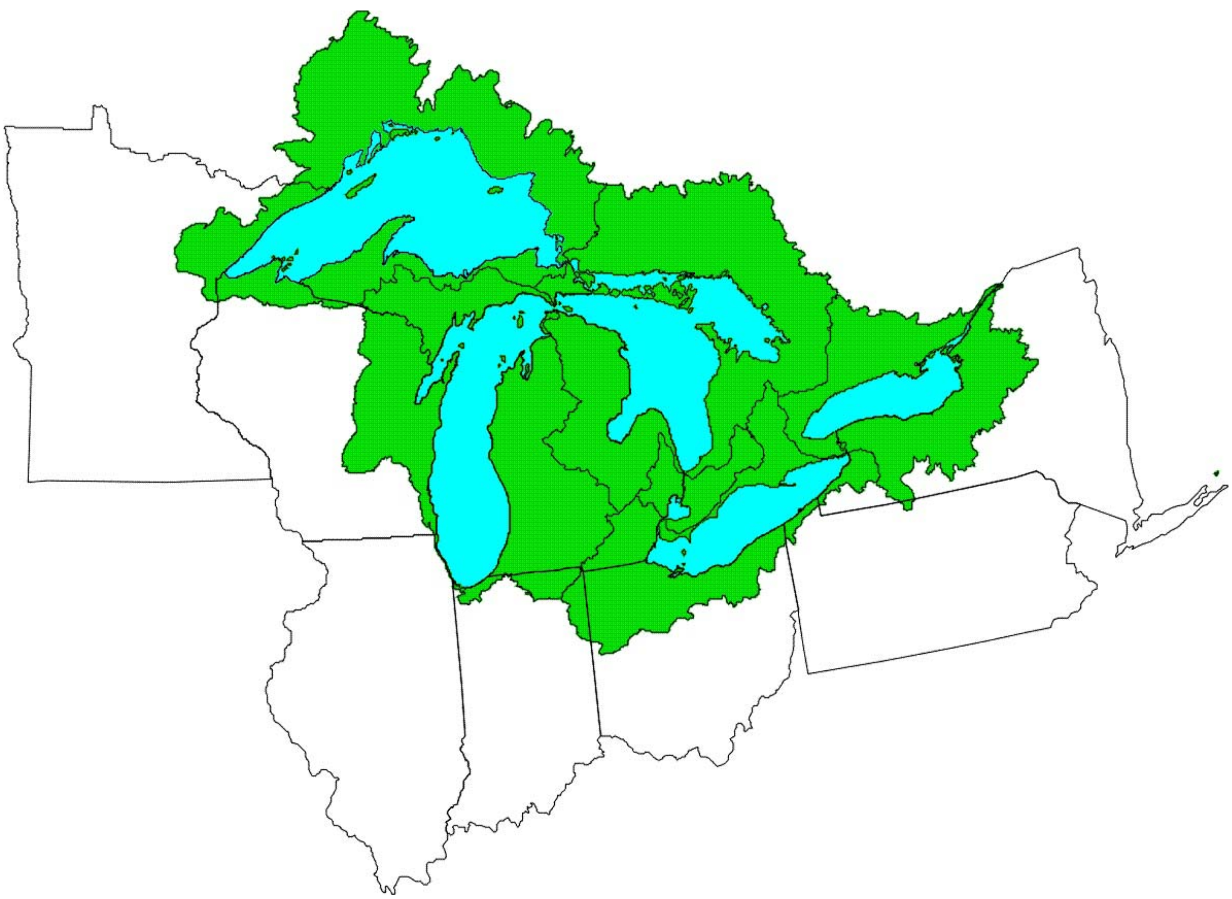
# Improvements to the Great Lakes – St. Lawrence River Biohydrological Information Base

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

**Appendix G: Water Quantity Impacts on Great Lakes – St. Lawrence River Ecosystems**



**April 2005**

US Army Corps
of Engineers®

# Measurement Converter Table

## U.S. to Metric

**Length**
feet x 0.305 = meters
miles x 1.6 = kilometers

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

**Area**
square miles x 2.6 = square kilometers

**Mass**
pounds x 0.45 = kilograms

## Metric to U.S.

**Length**
meter x 3.28 = feet
kilometers x 0.6 = miles

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

**Area**
square kilometers x 0.4 = square miles

**Mass**
kilograms x 2.2 = pounds

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# Appendix G:

## Water Quantity Impacts on Great Lakes - St. Lawrence River Ecosystems

### Introduction

The Great Lakes - St. Lawrence River ecosystem is both defined by and dependent upon water. An ecosystem is the interaction between biotic (living organisms) and abiotic (physical features, chemicals, water, etc.) factors for a given location. The Great Lakes - St. Lawrence River ecosystem is defined by the individual watersheds and the larger drainage basin; this includes the land draining into the Great Lakes, the Great Lakes themselves, the connecting channels and lakes and the various communities within this system. This ecosystem covers 234,000 square miles and spans eight states, one province and two countries comprising the largest system of freshwater lakes in the world (GLRAG, 2000). From the biologically diverse shorelines to the forested uplands, all of the components of the Great Lakes - St. Lawrence River ecosystem depend on water. Living organisms are primarily composed of water and depend on it for their survival. The hydrologic regime of a location determines the soil type which in turn determines the unique array of organisms and hence the habitat or community (Good *et al.*, 1978; Leibowitz *et al.*, 1987).

Over thousands of years of movement and retreat, this area was transformed by glaciers leaving behind bare soils and dumping loads of sedimentation. These fallouts of sedimentation formed the edge of the Great Lakes that were created from the melting glaciers. The scouring action of these glaciers left behind a blank canvas of bedrock and glacial till. Over time, pioneer species such as mosses, lichens, grasses, aspen and cedar moved in and became abundant in these areas. As the pioneer species matured, organic matter in the soil increased and new species of plants and animals moved in leading to successional changes in species assemblage (Kimmins, 1987). This once blank canvas continues to be painted and repainted as changes occur in the environment.

Prior to European settlement, the Great Lakes - St. Lawrence River basin was covered with old-growth forests, oak savannas, wetlands and prairies, all crucial components of the hydrologic cycle. Native Americans lived and thrived in this region for more than five centuries, maintaining a functioning ecosystem by regularly burning prairies and forests, only taking what they could use and moving to new locations at the first signs of environmental stress.

By the mid-1800s large-scale settlement began and logging was big industry in the Great Lakes - St. Lawrence River region. The earliest loggers harvested the easy to cut and abundant white pine, highly demanded for shipbuilding and construction. The trees were hundreds of years old and could not be replaced quickly; when the pines were gone, other species were harvested. Hardwoods, such as maple and oak, were cut to make furniture, barrels and specialty products. The intensity of this logging left much of the Great Lakes - St. Lawrence River basin stripped of trees and piled with slash (unutilized limbs of trees). These slash piles contributed to the intense and widespread fires of the late 1800s in Michigan and Wisconsin, further decimating the land.

Cutting the forest and denuding the land decreased surface friction and increased rates of runoff and erosion which lead to the siltation of streambeds. Streams were exposed to irradiation by direct sunlight. Rain falling on warmer soil added warm water to the watersheds. Temperatures of many streams rose as much as 10°C (Smith, 1972; Webster, 1982). The bare lands removed of forests permitted farming in much of the Great Lakes - St. Lawrence River basin and gave rise to further reduction of the land's water storage capacity.

The ever adapting Great Lakes' natural communities include the Great Lakes, the shorelines, the lowlands, the rivers and the forested uplands. It is the natural dynamics of these communities that lead to great species diversity and richness, with changes in habitat creating new niches in which organisms thrive. The environment is in a constant state of change with all species and processes playing an important role in the ecosystem, even if they are not yet fully understood.

Understanding how human alteration of the hydrologic regime affects the biological resources of the Great Lakes - St. Lawrence River basin in a large undertaking. This appendix summarizes and assesses biological information needed to enhance this understanding. More specifically, this appendix describes the various habitat types found in the basin, describes the data and information currently available for monitoring habitats and identifies data and information gaps. Then, the appendix integrates the information and data needs into tasks to improve the modeling of hydrologic impacts on various habitat types.

The last section of this appendix, entitled *Habitat Data and Information Inventory*, is the appendix's foundation. The data and information inventory is the first task of the Great Lakes Biohydrological Information Systems Study (refer to the main report). The assessment of gaps in the data and information holdings as inventoried in this section are formed into tasks. These tasks appear not only in the body of the appendix, but also in the *Implementation Options* section. The tasks developed in this appendix focus on improving the U.S. federal role in data collection and analysis. This section describes the implementation of the tasks at different options of implementation under the U.S. Army Corp of Engineers' plan formulation approach. This approach, in a broad sense, is being used to develop systematic alternative plans that Congress could consider for supporting the states' Great Lakes Charter Annex decisionmaking process.

In summary, this appendix:

1) describes the various habitat types found in the Great Lakes - St. Lawrence River basin;
2) describes the data and information currently available for monitoring habitats,;
3) identifies gaps in the data and information inventory;
4) assesses the streamflow data needs for regional water management issues and the Great Lakes Charter Annex; and
5) recommends steps in filling those data needs.

**Open Lake**
The five Laurentian Great Lakes: Lake Superior, Lake Michigan, Lake Huron, Lake Erie and Lake Ontario collectively represent the largest freshwater body in the world, both in terms of surface area (covering more than 94,000 square miles) and volume (holding an estimated 6 quadrillion gallons of water) (GLRAG, 2000). This massive water body influences the ecosystem in many ways. The Great Lakes moderate the region's climate, which ranges from subarctic in the north (with an annual average of 60 frost free days) to humid continental warm in the south (with an annual average of 160 frost free days) (TNC, 1997). In the summer, the lakes pull in the heat which leads to cooler summer temperatures and release this heat in the winter to provide milder winters. This giant water body also provides humidity and precipitation to much of the region. Prevailing winds push air masses across the lakes, pick up moisture from the lake surface and then drop that moisture over land on the other side of the lake. The lakes influence climate and hydrology, creating an ecologically unique and complex environment in which a wealth of species and communities thrive.

