that should be included in a decisionmaking standard. This research should outline which water conservation practices are most applicable to each water use sector and special local conditions, such as ecological sensitivities. A clearinghouse that details this research should be developed and maintained to provide water users and decisionmakers with the information.

3. **Develop and update state/provincial drought contingency plans to ensure adequate attention to water conservation.**

   As a basic step toward regional water conservation, drought contingency plans need to be adopted at the state and provincial levels. Increased understanding is needed on the range of natural variation of the resource and how to plan for the extremes. Jurisdictions (including states, provinces, municipalities and agricultural districts, among others) that have no drought contingency plan should develop them so they can address future water shortage situations.

4. **Develop specific water conservation provisions as part of state/provincial water management programs.**

   All states and provinces should develop water conservation provisions within their water management programs. Jurisdictions without any such program should devote the time and resources needed for plan development and implementation.

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.**

An economic analysis needs to be undertaken to demonstrate the economic benefits of various water conservation measures. This analysis should build upon previous efforts and help define which conservation approaches are "economically feasible" for the region.

6. **Develop a regional information/education program to promote the adoption of water conservation practices.**

   An information/education program at the regional level is needed to promote water conservation priorities and explain their benefits. This will help address the misperception that the Great Lakes basin's abundant water is readily available, without limit, as a supply source to all in-basin interests. The program should encourage water users to adjust consumption habits to minimize pressure on the resource. A variety of publicity tools should be employed, and the program should track performance over time and be regularly updated to reflect evolving needs.

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Chapter Five

Ecological Impacts Associated with Great Lakes Water Withdrawals

Introduction

The Great Lakes Charter of 1985 established a prior notice and consultation process for Great Lakes diversions and consumptive uses averaging more than 5 million gallons per day in any 30-day period. One of the five principles set forth in the Charter is the *Protection of the Water Resources of the Great Lakes*, which states that "diversions of

Great Blue Heron

Basin water resources will not be allowed if individually or cumulatively they would have any significant adverse impacts on lake levels, in-basin uses, and the Great Lakes Ecosystem." The Great Lakes Charter Annex builds on the Charter by seeking to develop an "enhanced water management system that …most importantly, protects, conserves, restores, and improves the Waters and Water-Dependent Natural Resources of the Great Lakes Basin." This pursuit of long-term sustainability for the basin's water resources would preserve water quantity and quality in a way that maintains or enhances the ability to provide social, economic and environmental services. A key tenet of this water resource management approach is to prevent water withdrawal and use from having adverse ecological impacts on the Great Lakes ecosystem.

In specifying its concern about preventing adverse ecological impacts of water withdrawals in the Great Lakes, Directive #3 of the Great Lakes Charter Annex calls for a new decisionmaking standard that the states and provinces will use to review new proposals to withdraw water or increase existing water withdrawals from the Great Lakes basin. The new standard is based upon four principles, including:

- *No significant adverse individual or cumulative impacts to the quantity or quality of the Waters and Water-Dependent Natural Resources of the Great Lakes Basin; and*
- *An Improvement to the Waters and Water-Dependent Natural Resources of the Great Lakes Basin.*

Implementation of such a decisionmaking standard in a fair and equitable way requires a quantitative understanding of the relationship between water withdrawals, other human uses and the cumulative ecological response of the system.

The Ecological Impacts Technical Subcommittee of this project compiled an inventory of the data and knowledge base and tools available for applying a regional resource-based decisionmaking standard and, in so doing, identified gaps in understanding and assessment capabilities.

Work under this project element included: a) the development of a list of "essential questions" regarding potential ecological impacts that should be addressed in reviewing water withdrawal proposals; b) a literature search and analysis; and c) an inventory of existing models.

This chapter presents the basic framework developed for assessing ecological impacts of water withdrawals/diversions, including a comprehensive list of "essential questions" that should be addressed in making such an assessment. An Experts Workshop, held in November 2001, provided initial input to the development of the preliminary set of questions, refinement of the framework and "essential questions," and identification of data and research needs relative to addressing these questions. The essential questions express *what decisionmakers need to know*. This chapter also presents a summary of a literature review and describes the model inventory. The literature search focuses on the knowledge and data available for assessing ecological impacts of water withdrawals/

diversions. The model inventory provides a list of modeling tools for making ecological assessments. These last two sections summarize *what is known in the area of ecological impacts* and *where the major gaps are.*

"Essential Questions" for Ecological Impact Assessment

Introduction

In November 2001, U.S. and Canadian scientists, policymakers and managers drawn from states, provinces, federal agencies and nongovernmental sectors participated in an Ecological Impacts Experts Workshop. The primary objectives of the workshop were to identify the types of "essential questions" that must be considered to evaluate the potential ecological impacts of any proposed water withdrawal, begin to develop an inventory of information on ecological impacts, and provide an opportunity for participants to raise related issues and concerns. Experts from a range of relevant disciplines were invited to serve on a panel to fulfill these objectives. Panel members included individuals with expertise in fisheries biology, surface and groundwater hydrology, wetlands ecology, aquatic ecology, bird ecology, environmental engineering, and other relevant disciplines. The full workshop summary is available in the Appendix.

Approach to Developing List of Essential Questions

An initial list of "essential questions" was presented for consideration. This information was derived by considering the range of possible impacts from a theoretical perspective and from the literature review (see Section 6.3), consulting with the Project Management Team, and reviewing the results and recommendations of an Ecological Indicators Workshop held in Burlington, Ontario (Leger et al., 2001). This initial list of questions was prepared for the workshop participants to react to and refine during the workshop. In developing this list, there was recognition that there are multiple levels of questions that relate to different levels of authority, and this list does not address all levels of detail. It was also recognized that, in a decision support framework, not all questions would be essential, and not all would need to be asked for every situation. Rather, the panelists were asked to develop a list of questions that are the *types* of questions that should be considered to assess impacts of water withdrawals.

Workshop participants were provided with background information, including the following guidance on the essential questions:

- Questions will be focused on scientific issues and not on regulatory or socio-economic issues (although the final decision support system may consider these);
- Questions may be posed to either regulated or regulator parties;
- Localized as well as regional and cumulative impacts should be considered;
- Human health impacts should be considered.

Figure 5-1 presents the proposed framework for assessment. Each box represents a category of essential questions, and the arrows indicate how these impacts interact. The list of questions is categorized by the main headers in the boxes of the framework.

Workshop participants refined the list of essential questions, and the outcome is presented below. In addition to the essential questions, participants identified several scientific and policy issues related to the larger assessment process. These issues included how to characterize the baseline

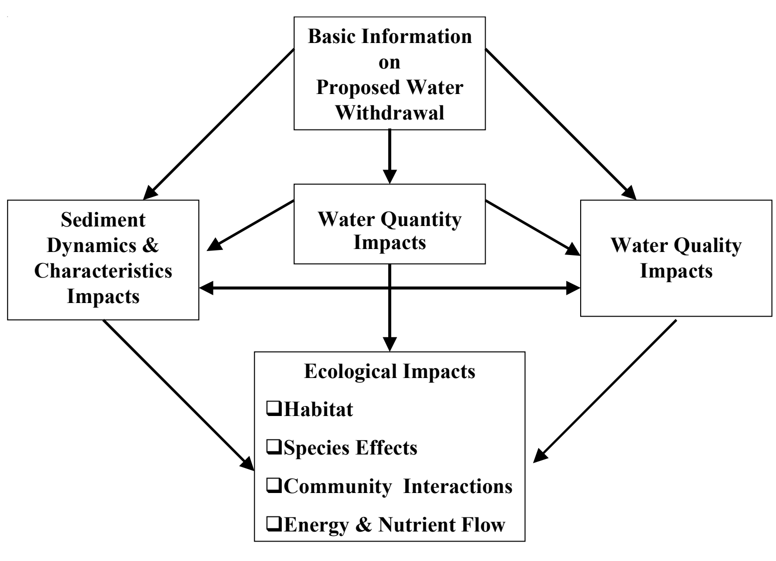

Figure 5-1
Proposed framework for ecological assessment of water withdrawals

condition, how to quantify ecologically significant change, how much of a change is acceptable from a policy perspective, and the need for management objectives. While several issues were discussed, it was beyond the intent of the workshop to reach consensus or draw conclusions related to these issues. Rather, the workshop provided an opportunity for an "open airing" of issues and concerns related to this topic.

List of Essential Questions

Category 1: Basic Information on Water Withdrawal

The first category of questions covers basic information on the proposed water withdrawal, such as the characteristics of the source and return water bodies, the proposed use of the water, and information related to the structure and operation. These questions also address alternatives to the proposed withdrawal, and the associated impacts.

1. **Where is the proposed water withdrawal?**
   If water withdrawal is from a Great Lake, St. Lawrence River, or Connecting Channel:
   - What is the specific location and depth of withdrawal?
   - What are the relevant hydrology, geometry, hydrodynamics, and water quality in the vicinity of the withdrawal?

   If water withdrawal is from a river:
   - Where is it located on the river?
   - What are the statistics on flow regime (average flow, 7Q10, 100 year flow)?
   - What are the key characteristics of the river and watershed? Characterize subwatersheds by land use types.

   If water withdrawal is from an inland lake:
   - What are the inflows and outflows?
   - What is the lake geometry?
   - What is the range of water levels?
   - What is hydraulic retention time?

   If water withdrawal is from a groundwater source:
   - What is the elevation of the water table?
   - What is the size of the aquifer?
   - What is the general characterization of the aquifer?
   - What is the estimated sustained yield of the aquifer?
   - How does this aquifer relate to the surface waters of the Great Lakes basin?
2. **What is the existing quality of the source water and sediments?**
   - Temperature
   - Nitrates
   - Dissolved oxygen
   - Buffering capacity
   - BOD
   - Salinity
   - Total dissolved solids
   - Sulfur
   - Pathogens
   - Water conductivity
   - Dissolved organic carbon
   - Persistent toxic substances
3. **Describe the current assimilative capacity of the source and return water.**
4. **Describe the key habitat characteristics for habitats associated with the source or receiving water (i.e., quality, access, resilience)**
   - Are there endangered or threatened species or fragile habitats associated with the source water? If so, list and describe.
   - Does the area of influence contain a significant amount of seasonal/semipermanent wetlands, bogs or fens that are directly linked to the water table? If so, describe.
5. **What components of the system are most sensitive to withdrawals? Which of these will most likely improve?**
6. **What are the existing uses (e.g., drinking water) of the source water body?**
7. **Is there a watershed management plan or objective for the area where the withdrawal is proposed to be made? For the source water? If so, is the proposal consistent with the plan?**
   - What are the existing water quality standards for the source water? For the return water?
8. **What is the proposed use of the withdrawn water?**
   - Will its water quality be altered by this use? What are the water use processes? If so, explain.
   - Will the use be consumptive? If yes, what fraction of withdrawn water is consumed?
   - What is the potential for future changes in the proposed use?
9. **What is the proposed rate of withdrawal?**

- Will there be seasonal or diurnal variations in withdrawal rate? If so, describe.
- What is the anticipated duration of this withdrawal? Will the diversion be essentially irreversible?
- Is an increase in water withdrawal anticipated in the future?

10. **Where is the unconsumed water proposed to be returned?**
    - Will the water be impounded before being returned? If so, describe.
    - Will it be treated before it is returned? If so, describe treatment.
    - If in same water body, where is return located with respect to withdrawal?
    - If different water body, what is the location of the water return?
    - What is the quality of the receiving water for the return?
    - Are there endangered or threatened species or fragile habitats associated with the receiving water? If so, describe.
    - What are the existing uses of the receiving water for the return?

11. **What will be the physical structure and operation of the proposed water withdrawal and return?** Describe the intake structure and operational plan in detail.
    - Will there be any physical, chemical, or biological impacts due to the withdrawal operation? Describe in detail and include entrainment or impingement effects.

12. **Are other options to this proposed withdrawal available? Can the location of the proposed withdrawal be changed to minimize the impact?** If so, describe the impacts that are associated with these alternatives.

Category 2: Water Quantity

Questions in this category relate to flows, water levels, groundwater yields, and other information about water quantity in the source and the receiving water.

1. **For the source water, receiving water for returns, and any other impacted waterbodies (including bypassed reaches, downstream waterbodies and impacted wetlands), does the withdrawal affect:** If yes to any of the questions, describe the impacts.
    - Baseflow?
    - Range and timing of water levels or water table elevation fluctuations (including seasonal ranges or fluctuations)?
    - Flows and flow variability?
    - High water mark? Stream status (permanent or intermittent)?
    - Index?
    - Recession (rate of recharge)?

2. **How large is the proposed water withdrawal in the context of total system flows in the source water and the receiving water?**

3. **If there are impoundments, will there be a reduction in peak flows?**
    - Will there be a loss in variation of water levels? If yes, describe the impacts.

4. **For groundwater withdrawals:**
    - How important is groundwater seepage in the overall water budget and water characteristics of hydrologically-connected surface waterbodies (e.g., baseflows, water temperature)?
    - Will there be a reduction in the amount of groundwater exchange with the river? Or timing of? Explain.
    - Will there be an effect on any drinking water wells? If yes, explain.

Category 3
Sediment Dynamics and Characteristics

Questions in Category 3 relate to potential changes in sediment suspension and distribution, or sediment characteristics as a result of the water withdrawal.

1. **Will there be a change in sediment suspension and distribution (i.e., erosion, accretion/deposition, turbidity) in the source water or the return water?**
    - What is the anticipated magnitude and extent of this impact?
    - Will this alter the shoreline geomorphic features or the location and area of shallow water zones? In what way?
    - Will this change result in the need for increased dredging? Explain.
    - If there are impoundments, will there be a reduction in total sediment delivery? Explain.
    - Will there be significant effects on dynamic beach/coastal processes? Explain.

2. **Will the water withdrawal affect wave energy dynamics?** If yes, describe the effects.

3. **Will there be a change in sediment characteristics in the source water or the return water?**
   - Will there be an increased sediment contamination by persistent toxic substances?
   - Will there be a change in the properties of suspended or bedded sediments?
   - Will there be an alteration of the organic carbon content of sediments?
   - Will there be an increased sediment oxygen demand?

Category 4: Water Quality

The following questions relate to the quality of the source and receiving water, including any potential impacts related to invasive species.

1. **How will the withdrawal alter the water quality of the source water and the return water? Address changes in:**
   - Temperature
   - Nitrates
   - Dissolved oxygen
   - Buffering capacity
   - BOD
   - Salinity
   - Total dissolved solids
   - Sulfur
   - Pathogens
   - Water conductivity
   - Dissolved organic carbon
   - Persistent toxic substances
   - Nutrients
2. **Are there invasive species in the source water or return water? Please list.**
   - How are invasive species in the source water affected (negative and positive impacts)?
   - What pathways, if any, will be created by the withdrawal/diversion that would allow invasive species to spread?
3. **Will the water use (e.g., irrigation) lead to degradation of unrelated water supplies (e.g., ground-water)?** Explain.
4. **Will there be alteration of the thermal profile in the source or receiving water?** Explain.

   If there are impoundments, will there be an increase in water temperature? Explain.

Category 5: Ecological Impacts

Questions in Category 5 relate to potential impacts on habitats, structure and function of the ecosystem, and any ecological benefits that may occur as a result of the proposed activity.

1. **For the source and return systems, will the changes in water quantity, sediment dynamics, and/or water quality:**

   affect aquatic or terrestrial habitats?
   - Will there be habitat loss or gain?
   - Which species habitats are impacted (fish, benthos, birds, amphibians, reptiles, mammals, invertebrates)? Will any sensitive species such as piping plover be impacted?
   - What are the habitat attributes that are impacted? For example, for migratory species, will access or connectivity be affected? Will resiliency of the habitat be affected?

   affect production or diversity of flora (including phytoplankton, periphyton, and macrophytes)?

   cause acute or chronic toxicity to any species?

   affect population levels or growth rates of any species in impacted system?

   affect hyporheic zone and subsequently affect surface aquatic systems?

   have an ecological impact on assemblages of endangered/threatened species?

Describe any changes in detail. Include consideration of any seasonal pattern of withdrawals, and the related effects on impacted species (e.g., access to fish spawning areas in the spring).

2. **For the source and return systems, will the changes in water quantity, sediment dynamics, and/or water quality:**

   affect predator-prey relationships or food web structure and/or function in the impacted system?
   - If yes, which species are impacted?
   - If yes, how will the whole community structure and function be impacted?

   cause a change in the energy flow or nutrient cycling through the ecosystem?

   cause an increased bioaccumulation of contaminants in the food web?

   lead to human health impacts through increased contaminant levels in fish or other pathways?

Describe any changes in detail.

3. **What ecological benefits, if any, will accrue from the proposed water withdrawal or diversion?**
4. **Will the withdrawal change the amount or the functioning of riparian land? Describe any changes.**

Category 6: Cumulative Impacts

The questions in Category 6 address the potential for cumulative impacts as a result of the proposed use and other existing and future uses of the water. Questions also address whether there are any features (such as land use) that may alter the impact of the proposed activity.

1. **From a lake-wide, river, connecting channel, and/or systemwide basis, how will this withdrawal (and return flow if applicable) affect:**
   - water levels and flows?
   - water quality and ecological health of the source water?
   - water quality and ecological health of the receiving water for the return?
2. **Will this withdrawal (and return flow if applicable), when combined with ongoing and anticipated future withdrawals, cause a deviation from the hydrology/hydraulics of the system that is required to maintain the health and integrity of the ecosystem? In what way?**
3. **Will changes in the hydrology/hydraulics of the Great Lakes-St. Lawrence River system that may result from global climate changes alter the impact of the water withdrawal? In what way?**
4. **Can further impacts be anticipated in the long-term on such things as land use or population, as a result of the project?**
5. **Are there any existing or potential features that would alter the impact of the water withdrawal (channel/lake structures, channel lake substrate, existing land use, water control structures, conservation)?** If so, describe.

Discussion

The essential questions should be considered when assessing the potential ecological impacts of water withdrawals, but not all of these questions need to be asked for all situations. Answers from basic questions would determine which set of questions would be asked next. In turn, answers to this second set of questions would determine which finer level questions would be asked. Certain questions would be skipped entirely, and the certainty and specificity of the questions that would be asked would depend on the unique needs of each case.

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. Some questions can be answered by referring to available information (e.g., what are the current uses of the water body?), while others may require site-specific studies to answer (e.g., will there be an impact on aquatic and terrestrial habitats?). Other questions may be very challenging, if not impossible, to answer given the current state of knowledge (e.g., will changes in the hydrology/hydraulics of the Great Lakes-St. Lawrence River system that may result from global climate changes alter the impact of the water withdrawal?).

The workshop highlighted many unresolved scientific and policy issues and questions. Some key scientific issues relate to characterization of baseline ecological conditions, detection of ecosystem health and integrity when they have already been compromised, and identification of "essential habitat" (quality and quantity components). Some key policy issues include deciding the socially acceptable levels of ecological change, determining the significance of impacts, and assessing cumulative impacts while accounting for future uses. The workshop emphasized the need for a decision framework as well as monitoring to post-audit decisions and address unanswered questions and uncertainties. The following two sections provide an overview of some resources available for addressing these questions.

Review and Analysis of Ecological Impacts Literature

Introduction

Background

The intent of the literature review report (available in the Appendix) was to compile the body of research relevant to the identification and quantification of ecological impacts that might arise from Great Lakes basin water withdrawals, including diversions. This topic encompasses the entire body of knowledge on the effects of physical, chemical, and biological conditions in a freshwater ecosystem on its structure and function. The reviewers, therefore, had to be reasonably discriminative in selecting literature.

The over-arching hypothesis in organizing this body of literature was that alterations in flow, water levels, or system geometry and hydrology in the course of withdrawing or diverting water for human use produce ecological effects in a serial manner. The withdrawal affects the physical and/or chemical environment, which in turn affects specific populations or groups of populations (i.e., communities). Next, ecosystem structure and function are affected through ecosystem processes such as competition, predator-prey interactions, energy flow, nutrient cycling, and habitat quality and quantity. Of course, ecosystem effects can feed back into the physical, chemical, individual population or community components of the ecosystem. Indeed, these feedback processes are a crucial part of ecosystems because they provide a measure of their stability and resilience to stressors. The final category, synoptic modeling studies, includes those studies that have attempted to demonstrate the coupling among the various types of effects, and thereby include the process understanding and feedbacks that allow a more generic application of site-specific observations.

