6. ECOLOGICAL IMPACTS ASSOCIATED WITH GREAT LAKES WATER WITHDRAWALS

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6.1 INTRODUCTION/PROJECT ELEMENT BACKGROUND

The Great Lakes Charter (signed in 1985) created a notice and consultation process for Great Lakes diversions. One of the five Principles set forth in the Charter is the "Protection of the Water Resources of the Great Lakes." The stated intent of this Principle is that *"diversions of 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 (signed in 2001) seeks to develop water resource management practices in the Great Lakes basin that guarantee the long-term sustainability of the basin's water resources. This means preserving the quantity and quality of the region's abundant water resources to maintain and even enhance its ability to provide social, economic, and environmental services to all the inhabitants of the basin ecosystem. This goal is stated in the Annex by declaring that it seeks 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."* One of the main tenets of any water resource management approach with this goal is to prevent the human withdrawal and use of the waters of the basin 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 invokes the establishment of a new decision-making 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 decision-making standard in a fair and equitable way requires, among the many knowledge domains indicated earlier in this report, a quantitative understanding of the relationship between water withdrawals and human uses that may take many forms and the cumulative ecological response of the system.

Because of the need for assessing the individual and cumulative ecological impacts of water withdrawals, one element of this project was to develop an "Inventory of Information on Ecological Impacts" of water withdrawals. This project element included: a) the development of a list of "essential questions" (with the aid of an Experts Workshop) that should be addressed in reviewing water withdrawal proposals regarding their potential ecological impacts; b) a literature search and analysis; and c) an inventory of existing models. The primary objective was to compile an inventory of the knowledge base and tools available for making the assessment required by Directive #3 of the Annex and in doing so identifying the gaps in understanding and assessment capability. This process of compiling this information then leads to the identification of research and data collection priorities for increasing confidence in making decisions regarding proposals for new or increased water withdrawals in the Great Lakes basin.

This chapter contains a presentation of the information gathered in achieving the above objective. The next section of this chapter (Section 6.2) presents the basic framework developed for assessing ecological impacts of water withdrawals/diversions. It also includes a comprehensive list of "essential questions" that should be addressed in making such an assessment; the "essential questions" express *what we need to know*. An Experts Workshop, held in November, 2001, served the purpose of providing initial input to the development of a preliminary set of questions and then refining the framework and "essential questions" and identifying data and research needs relative to addressing these questions.

The subsequent two sections (Sections 6.3 and 6.4) present a summary of the literature review and the model inventory, respectively. The literature search compiled a sense of the existing knowledge and database relative to assessing ecological impacts of water withdrawals/diversion. In the process, research and data needs to fill gaps were identified. The model inventory provided a list of modeling tools relevant to making an ecological assessment. In the process of compiling relevant models, needs in the area of tool development were also identified. In essence these two sections provide a summary of *what we do know and where the major gaps are.*

The final section of this Chapter (Section 6.5) provides a summary findings and recommendations of the important remaining data, knowledge and tool gaps to get from the present situation to effective implementation of the Annex.

6.2 "ESSENTIAL QUESTIONS" FOR ECOLOGICAL IMPACT ASSESSMENT

6.2.1 INTRODUCTION

In November 2001, U.S. and Canadian researchers/scientists were invited, along with policy/management officials from the states, provinces and relevant federal agencies, to an Experts' Workshop. The primary objectives of the Workshop were to identify the types of "essential questions" that must be considered to evaluate the potential for ecological impacts for any given water withdrawal proposal, begin to develop an inventory of information on ecological impacts, and provide an opportunity for participants to raise issues and concerns related to this topic. Experts from a range of relevant disciplines were invited to serve on an Experts' Panel to address 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 found in Appendix X.

6.2.1.1 Approach to Develop 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 will do so);
- 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 1 presents the proposed framework for assessment. Each box framework 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.

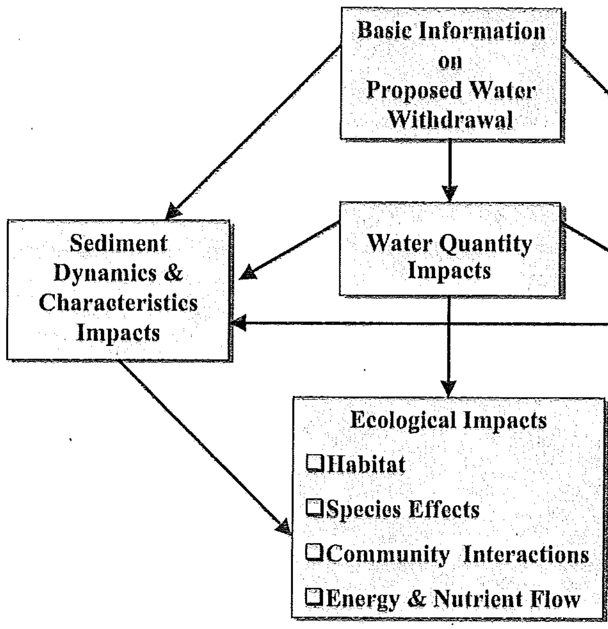

Figure 1. Proposed framework for ecological assessment of water withdrawals

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 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.