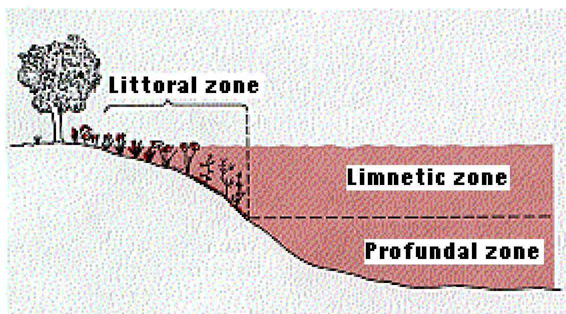

*Figure G-1: Lake zones*

The waters of the Great Lakes are diverse, providing habitat for a number of organisms. A lake is divided into three major zones, the littoral, limnetic and profundal (see Figure G-1). The littoral zone is found along the shoreline where the sunlight can reach the lakebed allowing rooted vegetation to grow. The littoral zone is also referred to as nearshore and will be discussed further in the shoreline category. The limnetic zone is the open, sunlit water beyond the littoral zone that extends to a depth where photosynthesis can no longer occur. Here lives a wide variety of phytoplankton, tiny free-floating plants that form the base of the food web providing food and oxygen for zooplankton and macroinvertebrates which make up a major food source for the blend of native and introduced fish species found in the deep dark waters of the profundal zone which extends beyond the limnetic zone to the lake bottom. On the lake bottom, detritus (loose particles and decaying organic matter) accumulates creating a niche for the diverse communities of bacterial and fungal decomposers that enrich the water with nutrients. These structural components are only one part of the complex lake ecosystem.

*Figure G-2: Lake Temperature Seasonal Change*

Due to the cold winters and warm summers, the Great Lakes show seasonal changes in density and temperature from the surface to the bottom. These fluctuations influence the spatial and temporal arrangements of plants and animals in the Lakes. In the winter a layer of ice may form on the lakes' surface. This lake ice melts in the spring and slowly warms to 4°C, a temperature when water is most dense. A spring overturn is started by winds blowing over the lake surface pushing the dense, cool water downward. The spring overturn moves water vertically carrying dissolved oxygen to lake bottoms and bringing nutrients released by sediment decomposition to the surface (see Figure G-2). The increased nutrients in the limnetic zone and the longer day lengths support higher rates of photosynthesis and lead to an abundance of primary producers.

By midsummer, the surface water temperatures rise well above 4°C creating a thermocline. A thermocline is a midlayer of water where the temperature changes abruptly and blocks vertical mixing. The warmer surface waters rest on the cooler, denser waters of the thermocline. Below the thermocline the decomposers convert detritus into nutrients and generally deplete these cold waters of dissolved oxygen. Above the thermocline, nutrient shortages limit photosynthesis by late summer. The cool temperatures of fall create cool surface water layers. These cool, dense upper layers then sink and dissolve the thermocline. This process is known as the fall overturn which mixes water vertically moving the dissolved oxygen to the lake bottom and nutrients to the surface. The replenishment of nutrients in the fall overturn drives a peak in primary productivity. However, this peak does not last long due to the onset of winter.

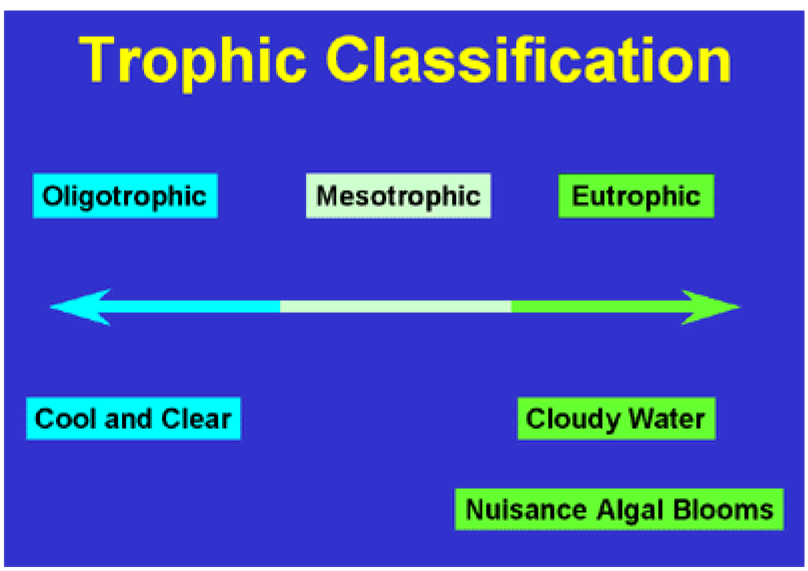


*Figure G-3: Trophic Phases*

Another factor influencing the types and abundance of organisms is the lake's trophic state. The trophic state of a lake is dependent on several components including nutrient loads, topography, climate, geologic history, lake basin soils and soils of the surrounding regions (see Figure G-3). Lakes Huron, Superior and Michigan are oligotrophic, meaning that the water is often deep, clear, nutrient poor and with low levels of primary productivity. Lake Ontario is mesotrophic with average clarity and primary productivity while Lake Erie is more eutrophic with shallow, nutrient rich waters and high primary productivity, most often recognized by algal blooms. These conditions occur naturally as sediments begin to accumulate in the lake basin. However, eutrophication – the processes that enrich a body of water with nutrients – can also be due to human activities, a few examples include sedimentation, deforestation and pollution.

Human influences are the cause behind the eutrophication of Lakes Ontario and Erie. Prior to European settlement and industry, all of the Great Lakes were in an oligotrophic state. The Lakes began to show their stress in the 20$^{th}$ century as agriculture intensified and the urban areas continued to grow around the lakes. The combination of synthetic fertilizers, untreated human wastes and phosphate detergents caused an acceleration of eutrophication in the lakes. In the mid-1900s, Lake Erie showed the first evidence of lake-wide eutrophic imbalance with massive algal blooms and the depletion of oxygen (Fuller *et al.*, 1995).

A number of waterways connect all of the Great Lakes to the Atlantic Ocean, both natural and manmade. Historically, these waterways contained a wealth of wildlife, harboring many species of freshwater clams and creating breeding sites for a variety of fish including the once thriving and now rare Lake Sturgeon. As cities began to spring up at the mouths of rivers, canals were cut to provide cheap transportation. By 1825, the Erie Canal had linked the Hudson River and Lake Erie, and the Lachine Canal allowed the worst rapids on the St. Lawrence River to be by-passed (Fuller *et al.*, 1995). The Miami and Erie Canals linked the Ohio River to Lake Erie. In 1829, the Welland Canal had bypassed Niagara Falls. The onset of the shipping industry completely altered the structure of the connecting waterways, stripping these once biologically diverse areas of their native flora and fauna.

By connecting formerly separated water bodies, these canals allowed the growth of a Great Lakes shipping industry, but they also ushered in the invasion of non-native species. The canals themselves and the ballast waters of the ship traffic they carried, allowed species such as the alewife, the sea lamprey, the Eurasian river ruffe, zebra mussel and other invasive species to enter the system and compete with native species. In an attempt to curb the alewife population, non-native Pacific and Atlantic salmon were introduced completely altering the food web.

In the late 1980's the zebra mussel was discovered in the Great Lakes. This mollusk is largely responsible for clearing the waters of Lake Erie by filtering out nutrients and other particles. The clarity of this lake has exceeded its natural state in increased light penetration which created a growth spurt in algae and submerged plants, a complete change in the aquatic environment. The introduction of zebra mussels has also altered the food web by competing with the native *Diporeia spp.*, a major food source for larval fish. This is thought to be the reason for the decline of yellow perch and other native game fish in the Great Lakes. Today the Great Lakes are inundated with invasive species brought in mostly by the shipping industry's ballast waters.

The Great Lakes waters are experiencing high levels of stress, through water withdrawal, invasive species introductions, pollution and human alteration. Most water withdrawals are from electrical power plants along the lakeshores for condenser cooling (Rousmaniere, 1979). Every day billions of small animals and plants and thousands of larger fish are killed by intakes and cooling systems (Rousmaniere, 1979). The water released back into the Great

Lakes after being used to cool condensers is often 10-20°C higher than surrounding waters, again altering the system (USGCRP, 2003).

Invasive species are becoming more common and altering the aquatic food web. Stocking of native and nonindigenous trout and salmon will likely continue indefinitely because eradication and control of invasive species is unlikely. Agricultural runoff has filled the bays with silt and polluted the waters, municipal and industrial wastes have overly enriched the system with nutrients and industrial pollutants such as oils and metals have affected the fish we eat. Human alteration, in the form of channels, locks, dams and shoreline hardening has changed the ecosystem, removing important spawning habitats and altogether altering their functionality. All of the above stressors have changed the Great Lakes aquatic ecosystem from an environment where native species thrive to one where they struggle to survive.

Several agencies study the open waters of the Great Lakes (see *Habitat Data and Information Inventory* section of this appendix for more specific information). The U.S. Fish and Wildlife Service (USF&WS) have fisheries databases for the entire Great Lakes and an algae study in Lake Superior. The U.S. Geological Survey (USGS) has distributional data on fisheries, invertebrates, habitats and contaminants for the entire Great Lakes, as well as a predator prey database for Lake Superior and an ecological health study on Lake Erie. The National Oceanic and Atmospheric Administration (NOAA) holds daily fishing records for the U.S. waters of the Great Lakes, data on trends in macroinvertebrate populations for Lake Michigan and algal bloom data for Saginaw Bay. The U.S. Environmental Protection Agency (USEPA) has compiled information on phytoplankton, invertebrate studies and water quality studies for the entire Great Lakes.

Agencies such as the Great Lakes Fisheries Commission and NatureServe respectively hold historic fisheries data and distributional data on habitats and species for the entire Great Lakes. The Ohio Department of Natural Resources (ODNR) has studies on sediment cores, lake-bottom sonar readings and lake trawling for Lake Erie. Environment Canada has a monitoring study on the environmental effects of effluent from industrial and other sources on fish, fish habitat and human uses of fisheries resources in the Canadian waters of the Great Lakes. The Nature Conservancy (TNC) has created computer software that allows hydrologists and ecologists to statistically characterize environmental regimes of lakes and to analyze changes in those characteristics over time. The Lake Huron Technical Committee has a Geographical Information System (GIS) inventory of aquatic resources and is working towards a basin wide project. The Natural Resources Research Institute has compiled a collection of GIS databases for Lake Superior.