Objectives

The objectives of the literature review were to:

- Identify and summarize literature that assesses the ecological impacts of water use, levels and flows; assess ecological thresholds with respect to water supply; and present indicators used to assess the ecological impacts of water use and the processes, functions and time scales of those indicators;
- Review frameworks that have been established to assess the ecological sensitivity of freshwater ecological systems to future water use and/or changes to water supply (e.g. under climate change); and
- Prepare a report that presents a descriptive inventory and analysis of literature addressing the ecological impacts of water use.

Approach

Both the published literature and a sampling of the "gray" literature (i.e., government reports and documents published outside of the traditional peer review and publication process) were searched using a variety of methods. The gray literature search focused primarily on the following organizations: U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS) and The Nature Conservancy. Also reviewed were reports and materials from special focused studies conducted by such organizations as the International Joint Commission.

Description of Categories

The literature search indicated that the problem of identifying ecological thresholds and indicators that could be used to assess the cumulative ecological impacts of water use, and their possible application to the Great Lakes-St. Lawrence River system, has not been addressed in the context of water uses and changes in levels and flows. However, as some of the references may have relevance to particular aspects of cumulative impact assessment, the authors grouped the references into four broad categories: 1) effects on physical habitat; 2) effects on populations and/or communities; 3) ecosystem effects; and 4) synoptic modeling studies. These categories are nonexclusive, so some papers could have fit into more than one category. Also, a number of large, focused studies have made or are making significant contributions to these four categories. Each of these studies was dealt with individually.

Effects on Physical Habitat: This category includes literature describing the effects of changes in water levels and flows on physical habitat (substrate, flow, depth and temperature), as well as assessments of physical habitat. Although climate change was not in itself a focus of this literature search, some references of interest have been included under this category. For example, climate change research that addresses changes in river flows, lake circulation and waters levels, as well as the ecological impacts of these changes, is described.

Effects on Populations and/or Communities: This category includes literature describing the effects of water use and of changes in water levels/flows on biological populations and communities. The literature in this category has been subdivided into two sections: effects on flora and effects on fauna. The former section includes literature that describes effects on phytoplankton, aquatic macrophytes and tree species. The latter subcategory includes literature describing effects on fisheries populations, muskrats, turtles and migrating birds. It also includes papers addressing minimum flow requirements for fish.

Saginaw Bay, Michigan

Ecosystem Effects: This category includes papers that describe ecosystem effects from water use or from changes in water levels/flows. A wetlands ecology subcategory specifically details literature on wetland functions, wetland stresses, and wetland assessments. A stream ecology and ecological assessment studies subcategory focuses on literature describing stream assessments and stream assessment techniques.

Synoptic Modeling Studies: This category includes papers describing conceptual or mathematical models. Such models have been employed to predict the spatial distribution of vegetation, to investigate the impact of flow diversion on benthic communities, and to predict habitat suitability for fish. This section also includes literature describing conceptual frameworks for analyzing the ecological impacts of water use in the Great Lakes-St. Lawrence River system. Models that examine relationships with living organisms, and therefore attempt to predict possible impacts or changes, are a very limited subset of the literature on modeling; this search did not include all types of models, (e.g., some hydraulic or hydrologic models).

Special Focused Studies: This category highlights a number of relevant large-scale studies. These studies focus on water level issues in the Great Lakes, ecological impacts from dam and hydropower regulation, and conceptual frameworks for investigating ecological impacts of changing water levels and flows. The papers describe work conducted by the International Joint Commission, the World Commission on Dams, United Nations Educational, Scientific and Cultural Organization's (UNESCO) Ecohydrology Programme, the Waterpower Project (Ontario, Canada) and The Nature Conservancy.

Descriptive Inventory of Literature

The following setions summarize the literature reviewed, organized by the categories described above.

Physical and Chemical Habitat Effects

Studies on the impacts of global climate change in the Great Lakes have great relevance to the assessment of potential impacts of large-scale withdrawals that might impact the water levels in the lakes themselves. Global climate change models vary in their predictions, but show a potential drop in average Great Lakes water levels by 1.5 to 8 feet (0.5 to 2.5 meters). This change in the hydrology of the Great Lakes basin will, of course, have a concentrating effect on all materials (nutrients, toxic chemicals, salinity, plankton, etc.) being carried by the water bodies. Studies have also produced forecasts of a systematic reduction in ice cover. But perhaps one of the major impacts of a decrease in average water levels will be the effect on the temperature regime of the lakes. These temperature changes will likely alter the amount of oxygen in the lakes and may have a significant impact on the movement, feeding and spawning habits of fish in the lakes. These changes can have widespread impacts on the reproductive success and resulting population dynamics of fish, a significant ecological indicator in the Great Lakes.

Many of the other studies in this category focused on the effects of flow and geometry changes in river and lake physical/chemical habitats in the watersheds that drain into the Great Lakes. Many studies dealing with stream habitats identified flow reduction effects on the area and quality of benthic (bottom level) habitats. One of the main observations was that minimum flow rates are required to prevent excess sedimentation in stream reaches that are providing quality fish spawning habitat. Flow alterations and resulting water level changes in inland lakes and river-impoundments (especially those impoundments in the St. Lawrence River) also affect light penetration, thereby causing a change in the nearshore area available for macrophyte (macroscopic plant) growth and a resulting shift in the distribution of primary production between open-water, phytoplankton and nearshore macrophytes.

Population/Community Effects

The population/community effects studies can be divided into flora and fauna. Studies on the impacts of flow and water level changes on flora were generally restricted to nearshore areas, rivers and impoundments. For example, in the St. Lawrence River, phytoplankton biomass decreased in response to flow reduction but species diversity increased. A number of studies found that unregulated water levels led to more diverse macrophyte plant communities while regulated lakes or impoundments had less diverse communities.

Studies of flow effects on fauna included both aquatic species (e.g., fish and benthic invertebrates) and terrestrial species (e.g., muskrats and turtles). Some studies connected water level or flow changes with some impacts on fish, benthos, muskrats and turtles, but these impacts were generally very subtle and connected indirectly to the changes in levels and flows. Some references to direct mortality or spawning effects on fish included the capture of fish larvae and juveniles in water intake systems and impediment of fish migration by dams. Manny (1984) estimated that in 1979, 1.2 billion fish larvae and 98 million juvenile and adult fish were drawn into the water intakes of 90 power plants on the shores of the Great Lakes.

Ecosystem Effects

Most of the available literature relative to effects of flow/level changes was directed at wetland and stream ecosystems. A good review of recent literature on North American freshwater wetlands was compiled by Adamus et al. (2001). This work generally agrees with literature that highlights important wetland ecosystem functions, such as groundwater recharge and discharge, flood storage, shoreline anchoring and dissipation of erosive forces, sediment trapping, nutrient retention and removal, food chain support through primary and secondary production, habitat and refuge for fish and wildlife, and active and passive recreation (Adamus and Stockwell, 1983). While many factors affect wetland function, fluctuating water levels, as exhibited in the Great Lakes under unregulated conditions, clearly are good for wetland diversity and productivity in support of the various functions.

Numerous studies on stream ecology exist that relate to ecosystem effects, and nearly all of these studies recognize the importance of flow (or velocity) and stream depth on ecosystem structure and function. However, these studies generally are not truly systematic and could not control for other stressors (both natural and anthropogenic) that can confound the ability to quantitatively link a stream ecosystem response to a change in the flow regime. Such factors as land use in the watershed, watershed size, and stream geomorphology are among the primary factors that lead to varied responses to flow alterations. These and other stream ecosystem complexities have resulted in increasing use of data-based adaptive management approaches, such as the Instream Flow Incremental Methodology (IFIM) (Bovee et al., 1998) and the Index of Biotic Integrity (IBI) (Karr, 1991). While the application of these methods has great value, the state of the science is far from developing a process-oriented knowledge base that allows for development of a generic, predictive framework to aid in decisionmaking.

Synoptic Modeling Studies

Many conceptual and mathematical models have been developed to relate receiving water and habitat quality to land use/cover in the watershed. In general, these models use a baseline hydrology/hydraulics regime to examine how changes in land use or pollutant loadings impact the system. While many of the models can examine how changes in hydrology may impact the system, these applications remain largely undeveloped.

A number of other models predict changes in riparian vegetation as a function of stream shoreline drying and inundation cycles (Auble et al., 1994, for example). These methods generally indicate that flow variability, particularly minimum and maximum flows, cause impacts.

Baker and Coon (1995a, 1995b) conducted a model development and field testing study that aimed to quantify the effects of stream flow. They diverted about 50 percent of the summer stream flow around a 0.7 kilometer (0.43 mile) reach of Hunt Creek, Michigan, and compared the observed response of benthic macroinvertebrates and brook trout to predictions of their model (PHABSIM – Physical Habitat Simulation). They found no change in the total density of benthic macroinvertebrates; however, they found significant reductions in riffle dwelling taxa (e.g., Heptageniidae). The model and experiment both suggested that measurable negative impacts to brook trout would require greater flow reductions than occurred in the study.

Discussion

In general, the literature offers few fully functional approaches for evaluating cause-effect relationships and cumulative impacts of changes in levels and flows, but the literature may help guide establishment of monitoring protocols and agendas for scientific research. Many of the papers that were reviewed describe the impacts of regulation, withdrawals, and dams on biota, landscape ecology, environmental flows, geomorphologic processes and vegetation landscape, but they lack specific information that relates these impacts to changes in levels or flows. Other articles compare regulated and non-regulated rivers, and a limited number propose assessment methodologies. Some papers describe physical characteristics and ecological aspects of nearshore habitats while others provide conceptual frameworks for describing impacts. In general, the studies explore trends in alterations of freshwater ecosystems, the ecological consequences of bio-physical alterations, and the need for an ecosystem approach. A few discuss the major scientific challenges and opportunities involved in effectively addressing the changes.

A striking diversity of key ecological indicators are used in the various publications: shoreline and nearshore vegetation, inland or riverine/lacustrine wetland vegetation, macrophytes and submerged vegetation, aquatic insects, plankton, benthos and various fish species. This indictor, or end point, concept has a very strong social value representation, but is often site-specific, creating difficulties for development of an integrative concept that can be applied to management objectives (Rogers and Biggs, 1999). The IJC and the U.S. and Canadian governments recognize the importance of restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes ecosystem (Great Lakes Water Quality Agreement, 1972). In an effort to provide indicators of Great Lakes ecosystem integrity and to implement those indicators, the governments, with IJC review and comment, have launched the large-scale State of the Lakes Ecosystem Conference (SOLEC) process to establish indicators and implement an ongoing monitoring effort to assess progress.

Tobico Marsh, Michigan

In the reviewed literature, the terms and concepts of measurements, indicators and thresholds are often used interchangeably. Sometimes the concept of a threshold is more of a descriptive value than a point that can be used to evaluate cumulative impacts. Lack of precision in the use of terminology is common; for example, some authors recognize a distinction between “effects” and “impacts.” This distinction reflects an intentional separation between scientific “assessment” of facts (effects) and the “evaluation” of the relative importance of these effects by the analyst or the public (impacts). While the analytical component or the scientific part of an analysis is often termed “assessment,” the term “evaluation” applies to the significance or importance of an impact and is often value-laden.

The literature review also pointed to a noticeable lack of research on the ecological effects of water withdrawals on connecting channels and the St. Lawrence River. These river systems are hydrologically distinct from the lakes and are especially sensitive areas, although further research is needed to reconcile differences of opinion about sensitivities of these waterways to withdrawals. A small water level change in one or more of the lakes may cause a large response in flow distribution and levels in connecting channels and the St. Lawrence River. For example, the St. Lawrence River is downstream of the lakes, and is thus susceptible to cumulative impacts from all upstream activities. Connecting channels are important fish producers and reservoirs of biodiversity. These waterways may be particularly at risk because they host a concentration of water users, including major hydropower facilities.

While this literature review has pointed out many studies that are relevant to the assessment of ecological impacts of water withdrawals and diversions, most of these studies are site-specific and descriptive in nature. Several test a hypothesis on the presence of a significant response in the system, but do not collect sufficient information for quantitative analysis of the deterministic, cause-effect relationships that underpin the empirical observations. This critical process understanding is needed, through synthesis and model development, to generalize the findings to the various types of Great Lakes basin ecosystems. Hardy (1998) makes an especially relevant point that the future of stream habitat modeling “remains an abstraction, in that integration of all the pieces has yet to be accomplished, field validation remains unproven, availability of an integrated analysis framework (i.e., computer software system) is not yet available, and a clear framework for selection and application of specific tools has not been developed.” Meyer et al. (1999) reach a similar conclusion: “We are limited by availability of both data and models. More extensive data sets and better models are needed linking hydrologic regime with ecosystem processes (productivity, nutrient dynamics, food web interactions), with ecological interactions (predation, species invasion), and with water quality.”

Ongoing Great Lakes research and development projects aim to develop the kind of comprehensive and quantitative assessment tools necessary to manage basin water resources in a way that maintains ecological integrity. For example, the IJC is conducting a large study to review and potentially revise the water level and flows regulation plan currently in place for the Lake Ontario-St. Lawrence River system. Part of this study will be to develop a quantitative model of the system’s ecological response to alternative regulation plans. This effort, intended to be completed by 2005, will potentially provide many useful tools and large amounts of data for assessing ecological impacts of water withdrawals and diversions.

Models for Ecological Impact Assessment

Introduction

Background

The descriptive model inventory (available in the Appendix) describes modeling tools that have been identified with prospective relevance to ecological impact assessment of water withdrawals in the Great Lakes-St. Lawrence River basin. The compilation of this information addresses the need for an understanding of the state of the science of existing quantitative tools that may be used in a Water Resources Management Decision Support System.

Objectives

Specific objectives of the model review were to:

- Identify models applicable directly and/or indirectly to the assessment of the ecological impacts of water withdrawals in the Great Lakes basin;
- For the selected models, identify key model characteristics, including the model purpose, past applications and experience, data requirements, strengths and weaknesses, ease of use, and applicability to assessing the effects of water withdrawals; and
- Compile the information into a user-friendly, descriptive inventory that provides supporting information.

Approach

A literature and web-based search was first conducted to identify relevant models. Models included in the inventory were selected on the basis of their relevance to the problem, their availability for general use, and their widespread use and acceptance. The inventory is not intended to provide a complete list of all models that may be relevant. Rather, it provides an adequate representation of the models that are available. A review sheet that describes key model characteristics and capabilities and other information was prepared for each selected model. A list of other models that may have relevance, but are not as widely distributed and used, was also prepared.

Information Provided in the Inventory

Models in five categories were reviewed: hydrodynamic/hydraulic; surface water quality; hydrology/watershed; ecological effects; and groundwater. For each selected model, the descriptive inventory in Appendix A of the models inventory provides the following key information:

- Category of model
- Developer and distributor
- Primary purpose
- Applications and experience
- Overview of characteristics
- Applicability for assessing ecological impacts of withdrawals
- Data requirements
- Ease of use
- Strengths and weaknesses
- Other notes and references

Where possible, references to useful websites and other references are also provided.

Model Descriptions

Review sheets were prepared for 38 models that fall into at least one of five categories. While the models included in the descriptive inventory are considered to be the most relevant for assessment of the ecological effects of water withdrawals and are generally accepted by the modeling community, other models may also be relevant. No geomorphic models for nearshore zones were included in the inventory, but some models that focus on hydrodynamic and sediment transport processes have been developed for some U.S. Great Lakes rivers by the U.S. Army Corps of Engineers under authority provided in Section 516(e) of the Water Resources Development Act (WRDA) of 1996. These should be reviewed in the future to assess their applicability to water withdrawals. Other categories may also need to be identified.

Hydrodynamic/Hydraulic Models

Hydrodynamic/hydraulic models provide a description of circulation, mixing and density stratification processes that can affect the water quality and transport of pollutants within a water body. These models use water body geometry, boundary conditions, inflows, withdrawals, and meteorological data to simulate water levels, flow velocities, salinities and temperatures. Information on physical properties of a water body (e.g., depth, slope of bed, precipitation, temperature) provides input parameters for these models. Physical processes simulated by hydrodynamic models include tidal, wind, buoyancy, turbulent momentum and mass transport. The spatial dimensions of these models include one-dimensional longitudinal, two-dimensional in the longitudinal and vertical, two-dimensional in the horizontal (vertically-averaged), and three-dimensional. Hydrodynamic models use numerical solutions to governing equations for the conservation of momentum and/or mass to predict water movements.

A hydraulic model can be used to simulate variations in the composition and distribution of habitats during different flow regimes, which is helpful information for development of habitat and bioenergetic models for fish. Table 5-1 provides a list of relevant hydrodynamic/hydraulic models, and indicates the models that are described in detailed review sheets in the models inventory report.

Hydrologic/Watershed Models

Hydrologic/watershed models are a useful assessment tool for managing the water resources of watersheds. This category includes models that simulate the generation and movement of water and water-borne pollutants from the point of origin to discharge into receiving waters. These models can be used to quantify total watershed contributions of flow, sediment, nutrients and other constituents. Linking hydrologic/watershed models with receiving water hydraulics and water quality models provides the ability to quantitatively relate water withdrawal-induced alterations of watershed hydrology to aquatic ecological impacts.

Generally, these models require data such as rainfall, evapotranspiration, temperature, humidity and solar intensity. The watershed loading models evaluate the effects of land uses and practices, land cover and soil properties on pollutant loadings to water bodies. Available hydrologic/watershed models vary from simple methods to detailed loading models. Simple models have very limited predictive capabilities and provide rough estimates since they are

Table 5-1
Hydrodynamic/Hydraulic Models

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/ Developer
CE-QUAL-RIV1*	Hydrodynamic & Water Quality Model for Streams	Dynamic	1-D	USACE
CE-QUAL-W2*	2D Laterally-averaged Water Quality Model	Dynamic	2-D vertical	USACE
CH3D-WES*	Curvilinear Hydrodynamics in Three Dimensions - Waterways Experiment Station	Dynamic	3-D	USACE
CORMIX	Mixing-Zone Model	Steady State	3-D	USEPA
DYNHYD5	Link-Node Tidal Hydrodynamic Model	Dynamic	1-D	USEPA (CEAM)
ECOMSED	Hydrodynamic and Sediment Transport Model	Dynamic	3-D	HydroQual, Inc.
EFDC*: Environmental Fluid Dynamics Code	Hydrodynamics and transport model	Dynamic	1-D to 3-D	Tetra-Tech/Virginia Institute of Marine Sciences
HEC-2/HEC-RAS*	River Analysis System	Steady State	1-D (HEC-2)	USACE (HEC)
HEM1D/HEM2D/HEM3D	Hydrodynamic Eutrophication Model	Dynamic	1-D to 3-D	Virginia Institute of Marine Science
HSCTM-2D	Hydrodynamic and Sediment and Contaminant Transport Model	Dynamic	2-D lateral	USEPA (CEAM)
MIKE-11/MIKE-21/ MIKE-3*	Generalized Modeling Package-1D/ 2D/3D - Hydrodynamics	Dynamic	1-, 2-, and 3-D	Danish Hydraulic Institute
POM	Princeton Ocean Model	Dynamic	3-D	Princeton University
RIVMOD-H	River Hydrodynamic Model	Dynamic	1-D	USEPA (CEAM)
RMA-2V*	Hydrodynamic analysis model	Dynamic	2-D lateral	USACE (WES)
UNET	1-D Unsteady Flow through a Full Network of Open Channels	Dynamic	1-D	USACE

*Indicates that model is reviewed in more detail in review sheets provided in Appendix A of the models inventory.

Model Developer Acronyms

CEAM	USEPA's Ctr. for Exposure Assessment Modeling
EPRI	Electric Power Research Institute
GLERL	NOAA's Great Lakes Env'tal Research Lab
HEC	USACE's Hydrologic Engineering Center
NALMS	North American Lake Management Society
NOAA	National Oceanic and Atmospheric Agency
OMNR	Ontario Ministry of Natural Resources
SFWMD	South Florida Water Management District
SWET	Soil and Water Engineering Technology, Inc.
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WES	USACE's Waterways Experiment Station

typically derived from empirical relationships. Detailed models are generally more complex with greater spatial and temporal resolutions, and they use storm events or continuous simulation to predict flow and pollutant concentrations for a range of flow conditions. These models include physical processes of infiltration, runoff, pollutant effects and groundwater-surface water interactions. Applications for these models vary depending on data availability and modeling needs. Table 5-2 provides a list of relevant hydrologic/watershed models and indicates the models that are described in detailed review sheets in the models inventory report.