6.2.2 LIST OF ESSENTIAL QUESTIONS

Category 1: Basic Information on Water Withdrawal

The first category of questions covers basic information on the 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 sub-watersheds by

Category 1: Basic Information on Water Withdrawal

land use types.

If water withdrawal is from an inland lake:

- What are the inflows and outflows?
- What is the lake geometry?
- What is 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
   - Dissolved oxygen
   - BOD
   - Total dissolved solids
   - Pathogens
   - Dissolved organic carbon
   - Nitrates
   - Buffering capacity
   - Salinity
   - Sulfur
   - Water conductivity
   - 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 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?**
   - What are the water use processes?
   - Will its water quality be altered by this use? 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?

Category 1: Basic Information on Water Withdrawal

- 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
   - Dissolved oxygen
   - BOD
   - Total dissolved solids
   - Pathogens
   - Dissolved organic carbon
   - Nutrients
   - Nitrates
   - Buffering capacity
   - Salinity
   - Sulfur
   - Water conductivity
   - Persistent Toxic Substances
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., groundwater)?** 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 hyperheic 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?

Category 5: Ecological Impacts

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 system-wide 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 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.

6.2.3 FINDINGS: IDENTIFICATION OF ESSENTIAL QUESTIONS

The essential questions should be considered to assess 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 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 determination of socially acceptable levels of ecological change, calculation of likely judgments on the significance of effects, and understanding and assessment of cumulative impacts while accounting for future uses. The workshop emphasized the need for a decision framework and monitoring to post-audit decisions and address the many unanswered questions and large uncertainties. Sections 6.3 and 6.4 provide an overview of some resources available for addressing these questions.

6.3 REVIEW AND ANALYSIS OF ECOLOGICAL IMPACTS LITERATURE

6.3.1 INTRODUCTION

6.3.1.1 Background

The focus of the literature review report (see Appendix Y) 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. Because 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 had to be reasonably selective.

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 functioning 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. In the literature review, all of these levels of effects were recognized as ecological effects and, therefore, they were categorized as listed above. The final category, synoptic modeling studies, includes those studies that have attempted to demonstrate the coupling among the first three effects, and thereby include the process understanding and feedbacks that allow a more generic application of site-specific observations.

6.3.1.2 Objectives

The objectives of the literature review were to:

- Identify and summarize literature that assesses the ecological impacts of water use, levels and flows; assesses ecological thresholds with respect to water supply; and presents 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.

6.3.1.3 Approach

Both the published literature and a sampling of the gray literature (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 (US COE), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (US FWS), and

The Nature Conservancy. Also reviewed were reports and materials from special focused studies such as reference studies of the International Joint Commission.

6.3.1.4 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 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 be classified under 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 and 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 section has been subdivided into two categories: 1) effects on flora; and 2) 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.

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, wetlands 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 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, including various hydraulic or hydrologic models.

Special Focused Studies: This category highlights a number of relevant large-scale studies that target some aspect of the study question. 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, World Commission on Dams, UNESCO's Ecohydrology Programme, the Waterpower Project (Ontario, Canada), and The Nature Conservancy.

6.3.2 DESCRIPTIVE INVENTORY OF LITERATURE

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

6.3.2.1 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. 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 endpoint 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 levels 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.

6.3.2.2 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 (fish and benthic invertebrates) and terrestrial species (muskrats and turtles). Some studies connected flow or water levels changes with some impacts on fish, benthos, muskrats and turtles, but these impacts were generally very subtle and connected indirectly to the changes in flows and levels. Some 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.

6.3.2.3 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 decision-making.

6.3.2.4 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, not the mean annual stream flows.

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 miles) 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 System). 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.

6.3.3 FINDINGS: LITERATURE REVIEW

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, without specific information relating these impacts to changes in flows or levels. Other articles compare regulated and non-regulated rivers, and a limited number propose assessment methodologies. Some papers describe physical characteristics and ecological aspects of shore zone 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.