While many agencies have distribution records for aquatic habitats, fish, invertebrates and phytoplankton in the Great Lakes, knowledge of the affects of water quantity on the system is lacking. It is uncertain how water withdrawal will affect the open lake. The majority of water withdrawal effects would likely be felt in the nearshore regions.

Improvements to modeling of hydrologic impacts on the nearshore habitats of Great Lakes and their shorelines are needed. This involves classifying nearshore habitat by hydrology and geomorphology, evaluating abiotic (nutrients, pH, salinity, climatic parameters) changes in nearshore habitats, modeling water levels and circulation impacts on nearshore habitats in the Great Lakes and their embayments, determining effects of sedimentation on nearshore habitat and evaluating impacts of landuse modifications on nearshore habitats.

**Interconnecting Waterways**

The interconnecting waterways of the Great Lakes include the St. Marys River (flowing from Lake Superior to Lakes Michigan-Huron), St. Clair River (flowing from Lake Huron to Lake St. Clair), Lake St. Clair (between the Detroit and St. Clair Rivers), Detroit River (flowing from Lake St. Clair to Lake Erie), Niagara River and Welland Canal (flowing from Lake Erie to Lake Ontario)and St. Lawrence River (flowing from Lake Ontario to the Atlantic Ocean).

The interconnecting waterways are biologically diverse areas, but physical alteration of these rivers has had profound effects on the waters and their biota. The St. Clair - Detroit River system was home to the most diverse freshwater mussel population in the world, once harboring 39 species of unionid mussels (Krchnak *et al.*, 2002). The decline of these species is due in a large part to the invasion of the zebra mussel, channel modification and pollution.

The Great Lakes interconnecting waterways were highly utilized for fish spawning and nursery sites. Today, many of these spawning habitats are missing, largely separated from the open waters of the lakes by dams and other structures. Channel dredging and shoreline alteration have permanently destroyed many coastal wetlands and large amounts of fish spawning habitat in the connecting waterways. Major hydropower facilities, located in many of the connecting waterways, may also present adverse affects on the aquatic fauna; however, their effects have not been extensively studied.

The interconnecting waterways have an important role in the transport of water, sediments, nutrients and contaminants. These rivers support a wide variety of recreational uses, are major navigation routes for inter-lake and ocean-going vessels and are the municipal and industrial water supplies for major population centers in the region. These rivers are also used to disperse the effluents from municipal sewage treatment plants and from industry, including those produced by wood pulp processing and paper manufacturing, electrical power production, steelmaking and casting, mineral extraction, chemical manufacturing, petrochemical production and refining and automobile manufacturing. The rivers also receive and redistribute pollutants from urban and agricultural run-off and from the atmosphere.

The USGS National Water Quality Assessment (NAWQA) Program collects biological and ecological data on Lake Erie and Lake St. Clair. The Great Lakes Commission (GLC) has developed an inventory of monitoring programs in the Lake St. Clair and Lake Michigan basins. The International Joint Commission (IJC) is conducting the Lake Ontario – St. Lawrence River Study (LOSLS) to look at the affects of water level fluctuations on the ecosystem. Environment Canada has consolidated scientific information and data on the physical and biotic characteristics of the St. Lawrence River. Environment Canada and the University of Montreal have data on algal species in the St. Lawrence River over the past 20 years.

Very little research is currently being conducted on the Welland Canal, the Straits of Mackinac, the Niagara, Detroit and St. Clair Rivers.

Modeling of hydrologic impacts on the interconnecting waterways needs to be improved. To accomplish this task, the following activities need to be accomplished: classify habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River by hydrology and geomorphology; evaluate abiotic changes, model water level and flow regime impacts; determine effects of sedimentation; and evaluate landuse modifications on habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**33-37 (Interconnecting Waterways Ecological Modeling):** Comprehensive modeling of habitats in the interconnecting waterways and the St. Lawrence River, including Lake St. Clair, is needed to track ecological impacts of cumulative water withdrawals.

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

**Tasks 33-37 (Interconnecting Waterways Ecological Modeling)**: U.S. federal agencies need to work collaboratively with regional, state and Canadian federal and provincial agencies, to improve modeling of potential hydrologic impacts of cumulative water withdrawals on habitats in the interconnecting waterways, including Lake St. Clair and the St. Lawrence River.

**33:** Detailed habitat models are generally unavailable to determine impacts of hydrologic changes due to cumulative water withdrawals in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

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

**Task 33:** The USGS, in cooperation with other U.S. federal agencies, Canadian federal and provincial interests, and other governmental and non-governmental institutions, needs to develop detailed models of habitat impacts in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River as a consequence of cumulative water withdrawals.

**34:** Changes in habitat extent, composition and diversity in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River are influenced by cumulative withdrawals of water upstream, as well as other local factors like land use encroachment, channelization and sediment transport modifications. Each of these factors needs to be discriminated in impact analyses.

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

**Task 34:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to evaluate the impacts of land use modifications on adjacent habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**35:** Regional sediment models are a necessary component of comprehensive ecological modeling of habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

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

**Task 35:** The USGS, in conjunction with the USACE, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to determine effects of sedimentation on habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**36:** Detailed classification of habitats by their geomorphic and hydrologic characteristics is needed to support ecological impact studies for the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

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

**Task 36:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to classify habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River by their hydrologic and geomorphologic characteristics.

**37: Cumulative water withdrawals could c**hanges the abiotic conditions of the habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River. These effects need to be monitored and modeled.

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

**Task 37:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures for evaluating abiotic changes in habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

## Shorelines

### Islands

The 35,000 islands of the Great Lakes form a superlative natural system. In fact, the largest lake island in the world is Manitoulin in Lake Huron (Ontario), covering 1,068 square miles (Calder, 1996). Due to their isolation, islands have unique properties and retain more of their natural heritage warranting special attention and protection. The properties of Great Lakes islands include high proportions of endemic and endangered species, fish spawning areas, nesting colonial waterbirds, feeding and resting sites for migratory birds and monarch butterflies, open and perched dunes, and a variety of geologic structures. These islands contain many critical natural features, cultural resources and recreational opportunities that, despite being threatened by pressures of unplanned development and habitat destruction, have yet to be holistically addressed. The Great Lakes islands provide an excellent potential for conserving the biodiversity and the unique biological legacy of the Great Lakes - St. Lawrence River basin.

Few agencies study the island habitats. Environment Canada has created a Great Lakes Environmental Sensitivity Atlas and database for the Great Lakes' shorelines that includes geomorphological, biological, cultural and human-use information. NatureServe has GIS distributional databases of habitats and species for the entire basin. The Great Lakes Basin Ecosystem Team has a GIS decision support system for Lake Michigan's barrier island beaches that is being extended to the entire Great Lakes - St. Lawrence River basin. The Northeast Midwest Institute continues to inventory information and data regarding the U.S.-Canada Great Lakes Islands. Little is known of the Great Lakes island habitats and their relation to water quantity. The effect of low lake water levels on these islands needs to be studied.

**Nearshore Waters**

The nearshore habitat is composed of periphery waters along the shoreline of all the Great Lakes between the land and the deeper offshore waters of the lake, where sunlight can penetrate to the bottom (the littoral zone). The plant and animal life in these waters must cope with a wide variety of environmental fluctuations. Air temperatures and sunlight may radically alter water temperature in localized areas. Wind speed and direction and tidal currents can stir up sediments, which in turn decrease light penetration necessary for photosynthesis. All organisms that live in the dynamic shallow waters must be adapted to survive fluctuations.

Virtually all species of Great Lakes fish use the nearshore waters for one or more critical life stages. The nearshore waters are areas of permanent residence for some fishes, migratory pathways for anadromous fishes and temporary feeding or nursery grounds for other species from the offshore waters. Only the deepwater ciscoes (members of the whitefish family) and the deepwater sculpin avoid and are rarely found in the nearshore waters (SOLEC, 1996).

Fish species' diversity and production in the nearshore waters are higher than in offshore waters; they also vary from lake to lake and are generally highest in the shallower, more enriched embayments with large tributary systems. During the summer, the nearshore waters are occupied by aquatic plant and animal communities that are adapted to the summer thermal regime. This adaptation, which has been studied most extensively in fish, reveals that each species has a narrow and relatively unique range of summer temperatures at which it grows best. Fish are highly mobile and actively seek that "preferred" range in summer. As a result, species with similar preferred temperature ranges generally have similar spatial distributions in summer.

Three major thermal groupings of fish communities occur in the Great Lakes: warmwater (e.g., catfish, bass and sunfish), coolwater (yellow perch, walleye and pike) and coldwater (trout, salmon, whitefish, deepwater sculpin). The nearshore waters also provide critical feeding and resting habitat for ducks, geese and swans and other waterfowl, especially during the fall and spring migrations. Aquatic mammals including muskrat, beaver, otter and mink are common in some undisturbed, sheltered waters in the lower reaches of tributaries and near coastal wetlands. Great Lakes nearshore waters are critical habitat for threatened or endangered species or species of special concern, including the bald eagle, osprey and freshwater mussels. Invasive aquatic plants and animals have become established in the Great Lakes, and most are more abundant in the nearshore waters.

Within the Great Lakes, topographic and bathymetric data, coupled with lake levels, allow for determination of water depth and can be used to gain a better understanding of underwater features for observing the dynamics of aquatic ecosystems, to observe and forecast winds and waves on the lakes, and to aid coastal decision-makers. It also impacts the distribution of sedimentary environments, benthic habitats, and contaminant accumulation. The biological effects of water level fluctuations in lakes is greatest in the shallow water of the nearshore and coastal wetlands, where even small changes in water levels can result in the conversion of a standing-water environment to an environment in which sediments are exposed to the air, or vice versa. These wetlands are adapted to short-term flooding and draining by storm tides (seiches) and to seasonal and longer-term changes (i.e., changes that occur over years or decades) in lake levels.

Low water levels of the Great Lakes affect the temperatures of the nearshore waters and coastal wetlands. Extremely high water temperatures in these shoreline habitats can lead to algal blooms, fish die offs and low oxygen levels. Also, low lake levels can expose the muddy bottoms of coastal wetlands, leading to a spurt in wetland plant growth. In contrast, high lake levels can suffocate coastal wetland plants and decrease plant diversity with only the highly aquatic plants able to survive. It is the fluctuation between high and low water levels that keeps these coastal wetlands diverse and functional.