Surface Water Quality Models

Surface water quality models address problems associated with variables that can result in fish kills, unpleasant tastes and odors, human health impacts and other ecosystem disturbances. This category includes models of dissolved oxygen, nutrient-eutrophication, sediment transport, and fate and transport of contaminants. Surface water quality models are used to analyze water quality related problems and to synthesize the principal components: inputs, reactions and physical transport, and outputs. The analysis of pollutants in surface waters describes load-response relationships, cause-effect mechanisms and, in some cases, the impact of pollutants on biota in the system. These models focus on the objective of protecting plants, animals, humans, wildlife, aquatic life and the environment from the negative effects of pollutants and toxic substances.

Some water quality models simulate the effect of pollution discharges from various sources to air, water and land. The external inputs include point and non-point sources. This category includes eutrophication models, which predict the production, transformation and decay of phytoplankton biomass in response to changes in nutrients, temperature and light. Table 5-3 provides a list of relevant surface water quality models and indicates the models that are described in detailed review sheets in the models inventory report.

Groundwater Models

Groundwater models address issues related to water supply, sub-surface containment transport, remediation and mine dewatering. These models can be used to track pollutants in the saturated and unsaturated zones and to evaluate pollutant transport occurring through migration and interactions of groundwater and surface water. Groundwater withdrawals can lower river and stream levels. The hydrology of the watershed can be impacted by precipitation, runoff, groundwater, surface storage and river levels. The watershed hydrology indirectly includes the groundwater components in these assessments.

Groundwater models generally require a large amount of information and a complete description of the flow system, as well as specialized expertise. Table 5-4 provides a list of relevant groundwater models and indicates the models that are described in a detailed review sheet in the models inventory report.

Ecological Effects Models

This category includes a wide variety of models and techniques for the ecological assessment of an aquatic system. It includes habitat and species classification, index systems, and toxicological and ecological models that simulate the effect of stressors on habitats. These types of models can examine or predict the status of a habitat, biological population or biological community. Water withdrawals can cause changes in the features of the system such as depth, velocity, temperature, oxygen, surface area and vegetation, and this information can be used to evaluate the effect on aquatic ecosystems. Ecosystem models that respond to these hydraulic and hydrologic changes will be most valuable for application to a Water Resources Management Decision Support System (WRMDSS).

Ecological effects models that address the impacts of water withdrawals use a wide range of evaluation and assessment techniques to examine ecosystem structure and function. Changes in water quantity, water quality and sediment dynamics driven by water withdrawals can affect many components and interactions in an aquatic ecosystem (e.g., species habitat, production and diversity of flora, predator-prey relationships and food web structure).

Due to the inherent connection between species and habitat, the effects models are best suited when used in combination with each other and with other categories of models. Several environmental impact assessment modeling frameworks have been developed to assess the effects of different flow conditions on aquatic ecosystems. For example, the Instream Flow Incremental Methodology (IFIM) is a habitat-

Table 5-2
Hydrologic/Watershed Models

Model	Description	Supporting Agency/ Developer
AGNPS	Agricultural Nonpoint Source Pollution Model	USDA
ALIS*	Aquatic Landscape Inventory System (ALIS) and associated database	OMNR
ANSWERS	Event based agricultural area run off/erosion model	University of Georgia
ATLSS*	Across trophic level system simulation for the freshwater wetlands of the everglades and big Cypress swamp	Coordinated through USGS
BASINS*	Better Assessment Science Integrating point and Nonpoint Sources	USEPA (CEAM)
CREAMS/ GLEAMS	Field scale run off/erosion model	USDA
ELM*	Everglades Landscape Model	SFWMD (H. Carl Fitz)
GAWSER	Object-Oriented Guelph All-Weather Storm Event Runoff Model	Schroeter and Associates (sponsored by OMNR and Grand River Conservation Authority)
GWLF	Generalized Watershed Loading Functions	USEPA (CEAM)
HSPF*	Hydrological Simulation Program – FORTRAN: Capable of simulating mixed-land-use watersheds (urban and rural) (1-D, Dynamic)	USEPA (CEAM)
LBRM *	GLERL Large Basin Runoff Model	NOAA (GLERL)
OFAT*	Ontario Flow Assessment Techniques Version 1.0	OMNR
SLAMM	Source Loading and Management Model	University of Alabama
SPARROW*	Spatially Referenced Regression On Watershed attributes	USGS
SWAT*	Soil and Water Assessment Tool	USDA
SWMM	Storm Water Management Model	USEPA (CEAM)
WAM*	Watershed Assessment Model	SWET
WARMF*	Watershed Analysis Risk Management Framework	Systech Engineering, Inc. (sponsored by EPRI)
WATFLOOD	The WATFLOOD Hydrologic Model	University of Waterloo (Nick Kouwen)

*Indicates that model is reviewed in more detail in review sheets provided in Appendix A of the models inventory.

Table 5-3
Surface Water Quality Models

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/Developer
AQUATOX*	Ecosystem Model	Dynamic	2-D	USEPA
CE-QUAL-ICM*	3-D Time variable integrated compartment eutrophication model	Dynamic	3-D	USACE
CE-QUAL-RIV1*	Hydrodynamic and water quality model for streams	Dynamic	1-D	USACE
CE-QUAL-W2*	2-D laterally averaged hydrodynamic and water quality model	Dynamic	1-D, 2-D	USACE
ECOFATE*	Ecosystem model	Dynamic	2-D	Simon Fraser University (Frank P. Gobas)
EUTROMOD*	Receiving water model	Steady-state	1-D	NALMS
GBTOX/GBOCS*	Green Bay Toxics Model	Dynamic	3-D	USEPA
HUDTOX	Contaminant Fate and Transport Model	Dynamic	3-D	USEPA
MIKE11-WQ/ MIKE21-WQ/ MIKE3WQ*	Generalized Modeling Package-1D(/2D/3D) Water Quality Module	Dynamic	1-D to 3-D	Danish Hydraulic Institute
QUAL2E*	Steady-state, 1-D stream water quality model	Steady-state	1-D	USEPA (CEAM)
QWASI	Quantitative Water Air Sediment Interaction Model			Trent University (Donald Mackay)
RATECON*	Rate Constant Model for Chemical Dynamics	Dynamic	1-D	Trent University (Donald Mackay)
SAGEM*	Saginaw Bay Ecosystem Model	Dynamic	3-D	USEPA
SMPTOX4*	Simplified Method Program – Variable-Complexity Stream Toxics Model	Steady-state	1-D	USEPA (CEAM)
WAQ-DELFTS3D	3-D time variable water quality model	Dynamic	3-D	WL Delft Hydraulics
WARMF*	Watershed Analysis Risk Management Framework			Systech Engineering, Inc. (with EPRI)
WASP5*	Water Quality Analysis Simulation Program	Dynamic	1-D to 3-D	USEPA
WASTOX	Water Quality Analysis Simulation of TOXics	Dynamic	1-D to 3-D	USEPA (CEAM)

*Indicates that model is reviewed in more detail in review sheets provided in Appendix A of the models inventory.

based impact assessment and water management tool used to manage stream fishery habitat. These steady flow frameworks would need to be modified to include the potential effects of changes in flow conditions on habitat and aquatic biota.

Table 5-5 provides a list of relevant ecological effects models and identifies the models described in a detailed review sheet in the models inventory report.

Selecting a Model

The selection of the appropriate models to address a particular management question should be based on many considerations, including management objectives, data availability and available resources. The models presented in the descriptive model inventory differ in their capabilities, complexity and resource requirements, and the inventory can assist in the model selection process. Model users should carefully define management problems and fully understand a system before selecting a model from this inventory. Many of these models require extensive data, which may necessitate expenditure of significant resources for site-specific application; resource and data availability for a given site are critical considerations in the model selection process.

In some contexts, a set of models might be needed to address multiple stressors and the interrelationship of various processes and components. In this case, the objectives can be met by using a combination of models. An integrated modeling framework comprised of a suite of models can be useful for assessing the effects of water use and water withdrawals on ecosystems. However, model linkage compatibilities must be considered, which may require significant resources to accomplish properly.

Generally, the complexity of a modeling application will increase (along with the development and application costs) as the complexity of the nature of the management problems increases. The model inventory describes models ranging from simple to complex. Simple models require less expertise and data, so a wider community can use them, but often they are limited in the management questions that can be credibly addressed. Complex models generally have high spatial, temporal and process resolutions, and they require large data sets and extensive computation efforts. These models can be used by a limited number of experts. In some cases, these more complex models have undergone limited field testing (i.e., ground-truthing on a variety of systems) and great caution should be taken in applying them on a site-specific basis without rigorous calibration and confirmation.

To select models from this inventory, user-specific information for the following factors will help identify the needs:

- **Management objective:** Outline a clear definition of the problem.
- **Global modeling objective:** Define the specific modeling need.
- **Spatial and temporal scales:** Define the resolution needs, including aspects like steady-state or time varying.
- **Constituents of concern/stressors:** Identify the conventional and toxic pollutants and biota that play a role in problem definition.
- **Data availability:** Identify available system-specific inputs, calibration, and validation for the data set.
- **Project constraints:** Identify the availability of modeling expertise, ease of use needs, model accuracy, and available time and budget.
- **Level of analysis:** Define whether the analysis is a screening level or detailed.

Discussion

The models presented in the descriptive inventory are organized into five categories, and differ in their capabilities, complexity and resource requirements. Model users should carefully define the management problem and gain a full understanding of the associated system before selecting models from this inventory. Among others, site-specific management objectives, data needs and accessibility, and resource availability should be considered in the model selection process. Also, model users should be aware that the inventory does not include all models related to physical and biological processes associated with water withdrawals.

Most of the models reviewed in the inventory are stand-alone models that address one or more aspects of the overall problem, such as hydrodynamics, sediment transport, water quality or ecological effects. The inventory did not find any single model that can, by itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario. For example, no single "off-the-shelf" model can answer the question: "For the source and return systems, will the changes in water quantity, sediment dynamics, and/or water

Table 5-4
Groundwater Models

Model	Description	Source
AQTESOLV	Aquifer Test Design and Analysis Computer Software	HydroSOLVE Inc.
Bioplume III	Transport of Dissolved Hydrocarbons under the influence of oxygen-limited biodegradation.	Scientific Software Group
Bioscreen	Simulates remediation through natural attenuation of dissolved hydrocarbons	USEPA
Chemflo	Simulates Water and Chemical Movement in Unsaturated Soils	Scientific Software Group
FLONET/TRANS	FLONET Computes potentials, streamlines and ground-water velocities in a vertical section through a confined or unconfined aquifer. FLOTRANS computes heads, velocities and contaminant concentrations in a vertical section through a confined or unconfined aquifer. It has advective-dispersive solute transport capability	International Ground Water Modeling Center (at Colorado School of Mines)
GEOPACK	Geostatistical Software for Conducting Analysis of the Spatial Variability of One or More Random Functions	Scientific Software Group
GMS*	Sophisticated Groundwater Modeling Environment for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D, SEEP2D, PEST, UTCHEM, and UCODE (1-D to 3-D)	Scientific Software Group
HSSM-DOS	Hydrocarbon Spill Screening Model (HSSM)	USEPA (CEAM)
MODFLOW/ Visual_MODFLOW*	Three-Dimensional Finite-Difference Ground-Water Flow Model	USGS/Scientific Software Group/ Waterloo Hydrogeologic, Inc.
MOFAT	Multiplephase Flow and Multi-component Transport Model (Dynamic, 2-D)	USEPA
MT3D99	A Modular 3D Solute Transport Model	Scientific Software Group
RETC	Analyzes Soil Water Retention and Hydraulic Conductivity Functions of Unsaturated Soils	Scientific Software Group
RITZ	Regulatory and Investigative Treatment Zone Model	Scientific Software Group
VLEACH	One-Dimensional Finite-Difference Vadose Zone Leaching Model	Scientific Software Group/USEPA
WhAEM	Wellhead Analytic Element Model (WhAEM2000)	USEPA (CEAM)
WHPA	Wellhead Protection Area Model (Steady-state, 2-D)	Scientific Software Group
WinTran	Groundwater Flow and Finite-Element Contaminant Transport Model	Scientific Software Group

*Indicates that model is reviewed in more detail in review sheets provided in Appendix A of the models inventory.

Table 5-5
Ecological Effects Models

Model	Description	Supporting Agency/Developer
ATLSS*	Across trophic level system simulation for the freshwater wetlands of the everglades and big Cypress swamp	Coordinated through USGS
ECOFATE *	Model to investigate whether existing or planned chemical emissions can be expected to pose an ecological or human health risk	Simon Fraser University (Frank P. Gobas)
ELM*	Everglades Landscape Model	SFWMD (H. Carl Fitz)
EXAMS II*	A fate and exposure model for assessing toxics in receiving waters	USEPA (CEAM)
FGETS*	Food and gill exchange of toxic substances: Fish bioaccumulation simulation modeling for laboratory and field condition	USEPA (CEAM)
HEP/HSI*	Habitat Evaluation Procedures/Habitat Suitability Indices: Species based-evaluation method that determines the quality and quantity of available habitat and measures the impact of land or water use changes on that habitat	USEPA (CEAM)
HES*	Habitat Evaluation System: Community-based evaluation technique to assess the impacts of development projects for aquatic and terrestrial habitat evaluations	USEPA (CEAM)
HGM	Hydrogeomorphic Assessment: Determines the integrity of physical, chemical, and biological functions of wetlands as they compare to reference conditions	USEPA (CEAM)
IFIM* PHABSIM TSLIB	Instream Flow Incremental Methodology: Collection of analytical procedures and computer models used to assess riverine habitats Physical Habitat Simulation: Programs that form the key microhabitat component under various channel configurations and flow management conditions Time-Series LIBrary: Creates habitat time series and habitat-duration curves using habitat discharge relationships produced by PHABSIM	USEPA (CEAM)
MNSTREM	Minnesota Stream Temperature Model: Simulates dynamic stream temperatures averaged over one to six hours	USEPA (CEAM)
PVA*	Population Viability Analyses: Population dynamics modeling for aquatic and terrestrial populations	USEPA (CEAM)
RBPs	Rapid Bioassessment Protocols: Techniques to characterize the biological integrity of streams and rivers	USEPA (CEAM)
SAGEM*	Saginaw Bay Ecosystem Model	USEPA
SNTEMP/SSTEMP*	Stream Network TEMPerature Model: Simulates mean daily water temperature for a stream network with multiple tributaries for multiple time periods Stream Segment for a Single Time Period: Simulates mean daily water temperature for a stream segment for a single time period	USEPA (CEAM)
WET II	Wetland Evaluation Technique, version 2.0: A community-based habitat evaluation approach that can provide a broad overview of potential project impacts on wetland habitat functions	USEPA (CEAM)

*Indicates that model is reviewed in more detail in review sheets provided in Appendix A of the models inventory.

quality affect predator-prey relationships of the food web structure in the impacted system?"

A suite of linked models can be used to address these types of management questions for different withdrawal scenarios. For example, a linked modeling framework comprised of groundwater, hydrodynamic, surface water quality, and ecological effects models may be developed to evaluate the impact of a groundwater withdrawal on surface water ecosystems. Figure 5-2 illustrates the interconnectivity of the five categories of models, with output from one category serving as input to another category.

The linked model frameworks can be built from the existing state-of-the-science models reviewed in this inventory and could provide very useful assessment tools in any decision support system framework. Additional modeling research is required to develop coupled models in situations that have process feedbacks between models of particular domains. For example, coupling surface water and groundwater models may be very important in assessing how a groundwater withdrawal might have ecological impacts that result from altered river flow.

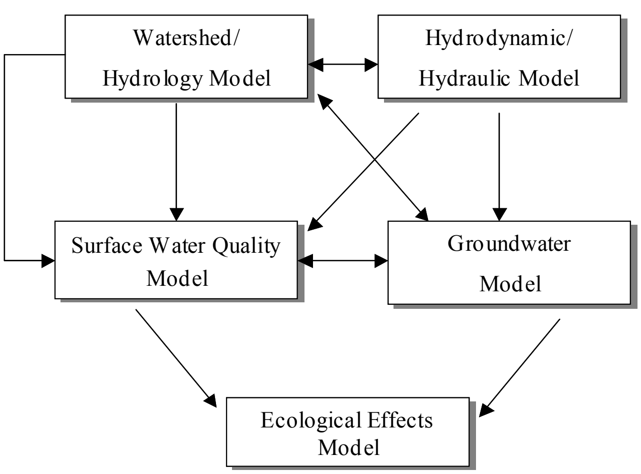

Figure 5-2
Interconnectivity of five categories of models

Findings and Recommendations

Findings

Project work on the ecological impacts of water withdrawals has identified and compiled a large amount of information that can be used by decisionmakers to develop and implement a process for assessing the ecological impacts of proposed water withdrawals. However, many information and knowledge gaps pose barriers to understanding these ecological impacts. Continued research and data collection are necessary, but these gaps in understanding and data cannot be allowed to slow progress toward development and application of tools that support the decisionmaking process.

Essential Questions for Ecological Impacts Assessment

Many essential questions must be considered to fully assess the ecological impacts of water withdrawals. 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. Not all of these questions need to be asked for all situations, and the questions are designed for a phased application. The "basic information" questions require answers that determine which assessment questions need to be asked and what level of analysis is needed.

Selected past and ongoing research studies and existing modeling tools provide useful resources to answer some of the essential questions. Some of the questions can be readily addressed using data and information that are often available from government agencies or can be approximated from related information. Some questions that require assessment and synthesis of information can be addressed using existing models, many of which are in the models inventory.

However, significant data gaps and information needs must be considered before many of the essential questions can be addressed. Many unresolved scientific and policy issues and questions were raised and discussed during the Experts Workshop. Key scientific issues that were identified include:

- how the baseline ecological condition is characterized;
- how the health and integrity of an ecosystem that has already been compromised is separated from water withdrawal impacts; and
- how "essential habitat" (quality and quantity components) is identified.

Numerous unresolved policy issues were also discussed, including:

- how much change is acceptable from a policy perspective;
- how the significance of impacts will be determined; and
- how cumulative impacts are understood and assessed, while accounting for future uses and modifications to the activities causing the impacts.

The Experts Workshop also emphasized the need for a decision framework, monitoring programs, and post-audits to assess decision outcomes.

Review and Analysis of Ecological Impacts Literature

The literature offers few practical approaches for evaluating 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. Many of the papers that were reviewed describe the impacts of regulation, withdrawals, and dams on biota, landscape ecology, environmental flows, geomorphologic processes and vegetation landscape, but they lack specific information that relates these impacts to changes in levels or flows. Other articles make comparisons between regulated and non-regulated rivers, and a limited number propose assessment methodologies. Some papers describe physical characteristics and ecological aspects of nearshore habitats while others provide conceptual frameworks for describing impacts. In general, the studies explore trends in alterations of freshwater ecosystems, the ecological consequences of biophysical alterations, and the need for an ecosystem approach. A few discuss the major scientific challenges and opportunities involved in effectively addressing the changes.

Models for Ecological Impacts Assessment

The assessment of cumulative ecological impacts from multiple stressors is confounded by the lack of integrative modeling tools. While the literature review revealed many studies that are relevant to assessment of ecological impacts of water withdrawals and diversions, most of these studies have been site-specific and descriptive in nature. Several test a hypothesis on the presence of a significant response in the system, but do not collect sufficient information for quantitative analysis of the deterministic, cause-effect relationships that underpin the empirical observations. This critical process understanding is needed, through synthesis and model development, to generalize the findings to the various types of ecosystems that exist in the Great Lakes-St. Lawrence River basin.

The outcome of the model review shows that no single model can, by itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario. Most of the models reviewed in the inventory are stand-alone models that address one or more aspects of the overall problem, such as hydrodynamics, sediment transport, water quality or ecological effects. However, a suite of linked models can be used to address these types of management questions for different withdrawal scenarios. For example, a linked modeling framework comprised of groundwater, hydrodynamic, surface water quality, and ecological effects models may be developed to evaluate the impact of a groundwater withdrawal on potentially impacted surface water ecosystems. This effort can be very resource intensive.