A striking diversity of key ecological end points are used in the various publications: shoreline and near-shore vegetation, inland or riverine/lacustrine wetland vegetation, macrophytes and submerged vegetation, aquatic insects, plankton, benthos and various fish species. The end points are species-specific, with nearly any type of living organism. This 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 & 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 SOLEC process to establish indicators and implement an ongoing monitoring effort to assess progress.

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. The St. Lawrence River is downstream of the lakes, and is thus susceptible to cumulative impacts from 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 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."

However, 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.

6.4 MODELS FOR ECOLOGICAL IMPACT ASSESSMENT

6.4.1 INTRODUCTION

6.4.1.1 Background

The descriptive model inventory (see Appendix Z) describes modeling tools that have been identified with prospective relevance to ecological impact assessment of water withdrawals in the Great Lakes-St. Lawrence 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.

6.4.1.2 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.

6.4.1.3 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 wide-spread 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.

6.4.1.4 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 reference

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

6.4.2 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 model 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 Great Lakes rivers and should be reviewed to assess their applicability to water withdrawals.

6.4.2.1 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, temperatures, and velocity field. Information on physical properties of water body, such as depth, slope of bed, precipitation and temperature, provide input parameters for these models. Physical processes simulated by hydrodynamic models include tidal, wind, and buoyancy or density forcing, and turbulent momentum and mass transport. The spatial dimensions of these models vary from one-dimensional longitudinal, two-dimensional in the longitudinal and vertical, two-dimensional in the horizontal (vertically-averaged), to fully three-dimensional. Hydrodynamic models use numerical solutions to fundamental 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 1 provides of list of relevant hydrodynamic/hydraulic models, and indicates the models that are described in detailed review sheets in the models inventory report.

Table 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	USACOE
CE-QUAL-W2*	2D Laterally-averaged Water Quality Model	Dynamic	2-D vertical	USACOE
CH3D-WES*	Curvilinear Hydrodynamics in Three Dimensions - Waterways Experiment Station	Dynamic	3-D	USACOE
CORMIX	A 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

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/ Developer
				Institute of Marine Sciences
HEC-2/HEC-RAS*	River Analysis System	Steady State	1-D (HEC-2)	USCOE/ HEC
HEM1D/HEM2D/HEM 3D	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	WES
UNET	1-D Unsteady Flow through a Full Network of Open Channels	Dynamic	1-D	USACOE

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

6.4.2.2 Hydrologic/Watershed Models

Hydrologic/watershed models are useful for assessing hydrology 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 of interest. The hydrologic/watershed models can be applied to evaluate surface and subsurface pollutant transport to receiving water bodies with subsequent simulation of instream transport and transformations, watershed hydrology and water quality of both conventional and toxic pollutants.

Generally, these models require data such as rainfall, records of 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 waterbodies. Available hydrologic/watershed models vary from simple methods to detailed loading models depending on their capabilities. Simple methods have very limited predictive capabilities and generally provide rough estimates since they are typically derived from empirical relationships. Detailed models are generally complex models 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. They include physical processes of infiltration, runoff, pollutant affects, groundwater and surface water interactions. Applications for these models vary depending on data availability and modeling needs. Table 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.

Table 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 (NPSM – Dynamic, QUAL2E – Steady state)	USEPA/CEAM
CREAMS/ GLEAMS	Field scale run off/erosion model	USDA
ELM*	Everglades Landscape Model	SFMD (H. Carl Fitz)
GAWSER	Object-Oriented Guelph All-Weather Storm Event Runoff Model	John A. Hinckley, Jr. (USCOE)
GWLF	Generalized Watershed Loading Functions	EPA/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	GLERL/NOAA
OFAT*	Ontario Flow Assessment Techniques (OFAT) 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. under the sponsorship of EPRI
WATFLOOD	The WATFLOOD Hydrologic Model	Nick Kouwen (Univ. of Waterloo, Ontario, Canada)

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

6.4.2.3 Surface Water Quality Models

Surface water quality models address problems associated with variables that can result in fish kills, taste and odor problems, 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 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 3 provides of list of relevant surface water quality models and indicates the models that are described in detailed review sheets in the models inventory report.

Table 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	USCOE
CE-QUAL-RIV1*	Hydrodynamic and water quality model for streams	Dynamic	1-D	USCOE
CE-QUAL-W2*	2-D laterally averaged hydrodynamic and water quality model	Dynamic	1-D, 2-D	USCOE
ECOFATE*	Ecosystem model	Dynamic	2-D	Simon Fraser University, Canada (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, Canada (Donald Mackay)

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/Developer
RATECON*	Rate Constant Model for Chemical Dynamics	Dynamic	1-D	Trent University, Canada (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. (w/ 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.