Many agencies conduct research on the nearshore waters. The USGS has a wealth of ecological information on the nearshore of Lake Erie and distributional data of aquatic species and their habitats for all of the Great Lakes. The NOAA has GIS data on the distribution of algal blooms in Saginaw Bay and Lake Erie, as well as Environmental Sensitivity Index maps.

The U.S. Army Corps of Engineers (USACE) and Environment Canada created a detailed geomorphic classification of all of the Great Lakes shorelines in support of the IJC's Levels Reference Study concluded in 1993 which are the basis for several contingency plans for oil and hazardous spills response planning. Environment Canada has also created a Great Lakes Environmental Sensitivity Atlas and database for the Great Lakes' shorelines that includes geomorphic, biological, cultural and human-use information. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The ODNR has spatial distributions of larval walleye in nearshore waters of western Lake Erie and a GIS database of nearshore habitat dynamics for Lakes Erie and Michigan.

Moderate-resolution topographic and bathymetric surveys of the nearshore elements of the U.S. Great Lakes – St. Lawrence River system were completed by the early 1970s. The majority of topographic elevations have been mapped by the USGS for nearshore areas twenty to thirty years ago. These data are frequently too coarse in detail (5 or 10-foot contours) to provide a useful basis for monitoring habitat change.

Bathymetric data have been collected by the National Ocean Service (NOS) of the NOAA, in cooperation with the Canadian Hydrographic Service over all of the Great Lakes and interconnecting waterways at least once. Chart revisions are updated infrequently and large tracks of nearshore areas have either too coarse sampling intervals or are seriously outdated, being collected more than four decades ago.

The NOAA is engaged in a program to compile a comprehensive Great Lakes bathymetric dataset of the highest accuracy attainable. This program is managed by the National

Geophysical Data Center (NGDC) and it relies on the cooperation of the NOAA's Great Lakes Environmental Research Laboratory (GLERL) and the National Ocean Service (NOS), the CHS, and other agencies (National Geophysical Data Center, 2003). These efforts will provide a comprehensive inventory of available bathymetric detail at the highest accuracy attainable, but it still will lack suitable nearshore detail to be used in ecological impact assessments.

Bathymetric detail is collected by the USACE primarily for areas in maintained navigation channels throughout the system including harbors. These data are usually collected to assess dredging needs. Recently the USACE has collected Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) data for numerous shoreline counties within the basin. SHOALS employs a survey technology known as Airborne Lidar Bathymetry (ALB) or Airborne Lidar Hydrography (ALH) which uses state-of-the-art LIDAR (Light Detection and Ranging) technology to rapidly and accurately measure lakebed depths and topographic elevations. (USACE, 2000). Large tracks of the nearshore areas of lakes Michigan, Erie and Ontario have been collected via airborne SHOAL surveys for use in erosion process models, which are extremely useful for assessing cumulative impacts of water withdrawal on nearshore habitats. Comprehensive airborne SHOALS surveys are desired for all Great Lakes shorelines.

More detailed ecological data is needed for the nearshore waters of the Great Lakes. The impact of water withdrawal on nearshore processes needs further investigation. In particular, improvement to modeling of hydrologic impacts on the nearshore habitats of Great Lakes is needed. This involves more detailed classification of nearshore habitats by their hydrologic and geomorphic characteristics, evaluating abiotic (nutrients, pH, salinity, climatic parameters) changes in nearshore habitats, modeling water levels and circulation impacts on nearshore habitats in the Great Lakes and their embayments, determining effects of sedimentation on nearshore habitat and evaluating impacts of landuse modifications on nearshore habitats.

### Coastal Wetlands

The Great Lakes coastal wetlands often merge into the nearshore waters and are directly influenced by the waters of the Great Lakes. While they share many of the same functions and values as inland wetlands, it is the impact of the large lakes that differentiates coastal wetland hydrology and vegetation structure from that of their inland counterparts. Whatever their size, these wetland plants are the primary producers that support the entire aquatic ecosystem and play an essential role in water quality improvement. Like the nearshore, these wetlands are essential breeding grounds for many Great Lakes fish and they also provide excellent habitat for many plants, invertebrates, amphibians, reptiles, birds and mammals. Migratory birds congregate around the calm waters to feast on the abundant supply of invertebrates and many species of Great Lakes fish which use these wetlands as spawning and nursery areas.

Coastal wetlands also absorb and cycle nutrients and organic material. They help regulate stream flow, improve water clarity by absorbing nutrients that lead to algal growth, settle sediments from upstream erosion and decrease contaminant concentrations such as nitrogen and phosphorus from washing into the lakes through sedimentation and uptake by plants and animals. As a result, coastal wetlands are essential to maintaining Great Lakes water quality. Coastal wetlands also protect adjacent terrestrial ecosystems from erosion by dissipating wave energy. Great Lakes coastal wetlands are heavily influenced by the rise and fall of lake water levels.  Since 1860, the Canadian and United States governments have tracked the Great Lakes water levels, and the record is one of constant change (reference: GLC&MISG).  These natural fluctuations impact a broad range of wetland characteristics, from water chemistry to plant community composition.  In fact, the water level stress is essential to maintaining coastal wetland biodiversity.  The most noticeable effect of changes in water levels is on plant life, which in turn will impact the animal life that relies on wetlands as habitat (Cronk and Fennessy, 2001).

The duration, frequency, timing and magnitude of water level fluctuations are critical for wetland plant communities.  The variability of these factors alters individual wetland structure and function.  Wetlands that exist with these water level changes are known as pulse-stable-systems – their plants and animals are adapted to and depend on a highly changeable wetland environment.  Water level fluctuations greatly affect coastal habitats by altering their species assemblages (Cronk and Fennessy, 2001).  High water levels drown emergent plants giving rise to submergent vegetation, while submergent plants and sometimes even emergent plants die with low water levels (depending on abruptness of the degree of change).

Great Lakes coastal wetlands are highly studied.  The USGS has distributional databases of aquatic species and habitats and studies of the effects of water level fluctuations on these habitats for the entire Great Lakes.  The USF&WS maintains the national wetlands inventory GIS database of wetland distribution for the entire Great Lakes.  The NOAA has data on the bottom-dwelling macroinvertebrate populations in southern Lake Michigan.  The USACE and Environment Canada have detailed shoreline GIS data for Lakes Erie and Ontario.  The USEPA has distributional data of aquatic wetland species at risk for the entire Great Lakes and a study of the phytoplankton populations in Lake Michigan.

NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin.  Michigan Natural Features Inventory (MNFI) has historic and current GIS distributional databases of vegetation for Michigan.  MNFI also has habitat and organism distributional data for Michigan, an inventory of Great Lakes coastal wetland plants, studies of abiotic factors in all Great Lakes' coastal wetlands and abiotic variability of Michigan's coastal wetlands.  The ODNR has spatial distributions of larval walleye in nearshore waters of western Lake Erie and descriptions of historic and present coastal wetlands of Lakes Erie, St. Clair, Michigan and Ontario.

The Great Lakes Commission has been coordinating monitoring programs for the coastal wetlands of all the Great Lakes.  Environment Canada has GIS databases of geomorphological, biological, cultural and human-use information for the Great Lakes' shorelines and a study of the coastal wetlands of Lake Ontario and the St. Lawrence River. The Ontario Ministry of Natural Resources (OMNR) has GIS databases of coastal wetlands for the entire Great Lakes.  Canadian and U.S. agencies have also formed a team to monitor the amphibians and birds of wetlands throughout the Great Lakes - St. Lawrence River basin.  The USGS has looked at the effects of water fluctuations on coastal wetlands.  These fluctuations could be due to natural variations in water level or affects of water withdrawal, this needs to further developed.

**Bluffs**

Bluffs are steep banks with a broad flat or rounded front located along the shorelines of the Great Lakes.  They occur frequently along the Great Lakes shoreline and are highly erodible areas composed of unconsolidated clay, till, or other sediments.  Swallows and Bald Eagles use bluffs for nesting sites, while hawks use the updrafts created by the bluffs for soaring along the shoreline to avoid crossing the open waters of the Great Lakes. Some bluffs display unusual microhabitats in groundwater seepage zones, sometimes called "hanging fens," which support large populations of rare plants. These hanging fens provide habitat for such uncommon wildflowers as Indian paintbrush, yellow lady's-slipper and queen lady's-slipper orchids. Actively eroding bluffs are a source of the sediments that are carried by wave action and deposited in beach areas.

Bluff studies of the Great Lakes include erosion research and distributional data. The USACE has a coastal analysis GIS system for all of the Great Lakes, including erosion data, and has conducted detailed potential damages study for lakes Michigan, Erie and Ontario shorelines. Environment Canada also has GIS databases of geomorphological, biological, cultural and human-use information for the Great Lakes' shorelines and a GIS classification database of the Canadian Great Lakes shoreline. The IJC is currently conducting comprehensive research on the effects of Lake Ontario outflow management on the habitats along the Lake Ontario and St. Lawrence River shorelines, including bluff areas. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The ODNR has a coastal erosion GIS database for Lake Erie.

The effects of water quantity on bluff habitats have not been explored in sufficient detail in the Great Lakes –St. Lawrence River basin. The gaps in understanding the relationship between water quantity and bluff habitats need to be addressed in further research.

**Cobble Beaches**

Cobble beaches occur on the sloping shorelines of the Great Lakes where dolomite and limestone bedrock are just beneath the surface (reference: MSU Extension). These beaches are constantly exposed to wind, ice, changing lake levels and lapping waves which creates a neutral to slightly alkaline substrate and sand between cobbles and boulders. These beaches are part of the geologic formation known as the Niagara Escarpment (reference: MITNC). Here only certain plants can survive in the calcium-rich soil on these rocky beaches, including the swamp sawgrass (*Cladium mariscoides*), shrubby cinquefoil (*Potentilla fruticosa*), bog reedgrass (*Calamagrostis inexpansa*), bluejoint reedgrass (*C. canadensis*), sweet gale (*Myrica gale*), water sedge (*Carex aquatilis*) and Tussock sedge (*C. stricta*). Animals utilize coarse beaches for many reasons. Birds perch in nearby trees from which they can fly to feed on insects, frogs or fish in neighboring marshes, swamps or forests. The endangered Piping Plover (*Charadrius melodus*) nests on cobble beaches and mammals use the shoreline as a travel and feeding corridor.