Additional Observations

In assessing *cumulative* impacts, the question remains, "at what scale should one attempt to view the impacts of multiple water withdrawals taken together?" The importance of assessing cumulative impacts was highlighted during the Experts Workshop because the spatial (e.g., watershed, lake, river, or whole basin) and time (e.g., 20 years or 100 years) scales over which withdrawal impacts might be observed are not known. Both time and space scales must be used for making assessments to satisfy Directive #3 of the Charter Annex. Based on the outcomes of the literature review, the essential questions and the model inventory, one finding stands out: 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 can affect the ecosystem.

There is also a noticeable lack of research on the ecological effects of water withdrawals on connecting channels and the St. Lawrence River. These river systems are hydrologically distinct from the lakes and are particularly sensitive areas, although further research is needed to reconcile differences of opinion about their sensitivity to withdrawals. A small change in water levels in one or more of the lakes may cause a large response in flow distribution and levels in connecting channels and the St. Lawrence River. For example, the St. Lawrence River is downstream of the lakes, and is thus susceptible to cumulative impacts from all upstream activities. Connecting channels are important fish producers and reservoirs of biodiversity. These waterways may be particularly at risk because they host a concentration of water users, including major hydropower facilities.

Recommendations

1. **Review and refine the list of "essential questions" to ensure comprehensiveness and feasibility in a decision support framework.**

   Input in the review process should be sought from both those who will be charged with answering a list of essential questions, and those who will be responsible for making subsequent decisions. The list of "essential questions" presented in the study report was developed and refined by attendees at an "Experts Workshop," based upon the outcomes of an extensive literature review and background work by a technical subcommittee. The questions reflect the collective thought and best professional judgment of experts from a multitude of scientific disciplines as well as representatives of the policy community. These questions offer a promising framework for assessing the prospective impacts of any given water withdrawal proposal. Before these questions are incorporated into a decision support framework, however, additional review by representatives of both the regulatory and regulated community is advised.

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.**

   The data mining and synthesis of knowledge are expected to lead to a need for watershed-scale research conducted to quantify the relationship between levels/flows and a range of sensitive ecological responses. There are opportunities now to conduct studies that can address some of the important information needs. For example, studies on the impacts of natural events such as the recent 40-centimeter (15.75-inch) drop in water levels on lakes Michigan and Huron would be valuable. Studies of this type have been limited in the past because of challenges due to the size of the system, the cost and long time frame of the studies, and the need for cooperation between multiple agencies. However, water use issues have highlighted the need for, and importance of, such studies. A number of environmental/ecological studies are under way for Lake Ontario and the St. Lawrence River as part of an International Joint Commission reference study to examine the impacts of changes to the level and flow regimes resulting from alternative regulation plans. These studies should be examined for their applicability to the water withdrawal issue.

3. **Develop indicators and thresholds to inform the discussion of "no significant adverse individual or cumulative impacts" relating to ecological effects from water withdrawals.**

   Studies can establish impact thresholds that can be used for assessing the cumulative impacts of multiple withdrawals or diversions on the study system. This effort should be coordinated with the SOLEC indicator process to ensure the establishment of a long-term reference data set.

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 the potential ecological impacts of those water withdrawals.**

   A need exists for a quantitative understanding of ecological effects of water withdrawals and diversions in the context of other system stressors (e.g., nutrient loads, toxic chemicals, invasive species) that can also cause adverse impacts. The modeling effort will need to rely on a linked model framework, as specified in Recommendation #5, because no single model can, by itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario.

5. **Develop linked model frameworks for selected water withdrawal scenarios by building on the existing model inventory.**

   The synthesis and modeling proposed in Recommendation #4 should be designed and conducted in the context of an integrated modeling study so that data collected and processes quantified through field research can provide a basis for developing integrated assessment models.

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.**

   Forecasts of the capacity of the Great Lakes-St. Lawrence River system should account for future scenarios that may alter water levels and flows. Although models provide limited information, current models do forecast a reduced availability of water due to these factors. There is a need for region-specific climate change studies to better understand how climate change will affect water levels and flows.

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.**

   This report documents the prospective need to assess impacts of water withdrawals from anywhere in the Great Lakes-St. Lawrence River basin. The "essential questions" presented in this chapter provide guidance for such assessments and require basic data and information at the appropriate temporal and spatial scales. For example, cumulative ecological impacts of altered water levels and flows could take years, or even decades, to manifest themselves at the ecosystem level. Long-term monitoring programs are required to relate level/flow changes to trends in ecosystem structure and function.

8. **Improve understanding of variability and uncertainty in levels and flows to strengthen the decision support system.**

   Uncertainty in the prediction and measurement of hydrologic changes in response to water withdrawals or diversions leads to uncertainty in the deterministic prediction of ecological responses. Research to quantify these cause-effect relationships and, by extension, the application of those relationships to make decisions must recognize these inherent uncertainties.

9. **Monitor ecological and hydrological responses to water withdrawal activities, with a special emphasis on sub-watersheds and nearshore zones.**

   Monitoring activities provide a means of "post-auditing" the decision and providing data and information for updating assessment tools. This allows a decision support system to evolve and improve over time.

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Chapter Six

Resource Improvement Standard for Water Resources Projects

Introduction

Directive #3 of Annex 2001 to the Great Lakes Charter calls for a new decisionmaking standard that is based, in part, on "an Improvement to the Waters and Water-Dependent Natural Resources of the Great Lakes Basin." This chapter presents an analysis of the "resource improvement" concept and explores issues and options in the application of the standard to the Great Lakes-St. Lawrence River basin, as illuminated by case studies. Although resource improvement was not part of the original project work plan, the Project Management Team agreed to support research on the topic to assist the regional policy development effort.

Sandpipers

Methodology

In March 2002, a Focus Group conference call was conducted to define the scope of the analysis effort. Focus Group participants included members of the governors' Charter Annex Working Group, some members of the Project Management Team and the Stakeholders Advisory Committee for the WRMDSS project, and staff of the Great Lakes Protection Fund. Focus Group participants discussed a background paper, distributed prior to the call, that addressed two primary objectives: 1) to clarify definitions of key terms in Annex Directive #3 statements concerning principles upon which a new decisionmaking standard is to be based; and 2) to obtain direction on the way that the new standard would be interpreted and applied. The guidance received during the call was used to prepare a briefing paper on the topic.

The conference call elicited consensus on some points and diverse viewpoints on others. There was general consensus that the issues paper should:

- Define the improvement concept, with an emphasis on case study examples;
- Focus on improvements to ecological health, not on human use and associated economic considerations; and
- Explore the relationship between water withdrawal and improvement.

Diverse viewpoints were expressed as to whether mitigation should be a component of Annex 2001, and the authors were asked to distinguish between mitigation and improvement in the briefing paper.

In June 2002, a briefing paper on analysis and prospective application of the resource improvement standard was prepared by Limno-Tech, Inc. (available in the Appendix). The paper presents the definition of improvement as defined in Annex 2001, discusses the goals of resource improvement, and examines how these goals have changed over time. Ten case study applications in different settings and for different purposes from within and outside the Great Lakes-St. Lawrence River region are presented and discussed. These case studies were selected to provide a range of examples to stimulate discussion on how the improvement standard may be applied to implementation of the Charter Annex.

The background material provided in the briefing paper has served as a departure point for discussions on the interpretation and application of the improvement standard. The final section of the briefing paper poses four questions that are critical to implementing a resource improvement standard and address issues of definition, interpretation and application.

The Great Lakes Commission convened a Resource Improvement Workshop on July 31, 2002 to discuss the issues raised in the paper, and to focus on key questions. Participants included members of the Annex Working Group, Project Management

Team, Stakeholders Advisory Committee, Great Lakes Protection Fund staff and various observers.

Resource Improvement Standard Concept

The term "Improvement to the Waters and Water Dependent Resources of the Great Lakes" is defined in the Charter Annex as:

> *. . . additional beneficial, restorative effects to the physical, chemical, and biological integrity of the Waters and Water-Dependent Natural Resources of the Basin, resulting from associated conservation measures, enhancement or restoration measures which include, but are not limited to, such practices as mitigating adverse effects of existing water withdrawals, restoring environmentally sensitive areas or implementing conservation measures in areas or facilities that are not part of the specific proposal undertaken by or on behalf of the withdrawer.*

The research for this paper focused on this definition and, in particular, on the following terms: *conservation*, *enhancement*, *restoration*, and *mitigating adverse effects.*

Goals of Resource Improvement

The concept of resource improvement is subjective and depends on the valuation framework that the observer applies to the natural world (Tietenberg, 1996). The element of time and the importance assigned to human uses of natural resources are two key dimensions of the framework by which resources are valued.

On one extreme, resources are valued only on the basis of the current services they provide to human populations. This valuation framework aims to maximize current human welfare. However, such a static and wholly anthropocentric view of resource valuation can threaten the viability of natural systems, sacrificing future environmental health to achieve short-term gain.

Many reject this static view of resource valuation in favor of a longer-term perspective that features measures that enhance both current and future resources. An example of this is modern forestry management practices that are forward-looking, valuing the future health of the forest along with its current health.

A logical question in this discussion is, what weight should be given to the future services to be provided by natural resources, relative to current services? One answer is to assign dollar values to future services and discount them using an interest rate, as is done to evaluate the future economic payoff from a capital investment. This puts investments in natural resources on the same footing as other investments, in terms of comparing their costs and benefits. The decision to maintain a forest, for example, would depend on the value of future yields, relative to payoffs from other investments.

Some would argue, however, that this model of resource planning assigns too little value to the environment that will be inherited by future generations, because they (future generations) cannot participate in today's decision process. The concept of sustainability balances these interests, dictating that every generation should inherit an environment whose resources are maintained and not degraded.

Even within the umbrella of sustainability, there are alternatives depending on the importance assigned to human use services. What exactly is to be sustained? One view is that the services provided to human populations should be sustained at current levels. In this view, a forest might be managed so that its yield of lumber does not decline with time.

An alternative view of sustainability is ecosystem-based, advocating not just for unborn human generations, but also for all living things, present and future. Based on this view, the environment should be managed in such a way that native populations of plants and animals remain healthy and viable, regardless of the services that they may or may not provide to human populations.

Over the course of the past 150 years, popular views of resource management have evolved to take an increasingly long-term and ecosystem-oriented perspective. The Annex 2001 definition of improvement appears to reflect this evolution, focusing on the "physical, chemical, and biological integrity of … resources," rather than the services that resources may provide to human populations. It should be recognized, however, that the definition may be open to differences in interpretation (e.g. some might argue that an increase in current commercial fishing yields due to the construction of a new dock might be described as "a beneficial effect … resulting from enhancement measures"). Implementation of Annex 2001 should be consistent with current societal values and needs, but also flexible enough to incorporate future changes in overall environmental goals.

Mitigation Versus Improvement

The definition of improvement in Annex 2001 includes "such practices as mitigating adverse effects of existing water withdrawals." Some participants in the Focus Group cited this language and emphasized that, with the exception of mitigating the adverse effects of existing water withdrawals, mitigation is not a component of the Annex because a principle of no significant adverse impacts is embodied in Directive #3. The Great Lakes Commission's Resource Improvement Standard Workshop on July 31, 2002 in Chicago provided a forum to discuss the issue of mitigation versus improvement. Discussion points from the workshop are summarized later in the chapter.

The Decisionmaking Standard Subcommittee to the governors' Annex Working Group has agreed that improvement is not mitigation and improvement begins only after mitigation has been addressed. Therefore, some policy case studies that match improvements to adverse impacts may not be appropriate prototypes.

Many of the resource improvement programs that exist today in the regulatory arena are designed to compensate for past damages or future unavoidable impacts, although some also require measures that go beyond mitigation and are directed at resource improvements. A common feature of the case studies in this chapter is that they try to offset activities that have negative effects with positive actions, and there is an effort to scale the positives and the negatives through some type of trading ratios. The challenge in applying these types of programs to implementation of Annex 2001 is how to scale improvements when no significant negative impacts are allowed.

Many existing mitigation programs apply the definition issued by the President's Council on Environmental Quality (40 US CFR, 1508.20), which includes:

(a) Avoiding the impact altogether by not taking a certain action or parts of an action.

(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation.

(c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.

(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.

(e) Compensating for the impact by replacing or providing substitute resources or environments.

Other approaches to resource improvement include programs, such as those run by conservation groups like The Nature Conservancy, which are not matched with resource use. Although these programs may have features that are applicable to the Annex 2001 improvement standard, they were not reviewed because of this missing link to resource use.

In the case studies discussed below, the role of mitigation in the program is highlighted and discussed, as appropriate.

Frameworks for Resource Improvement

Few existing regulatory programs specifically mandate resource improvement. The programs that have an element of resource improvement generally use different terms to describe it, or the improvement is implicit to the program rather than explicit in the regulations. An example is compensatory restoration as part of the U.S. federal/state Natural Resource Damage Assessments (NRDA) program. These compensatory measures are directed at overall improvements to the ecosystem to compensate for past damages, yet there is no specific language in the authorizing acts that describes a "resource improvement standard." For this reason, the concept is discussed below in the context of illustrative case studies, and relevant language from regulations or guidelines is cited as appropriate.

Related approaches have also been proposed. For example, a consortium of nongovernmental organizations submitted suggestions to the Council of Great Lakes Governors in May 2002 (Miller et al., 2002). These included requirements that improvements function in perpetuity; that they be tied to restoration plans; that they be matched to withdrawals by sub-basin where possible; that they be measured in terms of ecological rather than economic value; and that the withdrawals and improvements be scaled according to size, type and potential for unknown harm. Other approaches and diverse views exist on each of these aspects of improvement.

The importance of considering cumulative impacts in implementation of Annex 2001 was highlighted during the Focus Group and workshop discussions. During the review of case studies, these examples were examined to determine if cumulative impacts of multiple stressors (including multiple water withdrawals) are addressed through the program.

Some programs implicitly account for cumulative impacts by nature of the program design. For example, water quality trading programs take a whole watershed approach and focus on improvements as an outcome of trading between multiple dischargers that may have a cumulative impact. Canada manages fisheries habitat under a "net gain" policy that is designed to achieve an improvement in habitat while allowing for multiple uses with potentially cumulative impacts. Other programs focus only on the particular project under review and do not address cumulative impacts. An example of this type of program is the compensatory improvements component of NRDA program.

When applying a resource improvement standard, it is necessary to be aware of other programs (including those considered in this document) to ensure that a specific resource improvement is not being used for more than one program. This could defeat the purpose of the resource improvement standard; having one improvement offset more than one degradation through different programs would effectively constitute double counting.

Case Study Improvement Standard Applications

In this section, specific applications in different settings and for different purposes from within and outside the Great Lakes-St. Lawrence River region are discussed. For each case study, the following information is provided:

1. **Case study overview** provides a general description of the project or program. For each example, the "environmental currency" in which required future resource improvements are measured is described;
2. **Definition and application of resource improvement concept** describes why this example was selected as illustrative of an improvement concept;
3. **Associated issues** highlights relevant issues, including whether the case study is an example of mitigation; and
4. **Potential applicability to Annex 2001 implementation** discusses how a similar framework might be applied to implementation of Annex 2001.

These case studies do not constitute a comprehensive collection of all relevant examples that illustrate the resource improvement standard concept. Rather, they were selected to provide a sampling and a range of examples to stimulate discussion on how the improvement standard may be applied in implementation of Annex 2001. Each of these case studies illustrates certain features that could be applicable to resource improvement, rather than approaches that are consistent with Annex 2001 in every respect.

Natural Resource Damage Assessments: Compensatory Improvements

The objective of natural resource damage assessments (NRDAs) is to restore and improve injured resources in compensation for past and expected future damages. Damages are quantified in terms of dollar values, and this provides the currency in which required future resource improvements are measured.

Case Study Overview

NRDAs are based in the legal doctrine of public trust, under which title to natural resources is held by the state in trust for the people. The purpose of the trust is to preserve resources in a manner that makes them available to the public. The state may convey to private owners the right to use land and natural resources, but private interest is subservient to preserving the public's right to use and enjoy those resources.

NRDA provisions were included in U.S. legislation authorizing the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), the Oil Pollution Act, the National Marine Sanctuaries Act, and the Park System Act in order to establish specific public agencies as trustees for natural resources and give them the right to recover damages on behalf of the public. Damage assessments, therefore, take into account the cost to restore the resource, rather than just any diminution in the value of the resource, and the trustees are required to apply any damages collected toward "restoring, rehabilitating, replacing, or acquiring the equivalent of the injured resource." NRDA activities constitute mitigation of injuries, in that they identify and quantify damage that has been done and require an equivalent resource improvement, in terms of dollar value of services.

Figure 6-1 (Jones, 2000) illustrates the NRDA concept. Due to a historical release at time t_0, there is a loss of services provided by natural resources. An example might be a reduction in recreational fishing. The economic valuation of those total losses is represented by areas A + B, under a natural recovery scenario. Under active

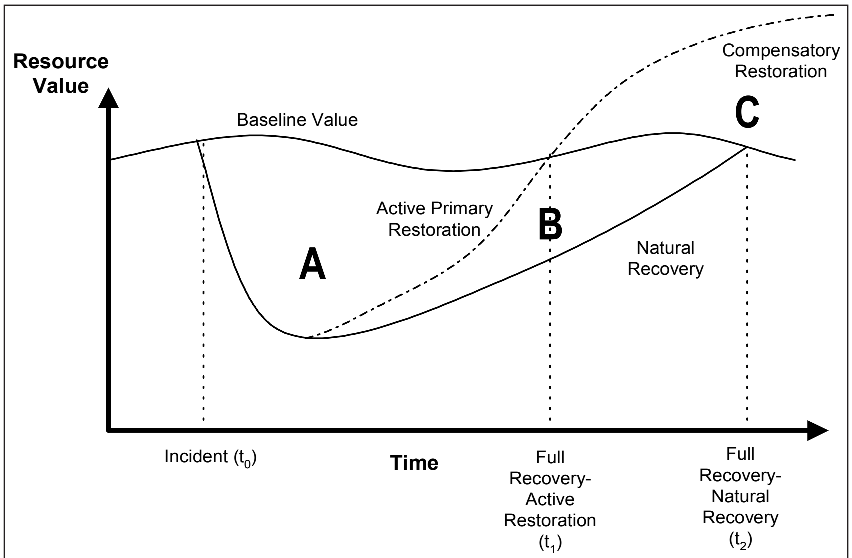

Figure 6-1
Relationship between compensatory restoration and interim lost value

restoration, the resource recovers faster and future losses are reduced. In the figure, losses are equal to only area A, because the portion of future losses represented by B is prevented. NRDA procedures provide for compensatory resource improvements, requiring provision of additional services with a value of C, in addition to the restoration of baseline services. Compensation is sufficient and complete when the present discounted value of losses A and of compensatory restoration C are equal and offsetting. Thus, NRDA requires active restoration to reduce losses, if possible, and also provide restoration to fully compensate for interim losses.

Definition and Application of Resource Improvement Concept

The baseline for NRDA, according to the definition in U.S. Department of Interior (USDOI) regulations, is "the condition or conditions that would have existed at the assessment area had the discharge of oil or release of hazardous substance not occurred." Thus, the damage to resources is not measured relative to pristine conditions: rather, it is measured relative to a hypothetical state in which this discharge did not occur but all other ongoing impacts did occur. Thus, the historical discharger must compensate the public for the effects of the discharge, but not for any other concurrent environmental degradation.

Damages are determined by identifying injured resources, quantifying services lost due to the injuries, and then determining the dollar values of those lost services. *Injury* is defined by USDOI regulations (43 US CFR 11) as "a measurable adverse change … in the chemical or physical quality or viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance…." *Services* are defined as "the physical and biological functions performed by the resource including the human uses of those functions." *Compensable value* is "the amount of money required to compensate the public for the loss in services provided by the injured resources between the time of the discharges and the time the resources and the services those resources provided are fully returned to baseline conditions."

Associated Issues

The human use of natural resources is the basis of NRDA. Damage is assessed only to the extent that resources provide services that are of measurable value to human populations. This includes both use (e.g., the benefits of recreation) and nonuse (also called passive or existence) values (e.g., valuing the knowledge that resources exist and are uninjured). Resources have no intrinsic value in NRDA, other than their value in providing these human services.