6.4.2.4 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 evaluate the transport of pollutants due to migration and interactions of groundwater and surface water. Groundwater withdrawals can result in lower river and stream water levels. The hydrology of the watershed can be impacted by precipitation, runoff, groundwater, surface storage, and river water levels. In fact, the watershed hydrology indirectly includes the groundwater components in assessing the impact of water quantity on watersheds.

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

Table 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	IGWMC Colorado School of Mines

Model	Description	Source
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.

6.4.2.5 Ecological Effects Models

This category includes a wide variety of models and techniques for the ecological assessment of the 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 decision support system.

Ecological effects models that address the impacts of water withdrawals include a wide range of evaluation and assessment techniques that affect the 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, including species habitat, production and diversity of flora, predator-prey relationships, and food web structure.

Because of 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-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 provides of list of relevant ecological effects models, and indicates the models that are described in a detailed review sheet in the models inventory report.

Table 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/HS*: 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	Used for determining the integrity of physical, chemical, and biological functions of wetlands as they compare to reference conditions	USEPA/CEAM
IFIM*: Instream Flow Incremental Methodology PHABSIM: Software that combines Fish-habitat preference models and discharge-habitat models TSLIB: Time-Series library	Collection of analytical procedures and computer models used to assess riverine habitats Describes the weighted Usable Area (a measure of habitat) under a variety of channel configurations and flow management conditions 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

Model	Description	Supporting Agency/Developer
SNTEMP*: Stream Network TEMPerature Model SSTEMP: Stream Segment for a Single Time Period	Models that simulate mean daily water temperature for a stream segment for a single time period Models that simulate mean daily water temperature for a stream network with multiple tributaries for multiple time periods	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.

6.4.3 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 should 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, 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 care 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 the 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.

6.4.4 FINDINGS: MODEL REVIEW

The models presented in the descriptive model inventory, which are divided in five categories, differ in their capabilities, complexity, and resource requirements. The model inventory provides useful information to support the model selection process, and model users should carefully define the management problem, and gain a full understanding of the associated system before selecting models from this inventory. Site-specific management objectives, data needs and accessibility, resource availability, and other considerations should be accounted for in the model selection process.

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 quality affect predator-prey relationships or food web structure and/or function in the impacted system?"

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 surface water ecosystems. Figure 2 illustrates the interconnectivity of the five categories of models, with output from one category serving as input to another category.

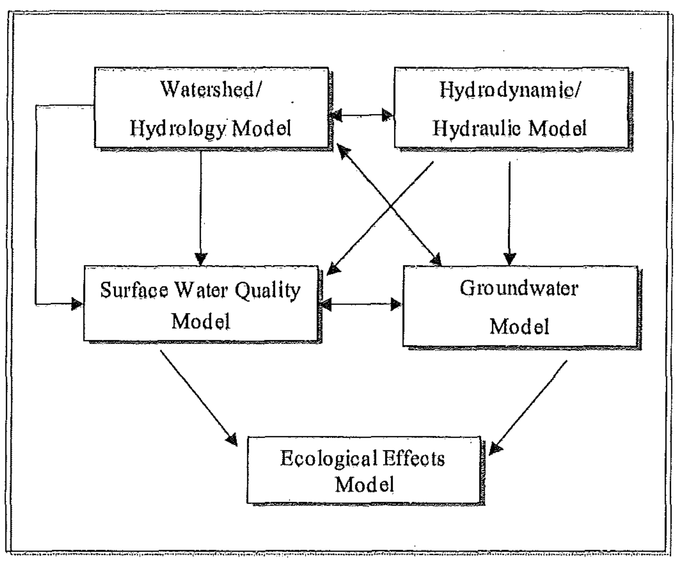

Figure 2. Interconnectivity of Five Categories of Models

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 that is developed for the Great Lakes basin. 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 would have ecological impacts that result from altered river flow.

6.5 FINDINGS AND RECOMMENDATIONS

6.5.1 FINDINGS

Project work on the ecological impacts of water withdrawals has identified and compiled a large amount of information that could be used by decisionmakers to develop and implement a process for assessing proposed water withdrawals. Although a reasonably good outline for assessing potential ecological impacts of water withdrawals and a large knowledge base both exist, many information and understanding 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. In moving forward, scientific questions must be addressed and must be complemented with consideration of policy and management aspects of implementing a basin-wide water resource protection and conservation ethic.