Cobble beach habitats are poorly studied. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. Environment Canada has GIS databases of geomorphic, biological, cultural and human-use information for the Great Lakes' shorelines. More information is needed on how water level changes affect these habitats.

**Sand Beaches**

Sand beaches provide habitat for a variety of organisms and protect lagoons and coastal marshes from wind and wave action. Algae and other microscopic plants thrive where the beach is constantly lapped by the water. These moist sands also provide rich feeding grounds for a great variety of migratory shorebirds. The beach collects debris that a variety of beetles, spiders and shorebirds like to feed upon. Mammals also congregate on these beaches, in particular humans utilize sand beaches as a major recreational site. The state and federally endangered piping plover relies on the sandy beaches for food and nesting. One reason for the decline of this bird is the increased use of beaches by recreational vehicles.

Sand beaches are ever-changing, relying on sediment from bluffs and rivers for replenishment. High-energy storm waves erode sand from the beach and deposit sand offshore as sandbars. Low-energy waves from calm weather move the sand back to the beach. Shoreline alteration and hardening impacts sandy beaches by changing deposition rates and transportation of sediments. These alterations began with the encroachment of homes along the lakeshore. As the waves naturally moved sand from one shore to the next, homeowners were shocked to find their beaches disappearing and erosion occurring beneath their homes. They began to build structures such as revetment, bulkheads, breakwaters and groins to protect their beaches. Ironically, these structures often lead to further erosion and displacement of sand. Other man-made structures, such as dams trap sediment and rob beaches of their natural replenishing sand.

Artificial shoreline structures and hardening of the shorelines in Lakes Erie, Michigan and western Lake Ontario have interrupted the important process of alongshore sediment transport that naturally erodes and replenishes sand beaches. This is also a problem in western Lake Superior, although the percentage of shoreline affected is less than for the other lakes. In addition to interrupting natural physical processes, shoreline alteration destroys critical wildlife habitat, replacing prime beach habitat with riprap and other structures unsuitable for foraging or breeding sites. Protecting coastlines may require measures to ensure a steady stream of sediment from rivers and a policy against armoring shorelines to prevent beach erosion.

Beach studies of the Great Lakes include erosion research and distributional data. The USACE has a coastal analysis system for all of the Great Lakes, a GIS erosion study for lakes Erie and Ontario and a GIS potential damages study for Lake Michigan. The USEPA has a distributional database of the Great Lakes ecoregions. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. Environment Canada has GIS databases of geomorphological, biological, cultural and human-use information for the Great Lakes' shorelines. Additional information on how water levels affect sand beaches is needed to determine how cumulative water withdrawals may impact these habitats.

**Dunes**

These complex systems were formed from glacial stratification or through thousands of years of wind and wave action. Dunes are known for their great breadth in plant diversity. They are unique and irreplaceable successional systems comprising the largest freshwater collection of sand dunes in the world (reference: TEACH). Dunes are the most diverse ecosystem in the Great Lakes - St. Lawrence River basin, supporting a large number of plants and animals in a relatively small area. Dunes also serve as a shield to the powerful winds and waves of the Great Lakes and act as a buffer, protecting inland areas from adverse weather. This is a highly dynamic natural community based on sand. The movement of sand ranges from free-blowing sand to sands that have become stabilized by plants. Despite strong wind, blowing sand, waves and severe extremes of drought and flooding, many plant species have specialized adaptations to these conditions. Sea rocket and clumps of marram grass tend to be the first plants to colonize sand beach areas. They are often followed by beach pea, bearberry, Lake Huron tansy, hoary puccoon and Pitcher's thistle, among other plants. As these early colonizing grasses develop and begin to hold more sand on dune ridges, woody plants such as white pine trees can grow. Despite inhospitably hot, cold, dry, wet and windy conditions, insects such as tiger beetles, ants and butterflies inhabit this area and several species of shorebirds nest along the beach or in the dunes.

Dune studies of the Great Lakes include erosion research and distributional data. The USACE has a coastal analysis system for all of the Great Lakes, a GIS erosion study for lakes Erie and Ontario and a GIS potential damages study for Lake Michigan. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. Environment Canada has GIS databases of geomorphological, biological, cultural and human-use information for the Great Lakes' shorelines and a GIS classification database of the Canadian Great Lakes shoreline. The TNC and Environment Canada has studied the threats of on and offshore sand dunes. More information is needed to determine the effects of water quantity on sand dunes.

**38-42 (Nearshore Ecological Modeling):** Ecological impact analysis requires comprehensive modeling of the nearshore dynamics for all of the Great Lakes.

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

**Tasks 38-42 (Nearshore Ecological Modeling):** The USGS, in conjunction with other federal agencies, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard procedures for modeling hydrologic impacts on nearshore habitats of Great Lakes and shorelines.

**38:** Modeling of water level and circulation impacts on nearshore habitats in the Great Lakes and their embayments are not detailed enough to support impact assessments.

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

**Task 38:** The USGS, in conjunction with the NOAA and the USACE, and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling tools for evaluating the hydrologic impacts of cumulative water withdrawals on nearshore habitats in the Great Lakes and their embayments.

**39:** Land use modifications on nearshore habitats need to be discriminated from those ecological impacts caused by water withdrawal.

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

**Task 39:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for repetitive evaluations of the impacts of land use modifications on nearshore habitats.

**40:** Regional sediment models are a necessary component of comprehensive ecological modeling of nearshore habitats.

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

**Task 40:** The USGS, in conjunction with the USACE, and in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining effects of sedimentation changes on nearshore habitat.

**41:** Consistent classification of the hydrologic and geomorphic characteristics of nearshore habitats is an essential component of comprehensive ecological impact assessments.

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

**Task 41:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to classify nearshore habitats by their hydrologic and geomorphic characteristics.

**42:** Changes in abiotic conditions in nearshore habitats are not comprehensively modeled to support ecological impact assessments.

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

**Task 42:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating abiotic changes in nearshore habitats.

## Tributaries

### Tributaries

The tributaries of the Great Lakes basin connect the surrounding lands to the Great Lakes, transporting nutrients across the watershed. The Great Lakes rivers and streams support a number of organisms. Invertebrates live in these waters, providing food for fish and waterfowl. Many rivers in the Great Lakes ecosystem provide waterfowl migration corridors due to the Atlantic and Mississippi Flyways, as well as major migration corridors for neo-tropical birds, butterflies and raptors; while providing principal spawning and nursery habitats for one-third of the fish species in the Great Lakes (TNC, 1997). Most modern stream ecosystems have little in common with those found prior to human impact. Early stream channels were heavily shaded by riparian vegetation and contained large amounts of fallen wood.

Human intervention in river systems has caused numerous changes through efforts to tame rivers for transportation, water supply, flood control, agriculture and power generation. Channelization has reduced the physical complexity of stream channels, increased stream velocity and caused extensive ecological degradation and loss of biological diversity.

Substrate composition plays a major role in determining the quality of the habitat and the channel hydraulics. Coarse stream beds provide important attachment sites and microconditions for a variety of aquatic macroinvertebrates, while fine sediments support a reduced density and diversity of macroinvertebrates. Most fish also require hard substrates for reproduction. The widespread physical alteration of rivers is a significant cause of freshwater species' decline.

Critical river, wetland and floodplain habitat for native freshwater species has been degraded or destroyed-and continues to be threatened-by these structural alterations that fundamentally change the shapes and natural flows of rivers and water quality. Dams built to support navigation, generate hydropower and divert water for irrigation block fish migrations, disrupt the transport of sediment and nutrients and eliminate natural variations in river flow that trigger fish reproduction and support wildlife habitat. Dams have driven certain species of salmon and pallid sturgeon to the brink of extinction. Levees built to control flooding destroy riverside wetlands and eliminate important spawning and feeding areas for fish and other species. Stabilizing riverbanks with rock (called "rip-rap") and channelization of rivers to support transportation and reduce flooding eliminates islands, sand bars and side channels.

The biological effects of water level fluctuations in rivers are greatest in shallow water, where even small changes in water levels can result in the conversion of a standing-water environment to an environment in which sediments are exposed to the air, or vice versa. Although natural flow regimes are dynamic, they are key to organizing and defining river ecosystems. The five components of the flow regime (magnitude, frequency, duration, timing and rate of change) influence ecologic integrity both directly and indirectly, through their effects on water quality, energy, habitat, biotic interactions and material transport. In rivers, aquatic habitat is defined largely by the movement of water, sediment and debris in the channel and between the channel and floodplain. Flow alteration increases aggradation and encroachment of riparian vegetation and accumulates fine sediments detrimental to fish habitats (Wesche *et al.*, 1988).

Streamflow is strongly correlated with many critical physicochemical characteristics of rivers, such as water temperature, channel geomorphology and habitat diversity and can be considered a "master variable" that governs the distribution and abundance of riverine species. Disruptions of natural flow through damming and channelization can cause extensive ecological degradation, loss of biological diversity, declines in water quality, extirpation of valued species, groundwater depletion and more frequent and intense flooding (MacKenzie and Ball, 2001). The ecological integrity of flowing water ecosystems depends on their natural dynamic character.

Few agencies study the riverine habitat. The USGS has GIS distributional data for aquatic species and habitats in the Great Lakes - St. Lawrence River basin. The USACE has been undertaking important sediment loading studies under Section 516 of the Water Resources Act of 1999. Under this program, sediment modeling has been conducted on all or parts of individual watersheds to each Great Lakes. Methods are being developed under this program which can be applied to all other U.S. tributaries to the Great Lakes.

The Michigan Department of Natural Resources (MDNR) has information about species and ecosystems in the tributary rivers of Michigan. The OMNR has a report on the aquatic habitat inventory for the province of Ontario. TNC has a software package that allows hydrologists and ecologists to statistically characterize environmental regimes of rivers and to analyze changes in those characteristics over time.

More information needs to be known regarding the affects of water quantity and movement on riverine habitats. Specifically, what are the affects of low water on the riverine habitats and how do flow altering structures, such as dams and channels, affect this habitat. Improvement in modeling of hydrologic impacts on tributaries is needed. This requires classifying tributaries by hydrology and geomorphology, monitoring abiotic conditions in tributaries, evaluating water levels and flow impacts, determining effects of sedimentation and evaluating landuse modifications on tributaries.