A controversial issue in NRDA is the estimation of nonuse values of resources. Although there is little doubt that people place value on the existence of natural resources from which they do not personally obtain any tangible services, there is much less agreement whether specific dollar estimates of those values are real and meaningful. Active uses require users to make economic choices; indirect but objective estimates of these values can, therefore, often be made. In contrast, nonuse values are estimated through questionnaire methods, asking people what they would be willing to pay to see a specific resource improvement. It is not practical to put respondents to a real test of their true willingness to pay for nonuse services and, consequently, their answers are not verifiable.

Although dollars are the standard currency of resource improvement in NRDA, services have been employed as an alternative currency in some cases. Most commonly this has been done through "habitat equivalency": habitat improvement is required as compensation for past habitat degradation, and full compensation requires that resource services gained by the improvement are sufficient to offset services previously lost due to the release. For example, services might be measured in terms of ability to support endangered migratory bird populations.

Potential Applicability to Annex 2001 Implementation

One distinction between the NRDA approach and Annex 2001 is NRDA's human use valuation of resources. Members of the Focus Group and workshop participants expressed a strong preference for ecosystem sustainability as a basis for resource improvement, rather than human use values.

Another important difference between NRDA procedures and the contemplated resource improvement standard under Annex 2001 is that NRDA is retrospective, whereas Annex 2001 is prospective. The Annex 2001 resource improvement standard would not be applied as compensation for effects of past withdrawals from the Great Lakes-St. Lawrence River basin.

Nevertheless, the methods used in NRDA to value resources are available to be considered for water withdrawals proposed under Annex 2001, with some history to illustrate their pros and cons. Any expected impact from water withdrawals would be evaluated in terms of reductions in resource services, and their associated use and nonuse values. The applicant would be required to provide compensation, in an equal amount or including a premium to account for uncertainty of estimation methods, either in cash or through in-kind resource improvement projects. A resource improvement standard would direct either form of compensation toward improvements providing sufficient services to offset the impact of the proposed water withdrawal. In practice, it would be desirable for the Great Lakes-St. Lawrence states and provinces to estimate the service losses associated with generic withdrawals in each sub-basin, and develop and maintain a list of desired improvements and their estimated service values. This would facilitate matches between water withdrawal applicants and compensating resource improvements.

Another potentially applicable concept is habitat equivalency. Expected potential natural resource service losses (e.g., decline in wildlife populations or diversity) due to proposed water withdrawals could be estimated for the various Great Lakes-St. Lawrence sub-basins. Candidate habitat improvements could also be catalogued, along with estimates of associated service improvements. Proposed new water withdrawals would then be matched with required habitat improvements to protect resources from net degradation. Annex 2001 would require that this be accomplished in such a way as to prevent adverse impact to the resource.

Water Quality Trading

Water quality trading provides an instructive resource improvement standard case study because trading programs require that every trade result in an improvement to water quality. The basic currency of water quality trading programs is pollutant loading rates, so that resource improvements are measured in terms of reduced total loads.

Case Study Overview

The primary objective of water quality trading is to reduce the cost of achieving water quality goals by providing dischargers with market-based flexibility. There can be numerous available means of reducing total pollutant loads to a target level, and trading programs allow dischargers to negotiate among themselves, selecting the most cost-effective method(s) and sharing the costs of implementation. A second objective is water quality improvement. Agencies that have allowed water quality trading have also required resource improvements in the form of overall load reductions, relative to preexisting water quality-based targets.

In practice, the most important avenue for trading is between point-source and nonpoint-source dischargers. In recent decades, the water quality threat posed by nonpoint sources, such as agricultural runoff and urban stormwater, has become increasingly clear. It is also often apparent that reductions in nonpoint-source loads can be achieved at lower costs than additional point-source load reductions because point-source loads have been more aggressively controlled by past environmental policies.

Water quality trading allows a point-source discharger to earn credit toward its permit limits by financing a load reduction program for a nonpoint-source discharger, effectively purchasing credits for load reduction. In this way, dischargers as a group can reduce or eliminate sources in order of their cost-effectiveness.

The so-called trading ratio is the key to effecting resource improvement under environmental trading programs. There is a discount applied to any credits purchased before they may be applied to meet the purchaser's permit requirements. For example, a 2:1 trading ratio requires two credits to be retired toward water quality improvement for each credit used to meet permit requirements. In this case, a point source discharger requiring a 1000 kg reduction to meet its permit requirements would need to finance a 2000 kg reduction in nonpoint-source loads to satisfy its permit through trading. Trading ratios may vary on a case-by-case basis, but are set above 1:1 to facilitate improvements.

Definition and Application of Resource Improvement Concept

The U.S. Environmental Protection Agency (USEPA) has released a proposed policy for trading involving nutrients and sediments (USEPA, 2002). According to the proposed policy, pollutant reduction credits may be expressed in rates or mass per unit of time. For example, if flow and concentration limits in a discharge permit effectively limit a discharger's phosphorus load in units of kilograms per month, then credits are expressed in the same units. The improvement of the resource brought about by a trading ratio greater than 1:1 would then likewise be measurable in units of kilograms per month.

The proposed USEPA policy also supports the use of credits "in ways that achieve ancillary environmental benefits beyond reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and/or waterfowl habitat." Credits for these activities may be used to supplement pollutant load reductions made at a 1:1 point/nonpoint-source trading ratio, to bring about a net environmental benefit.

Associated Issues

USEPA's proposed trading policy contains numerous safeguards against trading that would degrade water quality in one location while improving it in another, a possibility that arises when trading partners are in different locations. Key provisions, intended to ensure consistency with the Clean Water Act, include:

- **Watershed basis:** All trading should be within a watershed, so that that the total pollutant load within the watershed is reduced.
- **No localized impairment:** Any trades that would cause localized impairments of existing or designated uses are unacceptable.
- **Baselines for trades:** Parties earn credits only when they improve upon levels derived from, and consistent with, water quality standards. Where Total Maximum Daily Loads (TMDLs) have been established, the associated load allocations for dischargers constitute the baseline.
- **Trading ratios:** Trades should require the retirement of a portion of credits earned, to achieve water quality improvements and provide a margin of safety of load shifts between point and nonpoint sources.

Potential Applicability to Annex 2001 Implementation

Trading offers the potential to allocate existing Great Lakes water withdrawals to their most beneficial uses, while also improving Great Lakes resources. A trading framework for implementation of Annex 2001, analogous to water quality trading, would establish a baseline of Great Lakes water withdrawals, possibly at current levels, and would allow the flexibility for prospective users and existing users to trade in withdrawal credits. The most fundamental issue that arises in applying trading principles is whether Great Lakes water withdrawal rights should be established at current or at any other levels.

To effect resource improvements in any trading program, trading ratios need to be greater than 1:1. In this instance, a portion of the allowed withdrawal could be retired upon purchase of withdrawal rights or the purchaser would finance some additional resource improvement. The latter option would be analogous to the option in the USEPA proposed water quality-trading policy for the creation of credits "in ways that achieve ancillary environmental benefits beyond reductions in specific pollutant loads." The creation and restoration of wetlands, floodplains and habitat are currently high priorities in the Great Lakes-St. Lawrence River basin relative to reductions in water withdrawals below current levels. For this reason, requiring these ancillary activities may be a more beneficial way to achieve resource improvements than to retire water withdrawal rights.

As with water quality trading, it might also be beneficial to restrict trades to parties within common hydrological regions in order to minimize adverse local effects. In some cases, in order to be beneficial, tradeoffs might be restricted to the same sub-basin, or even the same reach. Finally, the baseline established for trading programs sets the target to be met by trading. If current rates of water withdrawal are satisfactory, then these could be used to set the baseline. If significantly lower withdrawal rates are desired, then this could be taken into account by setting a lower baseline.

Wetland Mitigation Banking

Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Permit applicants must provide justification for impacting wetlands and must avoid and minimize impacts to wetlands before a compensation (mitigation) proposal can be entertained. Applicants must compensate for all unavoidable wetland impacts by replacing the lost wetlands. Mitigation ratios result in a net gain of wetland acreage and range from 1.5: 1 to 3:1.

Case Study Overview

A wetlands mitigation bank is a wetland area that has been restored, created, enhanced, or (in exceptional circumstances) preserved, which is then set aside to compensate for future conversions of wetlands for development activities. The following description of mitigation banking is excerpted from a Congressional Research Service Report (Zinns, 1997):

> *Mitigation banking is relatively new, and federal mitigation banking policies continue to evolve…. Banking can occur only after three steps are taken in the federal process for protecting wetlands. First, wetland development must be avoided if possible; second, when this is unavoidable, impacts must be minimized; and third, impacts that can not be minimized to an acceptable level must be mitigated. Mitigation banking is an option only when mitigation on-site is not possible. Bank sponsors create wetland "credits" at a bank site that can be acquired by those who fall within the purview of these two programs and are required to offset wetland losses, or "debits," at other sites….*
>
> *Mitigation banking has many definitions, but most center on the restoration, creation, enhancement, or, in exceptional circumstances, the preservation of wetlands which will compensate for unavoidable wetland losses at another site. Banking is designed to coordinate mitigation at one location for habitat losses allowed under federal programs at other sites. Mitigation banking is used primarily when on-site mitigation can not be achieved or is not as environmentally beneficial. Mitigation banking involves a process in which a client may be required to obtain wetland units with similar functions and values at a nearby site to satisfy federal permit or program requirements.*
>
> *Bank operations vary widely, but all follow the same general principles. These principles use the terminology of financial institutions: transactions are described in terms of credits and debits to wetland resources. A bank sponsor creates credits as it restores, enhances, or creates wetlands at the bank site. These credits are either debited (money is not involved) or purchased by clients (a financial transaction) who are being required to compensate for wetland losses. When clients obtain these credits, they are withdrawn from the bank and become unavailable for future transactions. Clients are usually required to make these withdrawals prior to or concurrently with their proposed activity that will result in wetland losses. Banks may be allowed to transfer some credits, usually to fund their operations, before the site is fully established.*

USEPA lists several benefits of wetland mitigation banking, including:

- *Consolidation of numerous small, isolated or fragmented mitigation projects into a single large parcel may have greater ecological benefit.*
- *A mitigation bank can bring scientific and planning expertise and financial resources together, thereby increasing the likelihood of success in a way not practical for individual mitigation efforts.*

The environmental currency in which future resource improvements are measured is acreage of wetlands.

Definition and Application of Resource Improvement Concept

Mitigation ratios used in mitigation banking result in a net gain of wetland acreage and range from 1.5: 1 to 3:1. In terms of wetland acreage, this represents an improvement. However, some critics argue that, even though mitigation banking involves obtaining wetland units with similar functions and values at a nearby site, existing wetlands cannot be replaced because the same functions and values cannot be replicated. According to the U.S. Fish and Wildlife Service (USFWS), the rate of wetlands loss in the U.S. has slowed by 80 percent from 1986 to 1997 compared to the preceding decade (USFWS, 2001). However, forested wetlands and freshwater emergent wetlands show the most losses, while open water pond acreage has been increasing, reflecting substitution between these different wetland types.

Associated Issues

Mitigation banking is controversial. Supporters claim that mitigation banking, when compared with mitigation on-site, provides better-organized planning, an improved regulatory climate, greater commitment to long-term wetland protection, and more consolidation of habitat. Opponents claim that banking is a loophole and facilitates additional wetland destruction, that some types of wetlands are difficult to create or restore as thriving ecosystems, and that wetland losses are sometimes allowed before the bank is fully functional. More generally, supporters view policy flexibility as critical to success, especially for commercial banks, while critics worry that flexibility will lead to unacceptable losses of wetland functions and values (Zinns, 1997).

The success of wetland mitigation programs in general is currently a topic of much debate. A recent self-assessment of New Jersey's wetland program (Brouwer, 2002) revealed that New Jersey lost 22 percent of its wetland acreage over a recent four-year period. This contrasts sharply with the state's goal of creating two acres of wetland for every acre lost. The study focused primarily on the creation of entirely new wetlands.


Great Egret

Potential Applicability to Annex 2001 Implementation

One of the benefits of wetland mitigation banking listed by USEPA is that it consolidates numerous small, isolated or fragmented mitigation projects into a single large parcel, resulting in greater ecological benefits. USEPA also mentions that banking brings scientific and planning expertise and financial resources together, thereby increasing the likelihood of success in a way not practical for individual mitigation efforts. These characteristics are consistent with opinions expressed during the Focus Group and workshop that improvement measures need to be within the context of regional water management/ecosystem restoration plans. Such measures would provide greater ecological benefits than many isolated measures throughout the basin.

An example of a similar application is the development of "restoration banks" that involve stream enhancement projects that target exotic species invasions, nutrient reduction, and other restoration or enhancement goals. A bank sponsor would create credits as it carries out these projects at the bank site, and these credits would then be either debited or purchased by clients who are being required to provide a resource improvement in connection with a proposed water withdrawal. The water withdrawals may or may not be tied to the bank projects. An obvious difference between wetlands banking and Annex 2001 implementation is that wetlands banking requires a compensation for resources lost. If there is no adverse impact, then it is not obvious how to scale the resource improvement required for a proposed water withdrawal. One possibility would be to base resource improvements on mitigation of potential cumulative harm, and to scale individual resource improvement projects according to their contribution to that potential cumulative harm (if mitigation of potential harm is permitted).

Resource Improvement Trust Fund

Several programs exist across the country in which a fee or tax is paid for a service or product, and the revenues are collected in a trust fund. The money in this fund is then used for a variety of programs, including habitat and wetland conservation, and environmental restoration and clean-up efforts.

Case Study Overview

There are many examples of resource improvement trust funds. Several are provided below to illustrate the range of these types of programs.

- **Minnesota Fishing License:** The revenues collected from fishing licenses go into a dedicated fund for the Division of Fisheries and support activities such as stream surveys, fishery management, lake rehabilitation and improvements to spawning habitat.
- **Michigan Natural Resources Trust Fund (MNRTF):** The fund was established in 1976 to purchase lands for outdoor recreation and/or the protection of natural resources and open space. It also is used to assist in the appropriate development of land for public outdoor education. The MNRTF is supported by annual revenues from the extraction of non-renewable resources, primarily oil and gas, from state-owned lands.
- **Bottle Bills:** When a soft drink container is purchased with a deposit and the bottle is discarded without redeeming the deposit, this money typically returns to the beverage distributor who initiated the deposit. However, Massachusetts, Michigan and California collect unredeemed deposits and direct all or a percentage of the funds to an environmental fund. Examples of funded projects include hazardous waste cleanups, municipal recycling programs and brownfields redevelopment.
- **Federal Gasoline Excise Tax:** The gasoline tax is imposed on the manufacturer (the producer, refiner or importer) and is generally passed on to the consumer. Revenues collected from this tax primarily support the Highway Trust Fund, although 0.1 cent of the money collected supports the Leaking Underground Storage Tank Trust Fund to help fund clean-up efforts of leaking gasoline storage tanks.

The currency in which required future resource improvements are measured is dollars.

Definition and Application of Resource Improvement Concept

Each of the funds described above is dedicated to environmental improvement, with projects that range from remediation of contaminated sites to protection and enhancement of wildlife habitat. The amount of the fee or tax and the uses of the revenues can vary, but the common theme is that a benefit is created, either by those that use the resource (hunting and fishing licenses) or those who purchase certain products (bottle deposits and gasoline taxes).

Associated Issues

There can be questions about who pays into these funds, what the fees will be, what projects get funded, where they are located, and who makes the project funding decisions. Historically, some of these types of funds have been redirected into general funds and have not been used for the original intended purpose. Alternatively, authorities may cut back on general fund-based activities, effectively using these fees to augment the general fund.

Potential Applicability to Annex 2001 Implementation

Resource improvement trust funds may serve as an example for a "Great Lakes Ecological Restoration Fund." This fund could be used to finance restoration measures such as wetlands conservation, habitat restoration, or streambank erosion measures that have been identified in watershed restoration plans. Application of the trust fund payment procedure may simplify implementation of the improvement standard. By creating a uniform payment structure based on the characteristics of the water withdrawal, the fund could be administered to provide for local and/or regional improvements. The prioritization of projects and management of the fund may present challenges. While there would be interest in addressing local issues and concerns, there would also be interest in improvement projects that are consistent with broader regional water management and ecosystem restoration plans. Some states and provinces already have well-developed watershed management processes, while others (including Ontario and Québec) are currently developing new systems of water resource regulation. A key issue related to this type of a program is whether Great Lakes jurisdictions should charge a fee for water withdrawals and whether they have the legal authority to do so.

Endangered Species Act: Habitat Conservation Plans

Habitat Conservation Plans (HCPs) are a conservation tool under Section 10(a)(2)(A) of the Endangered Species Act (ESA) to recover endangered and threatened species on non-federal lands. More than 300 HCPs have been approved, and more than 300 are pending.

Case Study Overview

The goal of a Habitat Conservation Plan is to improve the survival and recovery of listed species. When a "taking" of a listed species may occur as a result of a proposed project or action, an incidental take permit is required, and a Habitat Conservation Plan must accompany the permit application. The ESA defines "take" as any activity that harms a threatened or endangered species, and "harm" can include habitat modification that injures species.

An HCP protects listed and unlisted species, and includes measures to monitor, minimize, and mitigate the impact on the listed species. It can apply to an individual landowner or multiple landowners, and may target an entire region. An HCP has five components:

1. Biological Goals and Objectives: guiding principles that reflect the best scientific information available;
2. Adaptive Management: method to address uncertainty and significant data gaps;
3. Monitoring: ensures compliance, gauges effectiveness of HCPs and informs choices under adaptive management;
4. Permit Duration: varying lengths but up to 50 years; and
5. Public Participation: 30 to 60 days for public comment.

The environmental currency in which required future resource improvements are measured is habitat equivalency.

Definition and Application of Resource Improvement Concept

Habitat Conservation Plans were selected as examples of an application of the resource improvement standard concept because they are used in water withdrawal requests that may impact endangered species, and their intent is to restore listed species, including improvements to degraded habitat and unlisted species. HCPs allow operational activities to occur while applying conservation and recovery measures to degraded habitat. The plans lay out measures to preserve, restore, protect and improve listed and unlisted species.

Associated Issues

Habitat Conservation Plans are directed at minimizing and mitigating any "taking" that may result from a project. HCPs provide a mechanism for water withdrawals to continue and increase in the future, and for the potential taking of a listed species. While these plans do involve mitigation measures to offset the harm, they go beyond individual species mitigation to include ecosystem restoration and improvement measures.

Potential Applicability to Annex 2001 Implementation

Habitat Conservation Plans may provide a model to allow for increased water withdrawals while improving water dependent natural resources, degraded habitat and water quality. HCP goals are similar to Annex 2001 objectives to protect, conserve, restore, improve and manage use of water. The plan is implemented and monitored to ensure that goals are met. HCPs also provide a mechanism to facilitate a voluntary long-term agreement by diverse stakeholders from a large geographic area.

Canadian Fisheries Act: Fish Habitat and Pollution Prevention Provisions

Sections 34 through 42 of the Canadian Fisheries Act contain habitat protection and pollution provisions. Key among these are sections 35 and 36. Section 35 instructs, "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat." The Minister of Fisheries and Oceans Canada (DFO) is the only person who can authorize, under certain conditions, habitat alterations, disruptions or destruction (HADD) of fish habitat. This case study examines the policy and guidelines related to Section 35, focusing on the policy objective of "net gain" in the productive capacity of fish habitats. Section 36 prohibits pollution unless authorized by regulations made by the Governor in Council of Canada.

Through administrative agreements, DFO has responsibility for the habitat provisions of the Fisheries Act, and Environment Canada has responsibility for the pollution prevention provisions. Both agencies work collaboratively in overall administration and in annual reports on regulatory activities to the Canadian Parliament.

Case Study Overview

To guide the DFO in the day-to-day administration of the habitat provisions of the Fisheries

Yellow Perch

Act, the Policy for the Management of Fish Habitat (1986) was developed. The overall objective of the policy is to achieve a net gain over time in the productive capacity of fisheries resources and includes three goals: fish habitat conservation, restoration, and development.

A key principle of the first habitat conservation goal is no net loss. DFO uses its review and approval process for proposed works and activities in and around Canadian fisheries waters to achieve a net gain that protects the productive capacity of existing fish habitats. The habitat policy objective is implemented by integrated resource management planning activities related to the three goals. DFO provides input at the early stages of watershed planning and identifies areas where activities that affect fish habitat may be restricted, areas where habitat restoration could be implemented and potential areas where development of fish habitat could offset habitat losses arising from other activities.