6.5.1.1 Essential Questions for Ecological Impacts Assessement

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 available data and information. For example, basic information questions include: "What are the statistics on flow regime?" and "what are the key characteristics of the river and watershed?" This type of information is 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. For example, one "Water Quality" question asks, "How will the withdrawal alter the water quality of the source water and the return water?" The model inventory describes many surface water quality models that may be employed to address these types of potential impacts.

However, there are significant data gaps and information needs that must be addressed 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 effects will be judged; and
- how cumulative impacts are understood and assessed, accounting for future uses and effects of features that modify the impacts.

The Experts Workshop emphasized the need for a decision framework and monitoring to post-audit decisions and address the many unanswered questions and large uncertainties.

6.5.1.2 Review and Analysis of Ecological Impacts Literature

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. Many of the papers that were reviewed describe the impacts of regulation, withdrawals, and dam construction and operation on biota, landscape ecology, environmental flows, geomorphologic processes and vegetation landscape, without specific information relating these impacts to changes in flows or levels. 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 shore zone 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.

6.5.1.3 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 in the Great Lakes basin. 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."

This observation is supported by the outcome of the model review, that no single model that 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.

Another finding is the 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 change in water level 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. The St. Lawrence River is downstream of the lakes, and is thus susceptible to cumulative impacts from 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.

Finally, 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 (watershed, lake, river, or whole basin) and time (20 years or 100 years) scales over which withdrawal impacts might be felt are not known. Both time and space scales used for making assessments must be selected to apply Directive #3 of the Annex.

6.5.2 RECOMMENDATIONS

1. **Reviewed and refined the list of "essential questions" to ensure their comprehensiveness and feasibility in a decision support framework. Input should be sought from both those who will be charged with answering such 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 "Expert's 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. **Direct future funding for research and development in this area at "data mining" the existing studies for both qualitative and quantitative stress-response relationships in this subject area. After mining the existing data, identify information gaps, and design targeted studies to collect the needed data and information.**

The data mining and synthesis of knowledge are expected to lead to a need for watershed-scale research conducted throughout the Great Lakes basin to <u>quantify</u> 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.

3. **Focus priorities for research and data needs on ecological impacts on identifying sensitivities through the development of indicators and thresholds that allow a determination of "no significant adverse impacts" in Directive #3.**

These studies can be used to 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 ecosystems (large lakes, inland lakes, streams and rivers, groundwaters) and potential ecological impacts of those water uses. Develop linked model frameworks for selected water withdrawal scenarios by building on the existing model inventory.**

The studies proposed above should be designed and conducted in the context of an integrated modeling study so that data collected and processes quantified in the field research can provide a basis for developing integrated assessment models. There is a need to develop a quantitative understanding of ecological impacts of water withdrawals and diversions in the context of other system stressors (e.g., nutrient loads, toxic chemicals, invasive species) that can cause similar impacts.

5. **Incorporate predictions of regional climate change, population growth, demand forecasting, and land use changes in assessments of water withdrawal impacts.**

Forecasts of the capacity of the Great Lakes St. Lawrence River Basin system should account for future scenarios that may alter water levels and flows. Current models 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.

6. **Improve data to address time and space scale issues in making cause-effect assessments. Often, the time and space scales of the hydrologic/hydraulic stressor are very different than those for the ecological manifestation of those stressors.**

It is likely that cumulative ecological impacts of altered water levels and flows will take decades to manifest themselves at the ecosystem level. Therefore, long-term monitoring programs relating level/flow habitat changes to trends in ecosystem structure and function should be initiated immediately and maintained for long time periods. Spatial issues must also be addressed. For example, the stressors may act on a whole lakes scale, while the impacts are very localized.

7. **Incorporate an understanding of variability and uncertainty in flows and levels into the decision making process. Consider ecological endpoints (system response) in the context of ranges of variability and maximum likely uncertainty in quantifying the hydrological changes (stressors) that will result from a given water withdrawal or the accumulative changes of multiple withdrawals in the same hydrologic unit.**

This recommendation recognizes that prediction and measurement of hydrologic changes in response to water withdrawals or diversions have uncertainty that leads to uncertainty in the deterministic prediction of ecological responses. The research to quantify these cause-effect relationships and the application of those relationships to make decisions must recognize the uncertainties inherent in the process.

8. **Include some level of monitoring the system's response to water withdrawal activities as a means of "post-auditing" the decision and providing data and information for updating assessment tools.**

In recognition of recommendation number 7, it is very important to monitor and gain knowledge from past decisions. In this way, the decision support system will evolve as a better understanding is gained through research and monitoring.

6.6 REFERENCES

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