Bathymetric data for rivers within the basin is of particular importance and is frequently lacking in detail for modeling purposes. The generation of bathymetric maps for rivers and lakes would greatly assist efforts to describe the physical and biological systems and monitor changes and impacts to these systems based on sedimentation and other point and nonpoint source pollution.

**Riparian Zones**

The vegetative areas along either sides of the river, known as riparian zones, are migratory corridors for wildlife. These lands are very important in terms of both structure and function. Riparian zones are naturally characterized by greater diversity and population densities of animals than is observed in upland forests and they provide cover for many mammals, amphibians, reptiles and insects moving between habitats (Schneider *et al.*, 1989).

The many trees and plants in the riparian zone aid in the stabilization of riverbank soil. Trees and plants along streambanks and lakeshores reduce soil erosion by their roots holding the soil together, making it more difficult for waves, currents and runoff to wash the soil away. Plants further prevent erosion by reducing the impact of raindrops on exposed soil. The result is a decreased input of sediment and suspended solids in the stream. Riparian zones help retain floodwater after heavy rains or snowmelts. Streamside wetlands mimic huge sponges absorbing and filtering water, reducing peakflow levels in streams and replenishing the groundwater.

As runoff water moves through the flora, it slows and drops sediment on the land that has been carried along. Since these sediments are deposited on the banks rather than in the streams, floods can actually be bank-building events. This settling process also keeps nutrients from flowing into streams and lakes, permitting plant roots to take up the nutrients that have dissolved in the runoff and soaked into the soil, reducing the amount of pollution flowing into lakes and streams. Because the soil is exceptionally fertile, riparian areas can produce stands of very large trees that provide shade, food and cover for stream dwellers.

Unfortunately, the rich floodplains are desirable timber resources because they can produce stands of very large trees. Once the trees are cleared, these areas are used as fertile agricultural lands and often farmed right to the bank of the stream, destroying the cleansing function of this vegetation and leading to increased loads of sediment and pollutants. Activities and disturbances such as: excessive livestock grazing, agriculture, road-building, urban development and recreation can also damage these sensitive riparian areas and decrease biodiversity in lower reaches of river floodplains. Over two-thirds of riparian zones have been altered in the U.S. alone, with the majority of this destruction occurring in the Midwest (Schultz *et al.*, 1994).

Riparian shrubs and trees are of great value to the ecosystem. They help keep stream temperatures cool in the summer, and their branches and leaves provide food and cover for stream dwellers. These cool streams provide habitat for trout, as well as a number of invertebrates, amphibians and reptiles. Streamside habitats provide food for waterfowl such as Canada geese and shorebirds including killdeer and spotted sandpiper. The riparian zone also provides food and cover for flocks of dark-eyed junco, white-crown sparrow, American robin and other species. Great blue heron, red-tailed hawk and great horned owl all nest in riparian habitat. In winter, bald eagles perch and roost in trees. One bird, the bank swallow, is found in riparian areas so often it was given the scientific name *Riparia riparia*.

Beaver and muskrat rely on riparian habitat for foraging and denning materials. Many other mammals rely on the rivers for drinking water and important cover and forage. Many reptiles and amphibians depend on these tributaries to lay eggs and provide food. Riparian insects, including mayflies, stoneflies, caddisflies, spiders and beetles, provide important links in the food web and are eaten by many other animals such as shrews, fish and birds. These riparian zones are also used by many animals as cover while moving from the lowlands to the uplands.

Subtle changes in hydrologic regimes may have a major influence on regeneration processes in floodplains (Schneider *et al.*, 1989). The overall affect of changing a river's hydrologic regime is a reduction in total acreage of bottomland hardwood forest (Schneider *et al.*, 1989). This change in hydrologic regime leads to a major loss in unique wildlife habitat located between the terrestrial and aquatic habitats (Schneider *et al.*, 1989). Bottomland hardwood forests serve as a boundary filter between the upland and river – absorbing nutrients and collecting sediments that are transported in the groundwater. The loss of this "filter" has lead to severely degraded aquatic habitats, loaded with sediments and lacking the structural cover needed for many aquatic species (Schneider *et al.*, 1989).

Few agencies study the riparian zone. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The MDNR has information about species and ecosystems in Michigan. More information is needed on riparian zones and the effects of alteration in water quantity and movement. The water level impact of dams in specific seasons/months when juvenile plants are particularly vulnerable should be explored. Research is needed to relate seed and seedling dynamics directly to water levels at specific dam-influenced sites.

## Lowlands

### Swales

Swales are types of wetlands found exclusively along Great Lakes shorelines interspersed between the sand dunes along the beach and those further inland. Globally rare and unique freshwater dune and swale wetland types are found exclusively behind the Great Lakes shorelines. Formed thousands of years ago when runoff from receding glaciers filled low-lying areas with fresh water in the beds where the old glacial lakes once lay, these swales are fertile wetlands no longer dependent on lake-level fluctuations for maintenance (TNC, 1997). This ecologically significant habitat supports a number of plants and animals which are state or federally recognized as threatened, endangered, or of special concern, including yellow-crowned night-herons, Karner blue butterflies and Blanding's turtles.

Several agencies study the swales of the Great Lakes. The USGS has distributional data of aquatic species and their distribution within the Great Lakes - St. Lawrence River basin. The USF&WS maintains the national wetland inventory GIS database with distributional data of wetlands in the Great Lakes - St. Lawrence River basin. The USEPA has distributional data of aquatic wetland species in the Great Lakes - St. Lawrence River basin. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The ODNR has descriptions of historic and present coastal wetlands of Lakes Erie, St. Clair, Michigan and Ontario. The MNFI has GIS databases of historic vegetation, species distribution and habitat distribution for Michigan, as well as reports on wetland vegetation for the Great Lakes. Environment Canada has GIS databases of geomorphological, biological, cultural and human-use information for the Great Lakes' shorelines and a report of the wetland types along the St. Lawrence River. The OMNR also has GIS databases of wetland in the Great Lakes - St. Lawrence River basin.

These habitat are separated from the Great Lakes and do not directly depend on them for water. Groundwater withdrawal may have an affect on these wetlands. Research on how water quantity and movement influences the swales is needed.

**Prairie/Grasslands**

Much of the Great Lakes' were once part of the grasslands that extended across the heart of the continent, known as tallgrass prairie. These prairies occur from the semi-wet, lowland sites behind the coastal wetlands to the drier sites located further upland. These prairies often have seasonal flooding, with their substrate constantly saturated by groundwater, and depend on fire for regeneration and prevention of the encroachment of trees (Albert and Koss, 1998; Curtis, 1959). This rich ecosystem is made up of hundreds of species of grasses and wildlflowers commonly including sedges (*Carex* spp.), joe-pye weed (*Eupatorium maculatum*), common boneset (*E. perfoliatum*), little bluestem (*Andropogon scoparius*), big bluestem (*A. gerardii*), Indian grass (*Sorghastrum nutans*), fringed brome (*Bromus ciliatus*), blue-joint grass (*Calamagrostis canadensis*), whorled loosestrife (*Lysimachia qaudriflora*), marsh wild-timothy (*Muhlenbergia glomerata*), Virginia mountain mint (*Pycnanthemum virginianum*), black-eyed Susan (*Rudbeckia hirta*), Ohio goldenrod (*Solidago ohioensis*), and marsh fern (*Thelypteris palustris*) (Albert and Koss, 1998). These plants provide food and cover for a number of insects, reptiles, amphibians birds and mammals.

Due to their fertile soil and lack of trees, tallgrass prairies are ideal for cultivating crops, these lands were among the first to be stripped and drained for agriculture, industry, urban and suburban development. Today, they are among the rarest landscapes in North America, with only remnants existing in pockets, functioning at a fraction of their former counterparts.

NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The MNFI has GIS databases of historic vegetation, species distribution and habitat distribution for Michigan. The OMNR has a GIS distributional database for prairies.

Prairies are intricately tied to natural hydrological regimes, which need to remain intact for the prairies and the surrounding lands to preserve (Albert and Kost, 1998). To maintain the vegetative structure of the tallgrass prairie, hydrology must be protected (Albert and Koss, 1998). Agriculture and residential development alters the groundwater flow into the tallgrass prairie with drains and wells (Albert and Koss, 1998). Groundwater extraction and redirected surface water lowers the underlying groundwater which diminishes the supply of the calcareous seepage underlying tallgrass prairie communities. The aquifer recharge area must be protected through land-use planning to retain the unique hydrology of the tallgrass prairie. Shrubs are slowly inundating prairies with disrupted aquifer recharge areas (Albert and Koss, 1998).

**Oak Savanna**

At the interface of the prairie and the forest lie oak savannas. These habitats are dominated by large oak trees and abundant grasses. They are mosaic communities, with the understory vegetation resembling that of a forest under the dense shade of large oak trees and that of a prairie in the abundance of light (Curtis, 1959; Bray, 1958). To survive, they depend on seasonal flooding and a regular cycle of fire to keep woody plants in check and release nutrients from dead plant material. Fire has played a significant role in generating and maintaining savannas in the Northern Great Lakes. Bur Oak (*Quercus macrocarpa*), an important savanna tree in this region, is capable of regenerating from underground "grubs" after fire or severe drought. Frequent burning leads to fires of low intensity, which rarely kill canopy trees but maintain an open understory.

Higher intensity fires stimulate sprouting by species like Bur Oak, leading to thickets of young woody plants among the grasses (Cohen, 2001). Before European settlement in the early 1800's oak savannas extended over large portions of Minnesota, Iowa, Missouri, Illinois, Wisconsin, Michigan, Indiana and Ohio, covering over 27 million acres or 11 million hectares (Nuzzo 1996). European settlement was accompanied by widespread replacement of oak savannas by farmland or degraded through intensive livestock grazing. Cessation of fires caused a further conversion of remnant savannas to oak forests (Grimm 1984). Today, only about 0.02 percent of the original area of oak savannas remains, and many of the remnants are degraded, threatened, or atypical of presettlement savannas (Grimm 1984). Oak savannas of the Midwest are one of the world's most endangered ecosystems.

The USEPA has information on oak savanna restoration. The Natural Heritage program has information on the oak savanna recovery program. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The MNFI has a historic vegetation GIS database for all of Michigan. The OMNR has a GIS distributional database for oak savannas in the Great Lakes - St. Lawrence River basin.