Determining effective measurements of the productive capacity of fish habitat on a regional or national basis is an ongoing topic of study for DFO. Capacity measurement provides a decisionmaking currency and, when productive capacity cannot be measured, DFO looks to effective substitutes to implement the objective of the habitat policy.

Definition and Application of Resource Improvement Concept

The goal of net gain aims to increase the productive capacity of fisheries. This goal is achieved by applying a hierarchy of preferred project options to the regulatory review process for proposed activities in and around Canadian fisheries waters. Design considerations, which prevent impacts, are always the first preference. However, when full prevention of impacts to fish habitat through project redesign or relocation is not possible, the Fisheries Act allows DFO to authorize the residual harmful alteration, disruption or destruction of habitat. Based on the habitat policy and departmental directives, DFO typically does not issue such authorizations without acceptable habitat compensation to offset the residual loss. The first preference is for habitat loss to be offset through the creation of similar habitat at or near the site. Less preferable options are considered and accepted based on specific circumstances.

Isle Royale National Park, Lake Superior

Associated Issues

This example illustrates a program designed to mitigate harmful alterations, disruptions or destruction of fish habitat. Applicants must pursue location and design options that will avoid impacts to fish habitats before DFO will consider authorizing works that would require habitat. When a project results in a HADD and the impacts are judged acceptable, compensatory restoration may be required. The preference is for habitat compensation to occur at or near the development site, but mitigation may occur further from the site where impacts are occurring. Unlike the wetland mitigation banking program, the policy of net gain in fish habitat is directed at an overall improvement that goes beyond no net loss in habitat.

Potential Applicability to Annex 2001 Implementation

The net gain policy of habitat for Canada's fisheries resources is similar to the principle of a net resource improvement in Annex 2001. Also similar are the Annex principle of "no significant adverse impacts" and the no net loss of habitat policy in the act. Actions that are implemented under the Policy for the Management of Fish Habitat are mitigative in nature whereas mitigation is not a component of Annex 2001.

Wetlands Reserve Program (WRP)

The Wetlands Reserve Program (WRP) assists landowners in restoring and protecting wetlands. The program was mandated by Section 1237 of the U.S. Food Security Act of 1985 (PL 99-198), as amended by the Food, Agriculture, Conservation and Trade Act of 1990 (PL-101-624) and the Federal Agriculture Improvement and Reform Act of 1996 (PL-104-127). WRP was reauthorized in the Farm Security and Rural Investment Act of 2002 (Farm Bill).

Case Study Overview

The Wetlands Reserve Program is a voluntary program that provides technical and financial assistance to eligible landowners to restore, enhance and protect wetlands. The U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) administers the program. Funding for WRP comes from the Commodity Credit Corporation. The program offers three enrollment options:

Permanent Easement. This is a conservation easement in perpetuity. Easement payments for this option equal the lowest of three amounts: the agricultural value of the land, an established payment cap, or an amount offered by the landowner. In addition to paying for the easement, USDA pays 100 percent of the costs of restoring the wetland.

30-Year Easement. Easement payments through this option are 75 percent of what would be paid for a permanent easement. USDA also pays 75 percent of restoration costs.

For both permanent and 30-year easements, USDA pays all costs associated with recording the easement in the local land records office, including recording fees, charges for abstracts, survey and appraisal fees, and title insurance.

Restoration Cost-Share Agreement. This is an agreement (generally for a minimum of 10 years) to re-establish degraded or lost wetland habitat. USDA pays 75 percent of the cost of the restoration activity. This enrollment option does not place an easement on the property.

Definition and Application of Resource Improvement Concept

The program provides an opportunity for landowners to receive financial incentives to enhance and restore wetlands in exchange for retiring marginally productive agricultural land. The program benefits the Great Lakes-St. Lawrence River basin by restoring and protecting wetland functions and values, and by developing fish and wildlife habitat. Wetlands also improve water quality by filtering sediments and chemicals, reducing flooding, and protecting biological diversity. As of November 2001, there have been 1,074,245 acres enrolled in WRP throughout the United States.

To be eligible for WRP, land must be restorable and suitable for wildlife benefits. Examples of eligible lands include farmed or converted wetlands; pasture or production forage land where the hydrology has been significantly degraded and can be restored; riparian areas linked to protected wetlands; and lands adjacent to protected wetlands that contribute significantly to wetland functions and values. Ineligible lands include wetlands converted after December 23, 1985; lands with timber stands established under the Conservation Reserve Program; federal lands; and lands where conditions make restoration impossible. Thus, any wetlands in this program represent land that has been reclaimed from prior conversion to agricultural land or which support protected wetlands, and they create a net gain in Great Lakes basin wetlands. Use of these wetlands in mitigation efforts is prohibited by statute.

Associated Issues

On acreage subject to a WRP easement, participants control access to the land and may lease the land for hunting, fishing and other undeveloped recreational activities. The purchase of a conservation easement by the U.S. government does not constitute an outright purchase of lands. At any time, a participant may request that additional activities be evaluated to determine if they are compatible uses for the site (e.g., hay cutting, livestock grazing or timber harvesting). Compatible uses are allowed only if they are fully consistent with the protection and enhancement of the wetland.

Implementation of WRP has illustrated the need for funding for technical assistance to landowners, not just financial assistance. NRCS and its partners, including conservation districts, provide a great deal of assistance to landowners as part of restoration activities. These include the design of wetland restoration practices and oversight of restoration activities. Easement acquisition, which guarantees that wetlands will be properly maintained, is an important part of the program, but involves a great deal of time and effort. NRCS and its partners also continue to provide assistance to landowners after completion of restoration activities. This assistance may be in the form of reviewing restoration measures, clarifying technical and administrative aspects of the easement, and providing basic biological and engineering advice on how to achieve optimum results for wetland dependent species.

WRP benefits the public by restoring and protecting wetland functions and values. It also benefits participants who receive financial and technical assistance; experience a reduction in problems associated with farming potentially difficult areas; and have incentives to develop wildlife recreational opportunities on their land.

Potential Applicability to Annex 2001 Implementation

Key issues related to this type of program include:

- Whether the relevant government entity has the legal authority to acquire and hold easements;
- The financial costs of both the easement purchase and cost-share for wetlands restoration; and
- The technical ability of the government entity to design and implement wetland restoration.

Partnership agreements between government entities and NRCS, conservation districts, and environmental groups could address the second and third issues. Also, funding mechanisms other than direct appropriation of funds to a program are available, such as the sale of bonds by state or local governments.

Recent Precedent

Less than two years have passed since the signing of Annex 2001 and, given that the Annex has not yet been implemented, precedents are few. However, one case study in Michigan may assist in the resource improvement work called for in the Annex.

Case Study Overview

The Perrier Group of America recently began operations at a water bottling facility in the Muskegon River watershed in west-central Michigan. At peak production, the plant will withdraw approximately 720,000 gallons per day of groundwater for purification, sterilization, bottling and distribution to consumers under the brand name Ice Mountain.

After conducting an extensive review and public hearing, the Michigan Department of Environmental Quality (MDEQ) issued a permit in August 2001 for the plant to construct and operate two wells. Company hydrogeologic tests and analyses reported that there would be no significant adverse impacts on adjacent private wells or on nearby surface waters and wetlands. In addition, studies performed by MDEQ reportedly anticipated that water withdrawals would have no significant impacts on fish and wildlife.

There has been a great amount of interest in, and concern related to this project. Lawsuits were filed by environmental and tribal groups concerned about the impacts to groundwater levels and nearby surface water. Another issue has been whether the sale of bottled water outside of the Great Lakes basin constitutes a diversion that would require consent of the Great Lakes governors under the Water Resources Development Act (WRDA) of 1986. The MDEQ concluded that the withdrawal does not constitute a diversion based on the customary exemption of water that is used for food products, beverages or bottled water and the traditional definition of diversions as being bulk exports out of the Great Lakes basin (MDEQ, 2001). The issue of how much of the water will remain within the basin and how much will be shipped to other states or countries is an ongoing topic of debate.

In anticipation of the implementation of Annex 2001, the Perrier Group incorporated several environmental restoration and protection features into its final project. These actions were not required by MDEQ and were voluntarily initiated. The environmental protection and restoration features include:

- The endowment of a $500,000 environmental stewardship fund to finance educational and environmental restoration projects throughout the Muskegon River watershed;
- The acquisition of development rights for over 1,100 acres of land surrounding the wells to protect the groundwater recharge; and
- The installation of over 60 monitoring wells to develop a long-term monitoring network, and data sharing.

The environmental currency in this case is water quantity and quality. Perrier offered water quality protections in exchange for water quantity reductions.

Definition and Application of Resource Improvement Concept

The intent of the environmental protection and restoration measures is to provide for an overall improvement in the Muskegon River watershed. In addition to demonstrating that the operations will have no significant adverse impacts, the applicant will also implement several measures to improve the quality of the watershed and advance the state of knowledge of water resources in the area.

The environmental stewardship fund was established to support efforts and programs that protect and enhance natural resources. An outside consultant will manage the fund, and board members will include community stakeholders and a Perrier representative. The board will oversee project grants and reach out to potential beneficiaries. This represents an improvement in the watershed by facilitating projects that improve water quality, restore natural wildlife habitat and restore and preserve critical wetlands, streams, and other bodies of water.

The undeveloped land surrounding the bottling facility is primarily pervious and allows rainwater to infiltrate and replenish the groundwater. Acquiring the land surrounding the wells will prevent the development of this area, minimizing surface runoff and maximizing infiltration. By preserving the 1,100 acres surrounding the wells, the groundwater is also protected from future sources of contamination.

The installation of the monitoring network serves as an early warning system so that pumping activities that have any adverse impacts can be corrected. Also, the data collected from these wells, such as aquifier levels and water quality information, will be shared with regulators, universities and the surrounding communities, allowing the area's groundwater resources to be better understood.

Associated Issues

The studies conducted prior to permitting indicated that there would be no significant adverse impacts due to the pumping. Therefore, the voluntary improvement measures defined above are not intended to mitigate adverse impacts. Rather, the watershed improvements are part of the project design. The measures are also an example of improvements tied directly to the use, a possible approach to the improvement standard. These improvements relate to protection and restoration of the watershed that provides the water for the facility.

Potential Applicability to Annex 2001 Implementation

The environmental protection and restoration measures in the final project plans may provide a precedent for future projects. The Perrier Group is believed to be the first party that intentionally developed a plan to incorporate the principles of Directive #3.

One comment expressed during the Focus Group session was that improvement measures should be developed within the context of regional water management/ecosystem restoration plans.

Applying the Resource Improvement Standard to Implementation

Key Questions

The background material provided in previous sections serves as a departure point for discussions on the interpretation and application of the improvement standard. Following are the types of questions that might be considered.

1. At what scale is the resource improvement standard appropriately applied?
    a. At what *spatial* scale is the resource improvement standard appropriately

applied (e.g., site specific, lake-wide, basin-wide)?

b. At what *time* scale is the resource improvement standard appropriately applied (e.g., 10 years, 50 years)?

2. What options are available for measuring improvement under the application of the resource improvement standard?
3. To what extent, if any, should mitigation be a consideration in the application of the resource improvement standard?
4. How should cumulative impacts be considered in the application of the resource improvement standard?

Summary of Resource Improvement Standard Workshop

These key questions were posed to participants during a workshop on July 31, 2002 in Chicago to generate ideas of how to implement a resource improvement standard. The intent was to inform the discussion rather than form consensus. Participants included members of the Annex Working Group, Project Management Team, Stakeholders Advisory Committee and numerous other parties. The responses to these questions, both raised directly at the workshop and submitted in writing by attendees, are summarized below.

1. **At what scale is the resource improvement standard appropriately applied?**

a. At what *spatial* scale is the resource improvement standard appropriately applied (e.g., site specific, lake-wide, basin-wide)?

Diverse opinions were expressed on this issue. Some argued that improvements should be located as closely as possible to new withdrawals, especially for withdrawals from aquifers, streams and rivers. Others pointed out that the requirement to avoid adverse impacts may make a spatial link between withdrawal and improvement unnecessary. The importance of flexibility in location was expressed, based on the need to find suitable land to accomplish effective improvements. It was also argued that the scale of an improvement should be consistent with the ability to measure that improvement, relative to a baseline condition. Some argued that this consideration points to local rather than basin- or lake-wide improvements, in part because of the great technical difficulty of forecasting baseline ecosystem health on a long-term scale.

On a different spatial issue, a concern about differences between in-basin and external water withdrawals was discussed. Legally, the proposed requirements might convey ownership rights to parties outside the Great Lakes basin, making Great Lakes waters an ordinary commodity with an established price. Related issues of riparian law were raised in connection with a proposal to withdraw water and restore Lake Superior coastline.

b. At what *time* scale is the resource improvement standard appropriately applied (e.g., 10 years, 50 years, etc.)?

The point was made that restoration projects take time to produce ecosystem benefits; a lag between initiation of a new withdrawal and effective resource improvement could therefore occur. Reactions to this idea were diverse: some argued that improvements should be undertaken in advance of new withdrawals, while others pointed out that delays in approval for needed withdrawals could reduce the attractiveness of the Great Lakes-St. Lawrence River basin to business.

Some argued that any improvements should be sustainable indefinitely, while others proposed an augmented flow of services over time as the appropriate standard. A temporal match between improvements and the productive life of water-withdrawing capital was also proposed.

The role of changes in hydrological conditions over time was also raised: both the value of water to users and the functional value of ecosystem improvements may vary as conditions change from drought to wet weather.

2. **What options are available for measuring improvement under the application of the resource improvement standard?**

U.S. and Canadian federal, provincial, and state governments already are monitoring Great Lakes ecosystem health, and these efforts could be used to measure improvements. Assessment tools (to support resource improvement decisionmaking) are also available or under development, including some being initiated by the Great Lakes Protection Fund.

Discussion also focused on measurement of improvements using environmental currencies, including dollar values. Some participants expressed interest in a trust fund which could be used to finance improvement projects. Currencies, such as acres of wetlands or dollar values of services provided, would lend simplicity to an improvement standard, but also would be imperfect measures of the true functional value of a resource improvement. Concerns raised with dollar valuation of improvements included the following: the “selling” of Great Lakes water; facilitating its export outside of the basin; its commodification; and uncertainties in quantifying nonhuman services.

3. **To what extent, if any, should mitigation be a consideration in the application of the resource improvement standard?**

Issues of potential adverse and beneficial impacts of water uses were discussed, along with the relationship of improvements to those impacts. The point was made that significant adverse impacts are not allowed under the Annex; policy examples that match improvements to adverse impacts may therefore not be appropriate prototypes. (A similar point was made for cumulative adverse impacts in the discussion of question 4: if they are not allowed under the Annex, then the relevance of measuring or mitigating them is questionable.) There was wide, although not universal, agreement that mitigation of harm caused by new withdrawals should not be part of the improvement standard. Withdrawal of groundwater in quantities less than the potential yield was given as an example of a withdrawal without adverse impacts.

Mitigation of existing harm was also discussed. The argument was made that this is a category of improvement explicitly identified under the Annex and that it should include in-kind improvements. Several dangers to be avoided were also identified, such as not allowing new users to get double credit for mitigation that already would be required and preventing use of the resource improvement standard as a tool to prohibit water use or manipulate desired outcomes from users.

Grand Haven Beach, Mich.

Others argued that potential adverse impacts could be mitigated as the first step in any new withdrawal, and that any additional ecosystem enhancements would then constitute the required improvements. If this approach is accepted, it was argued, there remains a challenge of achieving fairness in measuring improvements for applicants with differing circumstances.

Beneficial aspects of municipal and agricultural water uses were mentioned, and the point was made that human civilization is a part of the Great Lakes ecosystem, along with wildlife. Human benefits to Great Lakes users were suggested as a potential discriminator between in-basin and external users. Some participants argued that the intent of the Annex is to restrict consumptive use of diversions outside the basin. Others argued that benefits that are important to human society, even within the Great Lakes basin, are not necessarily improvements to waters and water-related resources, as specified in the Annex.

4. **How should cumulative impacts be considered in the application of the resource improvement standard?**

Both spatial and temporal aspects of this issue were discussed. These included the simultaneous contributions of each upstream user to downstream conditions and the ultimate cumulative impact of successive users in a single location. Both human use and ecosystem impacts were discussed. A National Environmental Policy Act definition of cumulative impact was suggested as a precedent: “incremental, when added to past, present, and reasonably foreseeable future impacts” (40 US CFR 1508.7).

Specific examples were discussed in which it would be technically challenging to estimate these cumulative impacts, lending uncertainty to implementation of an improvement standard. One proposed implementation method would estimate the cumulative impacts of a combination of many withdrawals, including a margin of safety to account for uncertainty, and then attribute fractions of those potential impacts to individual users according to their incremental withdrawals.

Findings and Recommendations

Findings

Successful implementation of the Great Lakes Charter Annex will, in large part, be determined by the development and application of a new decisionmaking standard for water withdrawal proposals, as called for in Directive #3 of the Annex. Key issues associated with standard development include: the definition and interpretation of Directive #3 terminology; transforming the four associated principles into straightforward policy measures; and addressing application issues, including assigning a spatial/temporal scale and preventing prospective cumulative impacts.

The case study analyses and resource improvement workshop were the primary tools used to research development and application of a resource improvement standard. The case studies generally provide examples of mitigation that have relevance, but not direct application, to the development of a resource improvement standard. None of the case studies provides a model for exclusive application to the Annex's resource improvement standard, but several case studies have elements of resource improvement that have been interpreted and applied in many settings. The workshop focused on four key questions and generated several ideas related to the definition, interpretation, and application of the resource improvement standard.

Given the potential range of water withdrawal scenarios in the Great Lakes basin, the resource improvement standard (and associated process) must be specific enough to provide scientifically sound guidance, yet flexible enough to accommodate the inherent uniqueness of individual proposals. A point that was made through the research effort is that, because the Annex decisionmaking standard will require "no significant adverse individual or cumulative impacts," 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 new withdrawal.

Resource improvement measures should all be directed toward a common baseline for measurement. Consideration should be given to specifying goals, objectives, and baseline conditions. Spatial and temporal parameters should be applied to the selection of prospective resource improvement measures so that benefits occur in the vicinity of the proposed withdrawal and during the lifetime of the proposed withdrawal.

A fundamental component of application of a resource improvement standard is the ability to measure an improvement. Therefore, consideration must be given to both the design of an appropriate methodology, and the data, information and resource requirements to support it. Data and information need to be collected on current and prospective ecological conditions to measure the effectiveness of resource improvement measures. An environmental currency must be selected that will be used to measure the amount of resource improvement that withdrawal applicants provide.

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.**

   These activities will serve the interest of identifying data, information and evaluation requirements for water withdrawal assessments. Many of the same data and knowledge base needs identified in Chapter Five for assessing significance of resource impacts are also needed for assessing resource improvements. The evaluation methodology should include both individual and cumulative standpoints and assist in measuring the "improvements" associated with the attendant conservation, enhancement or restoration activity.

2. **Continue and improve case study analysis and "scenario testing" to explore applications of a resource improvement standard.**

Ongoing work on a suite of projects supported by the Great Lakes Protection Fund should be carefully reviewed and augmented, as needed, by additional "scenarios testing" that leads to efficient and cost-effective methodologies for implementing the resource improvement standard.

3. **Conduct a more thorough study of the resource improvement concept.**

Such a study should: 1) look within and beyond North America for precedents for the improvement standard in existing laws and programs, 2) examine actual projects undertaken under these kinds of laws and programs, and 3) be pursued in partnership with organizations that have a primary ecological "improvement" mission, such as Fisheries and Oceans Canada, the U.S. Fish and Wildlife Service, The Nature Conservancy and the World Wildlife Fund.

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Chapter Seven

Information and Communications

The Need for Scientifically Sound Information

A recurring finding of this project is the lack of data and information that members of the scientific, management and policy communities consider to be fundamental to scientifically sound decisions regarding the withdrawal and use of Great Lakes-St. Lawrence River water resources. Additionally, numerous recommendations contained in this report address specific improvements regarding accounting of the waters of the Great Lakes-St. Lawrence River system, monitoring water uses, and assessing prospective ecological impacts of such use. Under this project, existing data and information have been assembled and characterized, and gaps have been identified. The next step in this endeavor is to organize data and information (both existing and prospective) so resource managers and decisionmakers can have ready access to it.

Directive #5 of Annex 2001 calls for "a decision support system that ensures the best available information." The governors and premiers stipulated in the Annex that the "design of an information gathering system … will include an assessment of available information and existing systems, a complete update of data on existing water uses, an identification of needs, provisions for a better understanding of the role of groundwater, and a plan to implement the ongoing decision support system." The Annex 2001 implementation process is moving forward, and a governor/premier-appointed Working Group is focusing on the development of binding agreements. Accurate, consistent, well-documented and easily accessible data and information should be the foundation of the decision support system.

The design of the decision support system will need to be a collaborative effort involving representatives of all likely decisionmakers, information providers and stakeholders. Further, the information systems that support the decisionmaking process will need to be designed for wide public access. Recent developments in Internet technologies will provide essential components in this endeavor.

The Information Base for a Decision Support System

Key points to consider about data and information with respect to the development of a Water Resources Management Decision Support System (WRMDSS) are as follows:

- We will likely never have access to all the data and information that is considered relevant to water resources planning and management; hence, decisions will be made with the best available information.
- Data and information standards will need to be promoted, developed and implemented as necessary. Further, metadata (detailed records about data sets) will become increasingly important to ensure that information is accurately interpreted and used in decisionmaking.
- Hydrologic and hydraulic data vary in density, resolution, scale and temporal characteristics. Consequently, assessing changes in the water resources of a watershed is substantially different than looking at water resource characteristics on the Great Lakes. Information must therefore be structured, managed and delivered at various "nested" scales and temporal formats.
- Improvements in monitoring of water withdrawals and uses throughout the region will coincide with a need for increased sophistication in database design and maintenance. Commensurate commitments to metadata production will be required.
- Scientifically sound data and information on ecological conditions and trends are being collected under compatible programs, as evidenced by the binational monitoring programs that are evolving to implement the State of the Lakes Ecosystem Conference (SOLEC) indicator suite. This data and information should be exploited to the fullest extent possible.
- Improvements in computer modeling of complex physical, chemical and biological

processes and associated visualization tools may play a crucial role in the WRMDSS. Connectivity between computer models demands greater attention.

- Technological advancements in interoperable computer networks, geographic information systems (GIS) and wireless communications will create significant opportunities for seamless and virtual information exchange between political jurisdictions.

Evolving Technologies

When considering decision support system options, it is important to understand the way communications and technology advances have contributed to changes in water resources management decisionmaking since the signing of the Great Lakes Charter in 1985. Some of the changes include the following:

The Internet – The Internet has been, in many respects, the most significant technological advancement of recent decades. Information is disseminated almost instantaneously to any number of stakeholders. Advances in Internet technology are expected to continue unabated for the foreseeable future. The Internet will most likely be the cornerstone for data and information access for a WRMDSS.

Electronic Communications and Compatibility – The explosion of the cellular communication industry, the advent of email, and improvements to traditional phone lines are continuing to transform business processes. These new technologies provide broad access to both centrally-managed and distributed data and information.

Real-Time Data – Advances have been made in automated and instantaneous dissemination of data from remote sampling locales. Almost all water level gauging systems in the region are equipped with some mechanism for instantaneous interrogation and satellite or radio-frequency data relay. Access to real-time data influences management decisions for many of the hydropower, commercial navigation, municipal, industrial and agricultural users in the Great Lakes-St. Lawrence River system.

Integrated Data Collection – Positional and temporal detail has improved tremendously over the last 15 years. Water level data are now collected from gauging sites at 6-minute (U.S.) or 15-minute (Canada) intervals and at mobile sampling locations using backpack or hand-held Global Positioning System (GPS) units.

Remote Sensing – Satellite and airborne imagery is becoming much more affordable for operational applications. These data have applicability in classification for land use, land cover and wetlands. Images collected over time can be used to monitor change.

Data Consistency, Uniformity and Display – Although significant shortfalls exist in data and information standardization, substantial progress has been made to allow various users to take advantage of water resources data and information. Gaps in water use inventories are being identified, and reporting is becoming more uniform and recurrent. Complex processes can now be simplified and visualized due to advancements in computing and Internet resources.

GIS – Geographic Information System (GIS) technology has advanced steadily, with improvements in distributed processing and relational database management tools. A current trend is the development of large-scale multi-jurisdictional "web mapping" projects. Web mapping frequently involves cooperative data serving nodes that deliver products to clients using the Internet. This technology will likely support the analysis of information needed for water resources management decisionmaking.

Metadata – Metadata in the broadest sense is the "history" of the data, including source, scale, accuracy and processing steps. Substantial progress has been made in defining data content standards for many GIS data themes, but a more substantial production of metadata for other data types is needed. The power of distributed data access, real-time web mapping, timely computer modeling and many other applications is compromised if metadata are incomplete.

The technological advances noted above have, in many respects, made the extraction of relevant data and information as much an "art form" as a science. Therefore, suitable resources must be invested in a careful systems-engineering assessment of the problems associated with data access, storage and retrieval.

Investments are being made in new wireless and fiber optic delivery mechanisms that should provide resource managers, stakeholders and interested citizens with improved abilities to acquire data and information across the Internet. Increases in computer storage capacities will also occur, but likely will be matched by increased data volumes. Increased computing speeds will continue to promote improvements in computer models and visualization tools.

These technological advances should promote a more open environment that improves public access to data and information. Although security considerations are likely to increase, effective "work-arounds" are likely to be found. Resource management decisions should become more sophisticated as abilities improve to acquire and analyze vast quantities of data and information, and to generate applicable options. Further, managers should be able to more effectively plan for the future, set reasonable targets, develop metrics, monitor progress and achieve desired results.

Examples of Operational Decision Support Systems

A decision support system (DSS) 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 decision support process consists of three phases of decisionmaking: *information gathering*, *options design* and *choice*. The information gathering phase typically involves identifying problem situations, causes and effects, and interrelationships. The information gathering system coordinates decision situation analysis by exploring and integrating data and information from a wide range of sources. In the options design phase, the DSS typically supports decisionmakers in the development of possible alternatives that reflect various interests, objectives and evaluation criteria. The nature of the choice phase depends upon the decisionmaker's preferences with respect to the importance of the evaluation criteria. Decision support systems range from highly deterministic and rule-based formulae to highly interactive and participatory processes.

The objective of a computer-based decision support system is to improve planning and decisionmaking by providing useful and scientifically sound information. It is most effective in collaborative decisionmaking. Expert or knowledge-based systems, and other analytical and modeling techniques, have been used to help scientists, managers and policymakers understand the complexity of physical and biological systems.

Many examples of decision support systems designed for research applications and demonstration purposes at a regional or watershed level can be found. Most have been developed to assess the environmental impact of natural resources use including agricultural, industrial and land use activities. Others have been applied to potential contamination and site suitability problems based on maximization of multiple criteria and minimization of threshold (constraint) values. Popular DSS-based software packages, such as IDRISI GIS, STELLA, ExpertChoice and a number of ESRI extensions, allow users to evaluate a decision problem through a multiple criteria decisionmaking (MCDM) process. This common approach allows the user to assess the relationships between a set of objectives and associated attributes. Many of the software packages are becoming "web-enabled," allowing for wider access and even multi-player gaming exercises.

The DSS framework innovatively supports resource management and planning by creating an information framework tailored to the information, communication and technical needs. In addition, it can support and promote an informed debate when multiple goals and interests must be simultaneously addressed to resolve conflicts and build consensus.

A DSS framework applied to the management of Lake Ellesmare in New Zealand identified various decisionmakers and stakeholders and educated them about differing perceptions on existing lake management problems (Gough and Ward, 1996). By concentrating on information gathering and consultation with affected parties, the framework helps improve the decisionmaking process and establish criteria for measuring desired outcomes.

The Colorado River Decision Support System (CRDSS) is a fully operational tool that enables agencies, water users and managers to organize, assess and evaluate a wide range of information and strategies on reservoir and river operations, water flow impacts, and water allocations. Designed by Riverside Technology, the CRDSS allows decisionmakers to analyze historical and real-time hydrologic data, run hydrologic simulation models and water rights allocation models, and study the effects of potential decisions. The primary component of the CRDSS is the HydroBase database that includes streamflow, climate, water rights, diversions, well permits, dam safety and land use data. These data feed into the consumptive use model to calculate the amount of water used by different interests. The results from scenario models are central to determining present and future uses of water. By allowing all applications to use the same, consistent information, this data-centered approach ensures data integrity and minimizes data redundancy (Bennett et al., 2001).

The Québec Ministry of Environment developed an integrated modeling system prototype to evaluate the impacts of municipal, industrial, forestry, and agricultural projects on the water quality and yield of a river basin (Rousseau et al., 2000). Comprised of a relational database management system, the modeling system has the ability to use both spatial and attribute data (e.g., digital elevation model, meteorology, soil, gauge locations, simulation results, livestock production, crop management) to generate scenarios that add water quality and flow dimensions to watershed assessments.

An operational DSS has also been implemented in the Great Lakes watershed. RAISON (Regional Analysis by Intelligent Systems ON microcomputers), developed at the National Water Research Institute of Environment Canada, is designed to help Great Lakes basin decisionmakers, managers and advisors locate relevant information for toxic chemicals (Lam and Swayne, 1993; Lam et al., 1995; Booty et al., 2001). The system consists of several layers of computational modules including a database, a spreadsheet, GIS, statistics, expert system, contouring, spatial visualization and graphs. Data on toxic chemicals provides input to the database table for further statistical analysis or optimization modeling. The system integrates text, maps, satellite images and other data with a combination of spatial algorithms, models and statistics to generate specific scenarios.

Information Integration

The essence of a DSS is the integration of data, information and knowledge from different sources to improve the decisionmaking process. However, as noted below, several factors can help or hinder the development and adoption of an integrated DSS for Great Lakes-St. Lawrence River water resources management.

Quality of Data – Several issues illustrate the need for system interoperability and data consistency. Large amounts of raw data are needed that come from different collection sources (i.e., water levels, river flows, air temperature, precipitation, meteorological parameters), which must be verified and corrected for final use. These sources typically are in different formats that must be converted for use in the WRMDSS. Some data must be current, but historic information may also be crucial. High resolution spatial or temporal data may also be essential to the decisionmaking process. In some instances, geospatial data may have different positional accuracies, making them more difficult to integrate into the WRMDSS.

System and Hardware Maintenance – The development of a WRMDSS should be considered a continuous process instead of a one-time development project, and be able to respond to current needs, stakeholder interests and future demands. Experiences have shown that, when dealing with a large set of data types from different sources, database tables and their fields should be carefully designed in the initial phase of the project. The WRMDSS will require data to be frequently updated, as the system will be otherwise useless.

Leadership and Management – Leadership and management set and achieve goals and objectives that sustain the value of the investment. Leadership also coordinates and communicates between different agencies across jurisdictions. Emphasis should be placed on the importance of the WRMDSS as a communications tool that provides an information infrastructure and framework for multiple users to make informed decisions based on the best available data collected.

Modeling Interconnectivity - In Chapter five, an extensive inventory is presented on the types of descriptive models that may be needed for the WRMDSS. To quantify the range of potential ecological impacts of a particular water withdrawal, a linked modeling framework will be necessary, comprised of groundwater, hydrodynamic, surface water quality and ecological effects models.

Information Dissemination – Key Considerations

The manner in which a broad range of information is displayed and presented will be key to the success the WRMDSS. Some key considerations follow.

Clearinghouse node – A clearinghouse node is a decentralized system of servers located on the Internet that contains descriptions of available digital data known as metadata. Metadata are collected in a standard format to facilitate query and consistent presentation across participating sites. A clearinghouse uses readily available web technology for the client side to query, search and present search results. By utilizing a standard method for these functions, a clearinghouse allows individual agencies, consortia and geographically defined communities to collectively promote their available digital spatial data.

Integrated and interoperable web pages – In promoting the availability, quality and requirements for digital data through a searchable online system, there must be integrated and interoperable web pages that provide a standard data and information dissemination mechanism to different target audiences.

Data warehouses – A data warehouse is a database designed to support organizational decisionmaking. It can be updated automatically and structured for rapid online queries. A warehouse stores historical and consolidated data (e.g., flow records, water levels, meteorological parameters) in a common format. This component is the most critical element of a DSS.

Distributed networks – A network, which functions closely with a clearinghouse node, is needed to retrieve data from multiple sources. Servers may be installed at local, regional or central offices, as dictated by organizational and logistical efficiencies. All clearinghouse servers in a distributed network are considered "peers" within the clearinghouse activity; there is no hierarchy among the servers. This permits direct query by any Internet user with minimal transactional processing and duplication of effort in the collection of digital spatial data. Cooperative digital data collection activities are fostered as well.

Distributed GIS mapping – Web-based GIS provides a visualization mechanism that allows users to access various sources of geospatial data. An open GIS architecture should be able to assess multiple forms of data. Users of geospatial data need to share data effectively and efficiently.

Enhancing Communications

An important part of the WRMDSS project has been the development of effective communications tools to provide access to available data and information. Below is a description of these tools and approaches and how they may be applied in the WRMDSS design. This listing is not comprehensive, but illustrates the array of available tools.

- **Internet** – A Great Lakes water use website has been a centerpiece of project activity and has been finalized with electronic versions of project products and an online regional water use database. The site is extensively linked through and highlighted on the Great Lakes Commission-managed Great Lakes Information Network (GLIN). GLIN is the pre-eminent Internet clearinghouse for data and information in the Great Lakes-St. Lawrence River region and, among many other services, supports a hydro-meteorological station directory and coordinated hydrologic/hydraulic data. GLIN also contributes significantly to the water resources management community via its "Daily News" feature, an electronic "clip service" that monitors print, radio and television media coverage of Great Lakes issues. GLIN also provides secure email discussion forums for targeted groups and topics. The websites and forums would support the needs of the region's governmental agencies during decisionmaking deliberations.
- **Intranet Portal** – An intranet portal is an internal communications tool that can be configured to include only state, provincial and federal regulatory agencies (and other key groups), in the interest of providing security and privacy for confidential infor-

mation exchange and deliberations. Some intranet functions are currently available to the WRMDSS project team via listservs and community email addresses. The intranet portal can also help researchers coordinate ongoing and prospective projects with colleagues, and provide policymakers and managers with data and information for the WRMDSS.

- **Online GIS –** The Great Lakes Commission supports new web-based GIS applications as a service to the International Joint Commission (IJC), the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA). The Great Lakes Commission staff is currently developing a GLIN-based framework for regional metadata clearinghouse and web-mapping applications. The GLIN website could provide an effective Internet presence for a coordinated and distributed GIS that would add a valuable dimension to the WRMDSS.
- **Conventional Hard Copy Dissemination** – The Great Lakes Commission's Advisor newsletter is used to disseminate project information and announcements to more than 3,500 policymakers, managers, researchers and other interested parties. Additionally, hard copies of some products (e.g., water use database report) have been published, publicized and made available to all interested parties. Hard copy products will continue to be the preferred medium for many entities in the region to keep current with water resources management issues and should be factored into the WRMDSS.
- **Meetings and Conferences** – The annual and semiannual meetings of the Great Lakes Commission have been used to report on progress, receive feedback, and release interim and final reports. These forums have been convenient and cost effective given that many of the WRMDSS project participants attend these meetings. Project findings and recommendations will also be presented and discussed at other related meetings and conferences where Great Lakes issues are discussed. Face-to-face communication among agency officials and with the public should continue to be a major vehicle for information dissemination and coordination of decisionmaking, and needs to be explicitly designed into the WRMDSS.

These communication tools are proven to be effective, and should be further refined to satisfy the needs of decisionmakers, managers, scientists and other interested parties.

Findings and Recommendations

A Water Resources Management Decision Support System is essential in supporting and promoting decisions through informed discussion and debate where multiple, and sometimes conflicting, goals and interests are involved. A variety of information dissemination and communications tools can be applied and, among others, include the Internet, intranet portals, online GIS and conventional communications.

Key considerations for integrating data and information into the WRMDSS 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 WRMDSS design process must also include the review and evaluation of alternative decision support frameworks – or models – that organize critical, yet disparate, data and information in a way that will foster science-based evaluation of withdrawal proposals. Decisionmakers, managers and scientists should be presented with multiple WRMDSS frameworks and be fully involved in testing and evaluation. The initial research, review and assessment process should not yield a single, specific alternative, but provide multiple options that decisionmakers (i.e., the Annex Working Group) can consider in reaching their own conclusions on which option or suite of options best meets the needs of the region.

The WRMDSS should provide easy access to relevant scientific data and information, including all key data sets and other products of the project: water use data by basin, jurisdiction and sector; consumptive use information; relevant literature (peer-reviewed and "gray") on ecological impacts; essential questions to assess ecological impacts; computer models; and data/information needed to apply a resource improvement standard.

Recommendations

1. **Develop integrated Internet web pages to facilitate data and information exchange, distribution and access.**

   Commitments should be made by all federal, state and provincial governments across the Great Lakes-St. Lawrence River system to cooperate fully in the development of the web pages. Information should be publicly accessible to the greatest extent possible.

2. **Develop metadata to accompany all geospatial and temporal data used in a Water Resources Management Decision Support System.**

   Metadata should be developed to accompany all geospatial and temporal data used in the WRMDSS; this will benefit decisionmaking by facilitating information discovery, networked GIS mapping, and assessment and consideration of information uncertainties.

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.**

   The WRMDSS should include a communications strategy. Existing and emerging Internet technologies, as well as email and online discussion groups, should be viewed as key components of the WRMDSS. Applicable meetings, conferences and symposia focused on information coordination and continued system development should also be used to facilitate communication.

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Chapter Eight

Pulling It All Together: Project Synthesis

Introduction

The results of this two-year project have been compiled and presented in this report to ensure their immediate use and benefit to water resources managers, decisionmakers and other interested parties. Through the inventory and assessment of available water resources data and information, project collaborators have come to realize that, while much is known about the complex nature of Great Lakes-St. Lawrence River water resources, much more still needs to be learned to advance science-based decisionmaking.

With the conclusion of this effort, state and provincial water resources policy experts, managers and decisionmakers will begin to grapple with application of project findings and recommendations to the Water Resources Management Decision Support System (WRMDSS) called for under the Charter Annex and within the context of existing provincial, state and federal laws and treaties. This chapter pulls together the project's several elements and, in so doing, will help the region's decisionmakers understand and address uncertainties associated with the water resource and its ecosystem; address key data and information gaps; and design interoperable and integrated communications, data management and assessment tools.

Using Data and Information to Inform Decisionmaking

The primary purpose of this project was to assess the status of current data and information and to identify associated gaps and needs. In writing this report, a challenge has been to balance the discussion and not adopt a "glass half empty" approach when critically examining the complexities related to data and information for decisionmaking. Much of the data that is currently available, in fact, adequately addresses the purposes for which it has been gathered, but this data may be inadequate to meet all future decisionmaking needs. This does not mean that agencies and jurisdictions lack commitment or have been negligent, but points to the need for enhanced planning to identify and accommodate the evolving nature and associated needs of water resources management decisionmaking.

Water resource management decisions are made within the context of existing state, provincial and federal laws and treaties, which help establish the parameters for a decision support system. An examination of these laws and treaties, many of which were briefly discussed in Chapter one, may also help determine which data and information are most relevant for a new decisionmaking process.

Focusing on Future Needs

Water resource management efforts in the Great Lakes-St. Lawrence River basin – including laws, policies, research activities and interjurisdictional agreements – have historically focused on the physical implications (i.e., alternation in levels and flows) of water withdrawals from the open lakes and larger tributaries. Over time, however, other ecological dimensions of water withdrawals have gained increased attention. For example:

1. The issue of scale has taken on greater importance. The region has come to realize that the ecological impacts of any given water withdrawal are most discernable at the sub-watershed level. Yet, data and information gathering efforts, as well as computer modeling and related analyses, have historically focused on a larger-scale, lake-wide or systemwide basis. This suggests the need for a fundamental examination of the current water withdrawal impact assessment process in the interest of securing both systemwide and sub-watershed level perspectives.
2. Enhanced understanding of groundwater resources suggests the need for a greater focus on groundwater research, management and protection. The role of groundwater in the hydrologic cycle is increasingly recognized (though not well understood), as is its contribution to surface water levels and flows.
3. Ecological impacts associated with water withdrawals have placed new demands on scientists and managers who have traditionally approached water resources projects primarily from a hydraulic/hydrologic standpoint. This suggests the need for an

assessment and refocusing of research, and development of new multi-disciplinary partnerships for scientific inquiry and decision support.