More information is needed on oak savannas and their connection to water quantity.

**Wetlands**

Wetlands are areas that are permanently or periodically covered by water. There are many differing types of wetlands, including bogs, fens, kettle holes, marshes, muskegs, peatlands, vernal ponds and swamps. They are all very important habitats that, like coastal wetlands, filter contaminants and balance liquids through water storage and water access. Wetland plants are deeply rooted which helps prevent erosion, control flooding, purify water, provide food and shelter for a diversity of wildlife and essential spawning and nesting sites for hundreds of species of invertebrates, birds, fish, reptiles and amphibians. Wetlands are some of most ecologically diverse and productive ecosystems on earth. Unfortunately, many people fail to understand their economic and ecological importance. Wetlands are highly endangered ecosystems occupying only about 2 percent of the world's area, they are important carbon sinks containing about 12 percent of the world's carbon (Odum, 1989). Also, they are major sources of atmospheric methane which acts as a homeostatic regulator of the upper atmospheric ozone layer that shields us from deadly ultraviolet radiation.

Wetlands have many values associated with the hydrological cycle since they are connected with and function as a part of all our important water resources (groundwater, rivers, lakes and estuaries). Wetlands have many functions including: recharge and discharge of groundwater, floodwater conveyance and storage, shoreline and erosion protection, high primary productivity, natural cleansing of water, settling of suspended solids, sediment filtration, nitrogen and phosphorus removal and habitat for fish, wildlife and plants.

Hydrologic regimes have a major impact on species diversity. Flooding provides a means of material movement, either dissolved or suspended. Wetlands subject to sheet flow flooding tend to be quite uniform (due to uniform mixing of water and sediments). Hydrologic regimes can contribute to elevation and substrate differences and species diversity. Hydrology is deemed to be the most important factor controlling wetland structure and function. Alterations in baseflow from groundwater into a wetland are known to negatively impact a wetlands diversity.

Hydrologic changes that result from human activities, such as agriculture or flood control, often lead to a decrease in wetland area or a change in the hydrologic regime of the area that remains. Water diversions (dams, groundwater pumping, irrigation) can significantly alter the hydroperiod (water level over time) of associated wetlands and change the distribution of wetland species (Cronk and Fennessy, 2001). Groundwater depletion is a threat to many riparian wetlands (Cronk and Fennessy, 2001). The availability of shallow groundwater has been shown to structure riparian plant communities and as the distance to the groundwater increases, the abundance of herbaceous wetland plants decrease dramatically (Cronk and Fennessy, 2001).

Stream channelization projects have altered or eliminated stream-side wetlands and their plant communities (Cronk and Fennessy, 2001). Many miles of streams and rivers have been channelized in order to expedite the drainage of water from uplands, control flooding, move water away from agriculture fields or urban areas and reduce meandering. The distribution, abundance and type of wetland plants are related to timing and duration of flooding, the timing and duration of soil saturation and soil characteristics.
Plant establishment is influenced by a number of hydrologic processes (inflow rates, water depth, timing and duration of flooding and groundwater exchanges) (Cronk and Fennessy, 2001). Many wetland plant seeds and seedlings require drawdown conditions for germination and establishment (Cronk and Fennessy, 2001).

When water levels are stabilized a decrease in species diversity and species type results (Cronk and Fennessy, 2001). Different species are adapted to different hydrologic conditions. Rare plant communities are particularly vulnerable to extirpation when water level is stabilized (Cronk and Fennessy, 2001). Changing water levels are important in offering propagules the opportunity to establish, making community composition temporally viable. Human induced hydrologic change may have the following affects on wetland habitats: an increase in the number and dominance of invasive species such as cattail and purple loosestrife; decrease in species diversity; mutualistic interactions (with pollinators or mycorrhizae) may decrease; domination by a single species (i.e. monocultures); and the presence of very dense or sparse stands of vegetation (Cronk and Fennessy, 2001).

The USGS has a report on the effects of water level fluctuations on wetlands for the entire Great Lakes - St. Lawrence River basin. The USF&WS has a GIS database of wetland distribution for the entire Great Lakes - St. Lawrence River basin. The USEPA has distributional information for aquatic wetland species at risk in the Great Lakes - St. Lawrence River basin. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. Canadian and U.S. agencies have also formed a team to monitor the amphibians and birds of wetlands throughout the Great Lakes - St. Lawrence River basin. The MNFI has a historic vegetation GIS database and current species and habitat distributional databases for all of Michigan. The MNFI also has a report on the vegetative response of Michigan marshes to water-level fluctuations. The ODNR has distributional information on the historic and current wetlands of the Great Lakes - St. Lawrence River basin. The OMNR has GIS data for natural areas in the province of Ontario and a GIS database of wetlands in the Great Lakes - St. Lawrence River basin. Environment Canada has classification of wetlands along the St. Lawrence River.

Although wetland functions have been extensively studied, little research has been conducted on the cumulative effects of water withdrawals on these habitats.

**Ponds & Lakes**

Other aquatic habitats of the Great Lakes lowlands are ponds and inland lakes. Lakes and ponds are permanently wet with size as the main difference between the two. A lake is usually defined as a body of water large enough to have at least one wind-swept beach; ponds usually are not large enough for winds to blow across the water and create strong waves to wash away plants trying to take root. Often lakes are attached to each other in a chain-like pattern and exchange flow like the Fox-Wolf River and Lake Winnebago in Wisconsin. Ponds are normally smaller, shallower and the water usually has a uniform temperature. Lakes and ponds typically support a number of organisms. The warm, shoreline waters of both lakes and ponds lends to the high concentration of food (i.e., duckweed and algae). Cover is also provided by the cattails and bulrushes growing along the shores, making the lakes and ponds in the Great Lakes - St. Lawrence River region a perfect home for large numbers of ducks, geese and other waterfowl.

The deeper waters support a number of plankton, tiny organisms consisting of both zooplankton and phytoplankton. These organisms support a variety of smaller fish and invertebrate species. In turn, these consumers support higher consumers including northern pike, largemouth bass, harlequin ducks, scooters, shovelers, great blue heron, mink and many other top predators. Ponds and lakes also serve as storage areas for surface water and often reservoirs for humans providing recreational resources and drinking water.

NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The OMNR has GIS data for natural areas in the province of Ontario. TNC has a software package that allows hydrologists and ecologists to statistically characterize environmental regimes of lakes and to analyze changes in those characteristics over time. Long-term monitoring data is needed. Once collected, this data can be used with TNC software to determine the affects of water withdrawal on lakes and ponds.

**43-47 (Lowland Ecological Modeling):** The ecological impacts of cumulative water withdrawals are likely to be most significant in lowland areas immediately adjacent to inland lakes, streams, rivers and river mouths. Detailed monitoring and modeling of these areas is critically important but significantly lacking.

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

**Tasks 43-47 (Lowland Ecological Modeling):** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of hydrologic impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**43:** Modeling water levels and flow impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths are currently insufficient to support ecological impact assessments.

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

**Task 43:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating water levels and flow impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**44:** Land use modifications adjacent to lowland habitats including wetlands, inland lakes, streams, rivers and river mouths need to be discriminated from those ecological impacts caused by water withdrawal.

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

**Task 44:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating the effects of land use modifications and encroachment on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**45:** Regional sediment models are a necessary component of comprehensive ecological modeling of lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

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

**Task 45:** The USACE, in conjunction with other U.S. federal agencies and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining the effects of cumulative withdrawals on sedimentation from lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**46:** The classification of lowland habitats including wetlands, inland lakes, streams, rivers and river mouths by their hydrologic and geomorphic characteristics is dated, incomplete and inconsistent.

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

**Task 46:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard procedures for classifying lowland habitats including wetlands, inland lakes, streams, rivers and river mouths by their hydrologic and geomorphologic characteristics.

**47:** Changes in abiotic conditions in lowland habitats including wetlands, inland lakes, streams, rivers and river mouths are not comprehensively modeled to support ecological impact assessments.

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

**Task 47:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard monitoring and modeling procedures for periodically evaluating changes in abiotic conditions in lowland areas, including wetlands, inland lakes, streams, rivers and river mouths.

## Forested Uplands

The Great Lakes - St. Lawrence River ecosystem is home to four basic upland habitats: deciduous, coniferous and mixed forests and fallow fields. Deciduous forest consists of trees that loose their leaves in the fall, such as the beech (*Fagus* spp.), maple (*Acer* spp.), walnut (*Juglans* spp.), hickory (*Carya* spp.) and oak (*Quercus* spp.). Coniferous forest refers to trees that bear cones or evergreens and includes white (*Picea glauca*) and black spruce (*P. mariana*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), paper birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*). The mixed forest consists of both deciduous and coniferous tree and includes red (*Pinus resinosa*) and white pine (*P. strobus*), eastern hemlock (*Tsuga canadensis*), yellow birch (*B. alleghaniensis*), maple and oak.

Fallow fields are abandoned farm fields dominated by grasses and shrubs that will eventually become forested. These forests of the Great Lakes - St. Lawrence River region have great economic value, annually generating billions of dollars in forest products. In addition to their commercial value, forests contribute greatly to aesthetics, ecosystem biodiversity, quality of life, clean air and water and reduction of soil erosion in the region.

Both climate and soil affect the Great Lakes - St. Lawrence River region's forest communities. The deciduous forests are generally found furthest south with the mixed in the middle and coniferous found furthest north. Diverse soil types within these forest communities affect the species assemblage. For example, sandy, well-drained soils in the southern Great Lakes - St. Lawrence River region will produce red oaks, but if the soil retains a little more moisture it produces black oaks (*Quercus velutina*). These various forests provide habitat for a number of organisms including decomposers (fungi, invertebrates and protists), producers (plants and fungi) and consumers (invertebrates, mammals, birds, amphibians and reptiles). The variation in the soils, climate and tree species brings diversification of associated protists, fungi, plants and animals. Some animals such as the Kirtland's warbler (*Dendroica kirtlandii*) live solely in jack pine forests, while the white-tailed deer can be found in nearly every forest type.