4. A better understanding of the cumulative impacts of water withdrawals over space and time is a priority need in developing and implementing the WRMDSS.

Future needs can also be addressed by building on current data collection processes. Water withdrawal and use data and information can assist managers and other decisionmakers in anticipating and planning for future changes in demand. The development and implementation of effective and comprehensive water management programs (including elements such as water conservation and drought contingency planning) is problematic because water demand information is not readily available.

The Importance of Scale in the Assessment of Water Resources Data and Information Needs and Gaps

"How sensitive is the Great Lakes-St. Lawrence River system to impacts associated with water withdrawals and diversions, and at what level can those impacts be ascertained?" This is a fundamental yet complicated question due to a variety of factors. For example, the Great Lakes-St. Lawrence River system is no longer a natural one. Changes to the system, primarily for navigation, hydropower and riparian purposes, have permanently altered the natural levels and flows regime. Diversions (both incoming and outgoing); construction of locks, dams and controlling works; and dredging and riparian encroachment in the interconnecting waterways have created changes that are orders of magnitude greater than any changes that might occur from small-scale withdrawals, diversion or export projects, even when considered cumulatively. In addition, major changes have occurred in natural hydrologic/hydraulic streamflow regimes due to largely irreversible land use modifications such as timber cutting, agricultural and transportation development, and residential expansions. At the global scale, climate change may cause additional alterations to the levels and flows of the Great Lakes-St. Lawrence River system. Being able to discriminate between the effects of each of these "forcing functions" will be crucial for an effective WRMDSS.

Hydrologic Scale Issues

As noted in Chapter two, the variability of the hydrologic system and the limitations of hydrologic measurements are factors that need to be considered in any decision support process and in the assessment of watershed sensitivities. All hydrologic and hydraulic phenomena are variable both temporally and spatially and can be treated at different scales of time and space, depending on the water use scenarios being examined. Most of the hydrologic data are reported as long-term averages at large spatial scales, with no direct measure of uncertainty. As a consequence, different water uses and hydrologic alterations may have different space-time scales. This is particularly applicable to the water withdrawal issue. For instance, a withdrawal of a given water quantity from a large water body could have very different impacts than a withdrawal of the same quantity from a small water body or stream.

Most hydrologic issues are analyzed within a given drainage basin or watershed. Watershed boundaries rarely coincide with territorial or jurisdictional boundaries (Singh, 1992). Watersheds vary tremendously in size, literally from a few acres to hundreds of thousands of square miles, such as the Great Lakes-St. Lawrence River basin. Large watersheds are comprised of smaller drainage basins, or sub-basins, which can be more manageable units for analysis.

The ordering of watersheds begins at the largest level of the watershed. In Canada, for example, the Great Lakes basin would be considered the primary or 1st level watershed. Individual lake watersheds (e.g., Lake Superior) would be considered a secondary or 2nd level watersheds, the sub-watersheds of the individual lakes would be considered tertiary or 3rd level watersheds, and so on.

In the United States, the U.S. Geological Survey (USGS) has a hydrologic unit classification system similar to Canada's. The first level of classification divides the United States into 21 regions, one of which is the Great Lakes basin (Region 4). The second level divides the 21 regions into 222 sub-regions. A sub-region includes the area drained by a river system, a reach of a river and its tributaries in that reach, closed basin(s), or a group of streams forming a coastal drainage area. The third level subdivides many of the sub-regions into 352 accounting units, which are portions of sub-regions or entire sub-regions. The fourth level is the cataloging unit, which is a geographic area representing part or all of a surface drainage basin, a

Indiana Dunes National Lakeshore, Lake Michigan

combination of drainage basins, or a distinct hydrologic feature.

These basin levels should not be confused with the Horton-Strahler stream-ordering scheme (Dunne and Leopold, 1978), which increases numerically from headwater streams. The system of stream ordering is a method of numbering streams as part of a drainage basin network. The main stream is always of the highest order. The smallest unbranched mapped tributaries are designated first order, streams which receive only first-order tributaries are second order, larger branches which receive only first-order and second-order tributaries are designated third order, and so on.

Assessing Impacts at the Sub-watershed Level

This report has repeatedly stated that the consequences of different water withdrawals are not equal across the basin and that the impacts are most clearly discernable at a sub-watershed level. The impacts of water withdrawals must therefore be considered at various scales ranging from the Great Lakes themselves to 4th level watersheds. Actions at the local level that have not been identified or seriously considered may have impacts with regional implications. For example, a water withdrawal from a small stream may not have measurable impacts to the Great Lakes-St. Lawrence River system levels and flows, but the withdrawal could reduce stream flow to a level that jeopardizes the habitat of an endangered species that is important to the region.

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. Each scale is important to understand the system and the relationship between supply, use and ecological impacts. The Canada/Ontario Water Use and Supply Project has been using this approach to better understand the water use and supply and ecological impacts at the various scales, as illustrated in Figure 8-1.

An increasing level of detail can be captured and represented as the resolution becomes finer. Individual withdrawals can be assessed at a local level to identify water availability, existing uses and ecological impacts based on the local watershed's known sensitivities. This nested structure also allows water use, supply and related impacts to be aggregated from a finer scale and carried through to higher levels to better assess both individual and cumulative impacts.

Along with scale, understanding the varying characteristics of watersheds is important to assessments of impacts. Size, shape, slope, elevation, density of channels, channel characteristics (depth/width), vegetation, land use, soil type,

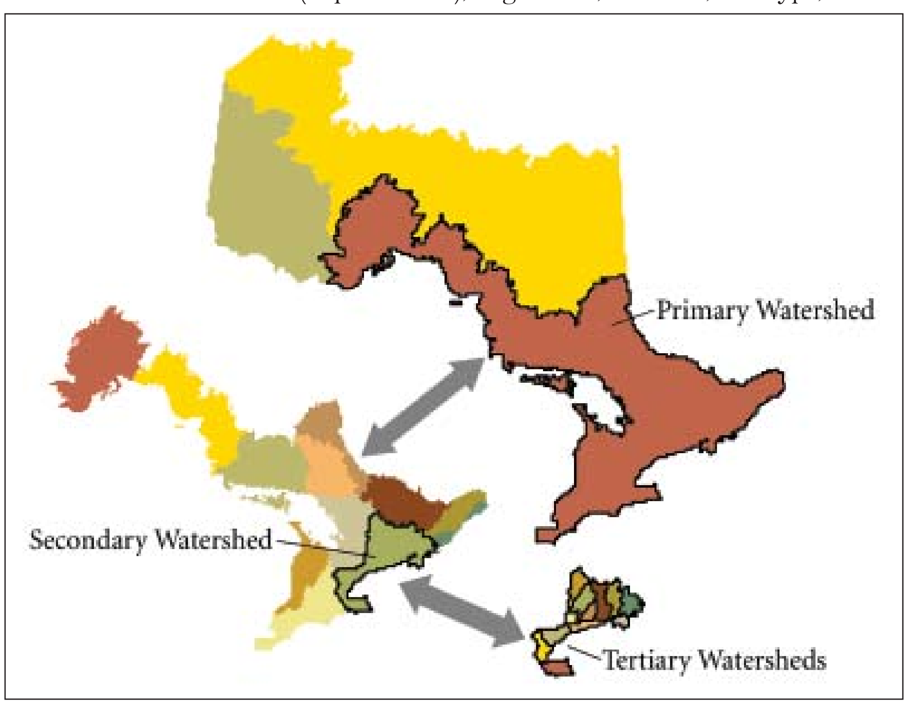


Figure 8-1
Conceptualization of nested watersheds

hydrogeology, lakes, wetlands, artificial drainage, water use and ecology represent some of the important characteristics of a drainage basin. The quality and quantity of water resources also varies among sub-watersheds of the Great Lakes-St. Lawrence River basin. The amount of precipitation, evaporation and runoff can vary significantly over relatively small spatial scales, and groundwater discharge to streams ranges from 10 percent of the streamflow to 80 percent of the streamflow (Piggott et al., 2001). Watersheds can also vary in the uniformity of groundwater flow over time, the type of land use, and the types of water uses. These natural and anthropogenic factors will all influence a watershed's ecologic and hydrologic sensitivity.

Understanding specific sub-watershed sensitivities will be important to developing informed water resource management decisions. For example, understanding a watershed's physical characteristics, current surface and groundwater supplies, current water uses, and ecological requirements could help characterize the watershed's sensitivities to water withdrawals or diversions. Water withdrawal limits, allocation strategies, or other strategies could then be targeted on highly sensitive watersheds that are already stressed by overuse. 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.

The Importance of Groundwater Data and Information Related to Water Resources Decisionmaking

The issue of scale is also important as it relates to the availability and use of groundwater resources in the Great Lakes-St. Lawrence River system. Groundwater discharges directly into the Great Lakes and connecting channels, but also provides some tributary stream flow. Groundwater that discharges to streams supports instream ecosystems by providing base flow and moderating water temperature. It is particularly important for maintaining water quality during periods of low flows, when almost all the flow in the stream can be from groundwater.

While the importance of groundwater discharge to the health of aquatic ecosystems is recognized, significant data and information gaps concerning the region's groundwater resources remain. For instance, each aquifer that contributes groundwater to the Great Lakes or their tributary streams has a potentiometric surface. This surface is similar to the earth's surface in that it has groundwater divides that are analogous to watershed divides. Groundwater on one side of the divide flows toward the Great Lakes; groundwater on the other side flows away from the Great Lakes. Groundwater and surface water divides do not usually share boundaries, and groundwater divides, unlike surface water divides, are not static and may vary in response to groundwater withdrawals. Some aquifers in certain parts of the Great Lakes region have mapped potentiometric surfaces and groundwater divides. In the remainder of the region, the area that contributes groundwater to the Great Lakes is unknown.

On a sub-watershed scale, sufficient streamflow and groundwater data are available in some, but not all, areas of the basin to predict the likely effects of in-stream and groundwater withdrawals. 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 the WRMDSS is to support investigations in areas which have been heretofore "data poor." Also, a basinwide groundwater flow model is needed to provide information that supports decisions on proposed groundwater withdrawals in the United States and Canada.

Reliable groundwater supplies continue to be readily available to the majority of the Great Lakes-St. Lawrence River basin's population. However, in some localized cases, inadequate or poor quality groundwater supplies have caused local water supply shortages. For example, Monroe County, Michigan, located in the southeast corner of the state, relies on groundwater for drinking water and irrigation, but aquifers have been depleted due to quarry operations. Oakland and Macomb Counties, also in southeastern Michigan, likewise have recently experienced aquifer depletion due to low rainfall, higher than normal temperatures and rapid residential development. The interest in protecting groundwater resources has heightened as a result of these and other occurrences of localized groundwater shortages in various parts of the Great Lakes-St. Lawrence River basin. In addition, the recent construction and operation of the Perrier bottling plant near Muskegon, Michigan has brought this issue to the forefront of public discussion. The groundwater issue and "better understanding its role in the Great Lakes basin" is an identified priority under Directive #6 of the Great Lakes Charter Annex. These examples point to the need to consider the importance of groundwater when developing the WRMDSS.

Importance of Data and Information in Assessing Ecological Impacts of Water Withdrawals

As understanding of the complexities of the Great Lakes-St. Lawrence River system has improved, concerns have been expressed regarding the ecological impacts of water withdrawals, particularly in sub-watersheds and the nearshore zone. These ecological impacts are important as they relate to the scale issue discussed above. Chapter two, which highlights the uncertainty involved with measuring components of the Great Lakes water balance, points out that, on a lake-wide scale, uncertainties in levels and flows tend to mask the potential effects (either individual or cumulative) of any given water withdrawal.

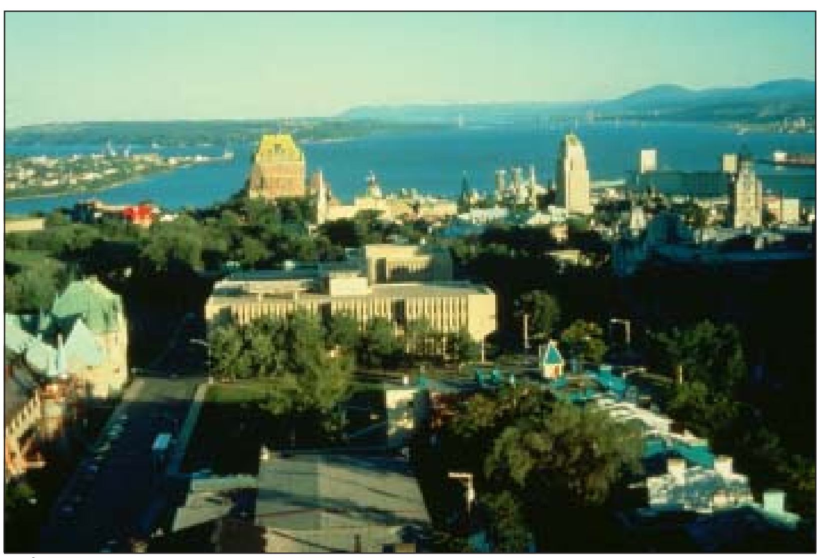
In nearshore areas, biota appears most likely to be affected by water withdrawals, rather than those organisms which inhabit the deeper portions of the Great Lakes. However, fish and other aquatic organisms that live in these deeper areas may be dependent on nearshore areas for food, spawning habitat and other needs. Also, water withdrawals may be only one factor or stressor present in certain watersheds that contribute to the measurement of impacts to an aquatic ecosystem. The impacts of a single withdrawal may not be measurable but, combined with other factors such as land-use changes, can result in significant, readily measurable impacts.

Better and more site-specific data and information on the ecological effects associated with water withdrawals are needed to support a regional resource-based decisionmaking standard (being developed under Directive #3 of the Annex). Activities pursued under this project highlight many of these data and information needs, as well as knowledge gaps. The literature reviewed under the project offers few practical approaches for addressing questions that relate to cause-effect relationships and cumulative impacts of changes in levels and flows, although some studies shed light on the 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 observation is supported by the outcome of the model review: no single model can, by itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario.

Continued research and data collection are necessary for more certain assessment of ecological impacts (particularly cumulative effects) of water withdrawals and diversions. However, these gaps in understanding and data cannot be allowed to slow progress toward building and applying tools for supporting the decisionmaking process.

The Importance of Considering 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 hydrologic 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 Lake 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 modification).



Québec City on the St. Lawrence River

The cumulative impacts of one or more water withdrawals must be considered in light of time and space dimensions and the complexities they suggest for a WRMDSS. A minor withdrawal, for example, may take place for years before its impact can be detected from a hydrologic or ecological standpoint. Further, that impact may be detected – at different points in time – at the location of the withdrawal, in the open waters of the lake basin, and/or far downstream in the St. Lawrence River.

The additive effect of multiple withdrawals is of significant concern as well. Consider, for example, a scenario in which a single minor withdrawal in a tributary is found to have no significant adverse impact on the withdrawal location or the larger Great Lakes-St. Lawrence River ecosystem. However, the cumulative impact of multiple withdrawals of the same quantity (and along the same tributary) may have devastating effects locally and measurable adverse effects on a broader scale. Hence, any WRMDSS and associated data and information gathering processes must accommodate the time and space dimensions associated with the cumulative impacts of both individual and multiple withdrawals. Mechanisms for assessing these impacts with any degree of precision have yet to be developed.

The Use of Scenarios/Case Studies to Evaluate Data and Information

Developing and working through plausible water withdrawal and use scenarios provides a valuable process for evaluating data and information needs and gaps. Two scenario evaluation exercises were convened under the WRMDSS project that helped scientists, managers and policymakers focus on key issues related to the region's ability to evaluate water withdrawal and use proposals. One exercise was convened by the Water Withdrawal and Use Technical Subcommittee (TSC 3) on September 10-11, 2001, to assist in the identification of water withdrawal and use data and information needs. Building upon this exercise, a project-wide scenarios evaluation workshop was held on May 15-16, 2002. This workshop brought a full range of interests and expertise to bear on the evaluation of three mock water projects. It also informed the discussion of the full range of data and information needs related to the hydrology and hydraulics of the Great Lakes-St. Lawrence River system, water withdrawal and use, ecological effects from water projects, and associated potential cumulative impacts. Additional purposes of the workshop were to inform the Annex 2001 implementation process about data and information needs and availability, and to begin conceptualization of informational components and characteristics of an effective WRMDSS.

Some of the observations and ideas generated at the workshop demonstrate how scenarios/case study analyses can enhance understanding of data and information needs and requirements. Samples of the observations from the May 15-16 workshop are presented below:

- The ability of current data and the state of science to inform cumulative impact assessments is limited and must be addressed in the development and application of any WRMDSS.
- The relationship between hydrologic changes and ecological impacts, particularly related to cumulative impacts in the nearshore zone, is not currently well known. For instance, data coverage for wetlands is incomplete, inconsistent, and non-periodic, making it impossible to monitor changes over time.
- When considering a WRMDSS, decision standards, data collection programs and modeling efforts should be applicable to decisionmaking both on large (entire basin) and small (sub-watershed) scales.
- Dedicated, long-term monitoring programs coordinated at the basinwide level are critical to the success of any decisionmaking process.
- Demand forecasting is a useful tool to provide guidance to any WRMDSS.
- The scenario process is a useful tool that can be further employed to identify data and information needs, test alternate decisionmaking processes, and identify and assemble the components of a WRMDSS.

Looking Into the Future: Other Issues Influencing Water Resources Decision Support

Research, management and policy activities need to anticipate and adapt to changes in the near and intermediate future that might significantly affect how water resources management decisions are made as well as the data and information requirements to support the evolving decisionmaking process. Any decision support "toolkit" needs to be as robust as possible to withstand the "test of time" and accommodate changes in the supply, distribution, quality and use of water resources. Unanticipated ecological stressors will likely arise, complicating the region's ability to manage the resource effectively. Technologies will also continue to evolve, some at a very rapid pace. A brief discussion of these issues follows:

- Climate variability is the norm for the region, not the exception. Long-term climate changes are likely to occur and will be accompanied by varying ranges of water levels and supply (Great Lakes Regional Assessment Group, 2000). Advances in climate prediction and risk assessments are needed to assist managers in anticipating these effects.
- Substantial changes in land use will continue. Residential property development will reduce agricultural lands and urban redevelopment will continue to be a societal objective. Agricultural changes are likely to continue into more selective "niches," requiring significant changes in local water demands (Thorp et al., 1998). Recreational opportunities will continue to transform the landscape (e.g., golf course development) and recreational boating will encourage greater controls of water levels throughout the system (Golf Research Group, 1997).
- Municipalities have been expanding water treatment capabilities as a major infrastructure investment (Hill, 2002). Service areas are expanding regularly. Also substantial changes have occurred in the bottled water and related beverage industries, and societal shifts from tap water to bottled water may continue (International Bottled Water Association, 2002).
- A number of ecological stressors will continue and, in some cases, will increase in relevance. Impacts of new exotic or invasive species can (and will) complicate the region's ability to discriminate between causes and effects, particularly in the indicator wetland environments (Glassner-Shwayder, 2000). Coastal wetlands are also highly impacted by adjacent land use changes, hardening of nearby shorelines and changes in sediment supplies.
- The technological advances experienced in the last decade are likely to continue. Investments in new wireless and fiber optic delivery mechanisms will provide scientists, resource managers, water users and the concerned citizenry with a greater ability to access and process data and information in an efficient manner. Increases in computer storage capacities will also likely occur to match the increased data volumes that are expected. Increased computing speeds and evolving software tools will make integrated products for resource management more user friendly.
- These technological advances continue to push resource management protocols into the public arena, and public involvement in the decisionmaking process will likely increase as a consequence. The level of sophistication of resource management will also likely improve. Managers will have the ability to access and process vast quantities of data and information and better discern options for the problems at hand. Further, resource managers will be able to embrace a "systems-engineering" perspective on problem solving, more effectively planning for the future, setting reasonable targets, monitoring progress and achieving desired results.

Concluding Observations

The numerous recommendations of this report address the need to improve the quality and quantity of data and information relevant to examining water withdrawal and use proposals and their impacts.

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 will 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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