Aside from ecosystem biodiversity, the Great Lakes forests also contribute greatly to the air we breathe. By taking in carbon dioxide and converting it to oxygen during photosynthesis, trees naturally remove excess carbon from the air. During photosynthesis, trees remove other chemicals from the atmosphere, such as nitrogen oxides, airborne ammonia, some sulfur dioxide and ozone that are part of the smog and greenhouse effect problems. Trees affect air quality by collecting dust and other air particles on their leaf surfaces until washed to the ground during a rainstorm. Thus, forests, and for that matter all plants, act as natural air filters. Through photosynthesis and evapotranspiration (natural plant processes) air is filtered through the tree, cleaned, cooled and released back into the atmosphere.

During early European settlement, much of the upland habitats were logged, nearly cleared of every tree. Where forests were once dominated by pines, spruce-fir-cedar and maple-basswood-birch stands of aspen and birch now exist. Not only has the composition of these forest stands been altered, but also much of this land has been fragmented, especially in the lower Great Lakes - St. Lawrence River basin. This fragmentation has made it difficult for many native, forest dwelling species to disperse, while easing the establishment of invasive species, as in the case of garlic mustard (*Alliaria petiolata*).

Forests are a crucial part of the hydrologic cycle (Gates *et al.*, 1983). The upland habitats form the main catchment area for the region, and its geology, soils and plant cover determine the basic quality of the surface and ground waters in the region. The roots of trees remove nutrients from groundwater. However, following a timber harvest runoff increases and much of the stored water is lost from the system. Clearcutting a forest will lead to increased erosion and possibly eutrophication of nearby streams.

The USDA Forest Service has two databases on plant species that include ecological and distributional information for the Great Lakes - St. Lawrence River basin. NatureServe has GIS distributional databases of habitats and species for the entire Great Lakes - St. Lawrence River basin. The MNFI has a historic vegetation GIS database and current species and habitat distributional databases for all of Michigan. The OMNR has GIS data for natural areas and a GIS database of forest resources in the province of Ontario. The Natural

Resources Research Institute has a collection of GIS databases including forest types and land cover for the Lake Superior Basin.

The effects of timber harvests on hydrology are well known; however we do not know the effects of water withdrawal on these forests. Improvements to modeling of hydrologic impacts on uplands are needed. This can be accomplished by classifying upland habitats by geomorphology, modeling upland habitat response to climatic changes, evaluating ground water withdrawal impacts and evaluating landuse modifications on upland habitats.

**48-51 (Upland Ecological Modeling):** Comprehensive modeling of uplands habitats is needed to track the ecological impacts of cumulative water withdrawals.

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

**Tasks 48-51 (Upland Ecological Modeling):** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of cumulative water withdrawal impacts on upland habitats.

**48:** Modeling of groundwater withdrawal impacts on upland habitats are currently insufficient to support impact assessments.

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

**Task 48:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the hydrologic implications of ground water withdrawal on upland habitats.

**49:** Land use modifications on upland habitats need to be discriminated from those ecological impacts caused by cumulative water withdrawal.

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

**Task 49:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the effects of land use modifications on upland habitats.

**50:** Geomorphic classification of upland habitats to support habitat modeling does not exist.

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

**50:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to comprehensively classify upland habitats by their geomorphic characteristics.

**51:** Modeling upland habitat responses to climatic change is sporadic and incomplete.

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

**Task 51:** The USGS, in collaboration with the NOAA and other U.S. federal agencies, and in cooperation with state, regional and academic institutions, needs to develop standard modeling procedures for monitoring upland habitat responses to climatic changes.

## Implementation Options – Water Withdrawal Impacts on Habitats

Tasks for improving the information base on Great Lakes - St. Lawrence River habitats are presented below. These tasks are defined within a comprehensive framework for U.S. federal involvement in the development and maintenance of an information base to support science-based decisions on water withdrawals and diversions from the Great Lakes - St. Lawrence River basin. Each task is defined at different options of implementation under the USACE plan formulation approach. This approach, in a broad sense, is being used to develop systematic alternative plans that Congress could consider for supporting the states' Great Lakes Charter Annex decisionmaking process.

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

Described below are the five implementation options:

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

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

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

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

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

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

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

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

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

### Risk and Uncertainty

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

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

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

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

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

### *Integrated Information System Tasks*

Tasks 33-51 described in this appendix present an integrated approach towards collecting and managing information on the effects of cumulative water withdrawals on sensitive habitats throughout the Great Lakes – St. Lawrence River system. It is important to see these tasks as "building blocks" for the integrated information system. Improvements under any specific task will provide incremental benefit, but the sum of the parts provides the greatest opportunity for reducing uncertainties under each implementation alternative. These tasks are repeated below to present logical interrelationships.

Tasks 33-37 (Interconnecting Waterways Ecological Modeling): U.S. federal agencies need to work collaboratively with regional, state and Canadian federal and provincial agencies, to improve modeling of potential hydrologic impacts of cumulative water withdrawals on habitats in the interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Task 33: The USGS, in cooperation with other U.S. federal agencies, Canadian federal and provincial interests, and other governmental and non-governmental institutions, needs to develop detailed models of habitat impacts in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River as a consequence of cumulative water withdrawals.

Task 34: The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to evaluate the impacts of land use modifications on adjacent habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Task 35: The USGS, in conjunction with the USACE, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to determine effects of sedimentation on habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Task 36**:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to classify habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River by their hydrologic and geomorphologic characteristics.

Task 37: The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures for evaluating abiotic changes in habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Tasks 38-42 (Nearshore Ecological Modeling): The USGS, in conjunction with other federal agencies, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard procedures for modeling hydrologic impacts on nearshore habitats of Great Lakes and shorelines.

Task 38: The USGS, in conjunction with the NOAA and the USACE, and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling tools for evaluating the hydrologic impacts of cumulative water withdrawals on nearshore habitats in the Great Lakes and their embayments.

Task 39: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for repetitive evaluations of the impacts of land use modifications on nearshore habitats.

Task 40: The USGS, in conjunction with the USACE, and in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining effects of sedimentation changes on nearshore habitat.

Task 41: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to classify nearshore habitats by their hydrologic and geomorphic characteristics.

Task 42: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating abiotic changes in nearshore habitats.

Tasks 43-47 (Lowland Ecological Modeling): The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of hydrologic impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

Task 43: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating water levels and flow impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

Task 44**:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating the effects of land use modifications on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

Task 45: The USACE, in conjunction with other U.S. federal agencies and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining the effects of cumulative water withdrawal on sedimentation from lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

Task 46: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard procedures for classifying lowland habitats including wetlands, inland lakes, streams, rivers and river mouths by their hydrologic and geomorphologic characteristics.

Task 47: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard monitoring and modeling procedures for periodically evaluating changes in abiotic conditions in lowland areas, including wetlands, inland lakes, streams, rivers and river mouths.

Tasks 48-51 (Upland Ecological Modeling): The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of cumulative water withdrawal impacts on upland habitats.

Task 48**:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the hydrologic implications of ground water withdrawal on upland habitats.

Task 49: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the effects of land use modifications on upland habitats.

Task 50: The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to comprehensively classify upland habitats by their geomorphic characteristics.

Task 51: The USGS, in collaboration with the NOAA and other U.S. federal agencies, and in cooperation with state, regional and academic institutions, needs to develop standard modeling procedures for monitoring upland habitat responses to climatic changes.

### *Implementation Mechanisms and Costs*

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

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**Tasks 33-37 (Interconnecting Waterways Ecological Modeling):** U.S. federal agencies need to work collaboratively with regional, state and Canadian federal and provincial agencies, to improve modeling of potential hydrologic impacts of cumulative water withdrawals on habitats in the interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**Without Plan** (33-37) – Significant work is underway to model water levels and flow impacts on habitats within the St. Lawrence River and other site specific locations in the Great Lakes interconnecting waterways. Future work will build on current investments but still will be lacking in spatial and temporal consistency.

**Minimum Investment** (33-37) – Develop prototype hydrologic impact models for the Detroit and St. Clair Rivers. Classify habitats by hydrology and geomorphology on all interconnecting waterways

**Selective Implementation** (33-37) – Initiate comprehensive habitat modeling on the St. Clair and Detroit River systems, taking advantage of additional data collection of abiotic parameters at existing water level gauges and buoys on Lake St. Clair, sedimentation studies and geomorphic classifications.

**Enhanced Implementation** (33-37) – Complete comprehensive habitat modeling for St. Marys, Detroit and St. Clair Rivers and Lake St. Clair, taking advantage of additional abiotic data collected at existing water level gauges and buoys, sedimentation studies, and geomorphic classifications.

**Full Implementation** (33-37) – Complete comprehensive habitat modeling for all Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River, taking advantage of additional data on abiotic parameters, sedimentation studies and geomorphic classifications.

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**Task 33:** The USGS, in cooperation with other U.S. federal agencies, Canadian federal and provincial interests, and other governmental and non-governmental institutions, needs to develop detailed models of habitat impacts in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River as a consequence of cumulative water withdrawals.

**Without Plan** (33) – Currently water levels are adequately measured in all of the interconnecting waterways, Lake St. Clair and the St. Lawrence River. In-place flow meters have been deployed in the Detroit and St. Clair Rivers for research studies. One research buoy has been deployed in Lake St. Clair but is not a permanent fixture. Circulation modeling is based upon hydrodynamic models currently under initial development. Operational utilization is hampered by lack of funding and low priority. No comprehensive habitat impact models exist that incorporate these interrelated pieces.

**Minimum Investment** (33) – Develop and implement a prototype habitat impact model for the Detroit and St. Clair rivers and Lake St. Clair, which fully utilizes existing hydrodynamic modeling, improved flow monitoring, water level gauging and buoy observations at a cost of $500 K over two years.

**Selective Implementation** (33) – Implement and maintain a continuous habitat impact models for each of the Great Lakes interconnecting waterways, the St. Lawrence River and Lake St. Clair which rely upon imbedded hydrodynamic models and upgraded flow monitoring, water level gauging and buoy observations at a cost of $10 M over 10 years.

**Enhanced Implementation** (33) – Implement and maintain a continuous habitat impact models for each of the Great Lakes interconnecting waterways, the St. Lawrence River and

Lake St. Clair which rely upon imbedded hydrodynamic models and upgraded flow monitoring, water level gauging and buoy observations at a cost of $10 M over 10 years.

**Full Implementation** (33) – Implement and maintain a continuous habitat impact models for each of the Great Lakes interconnecting waterways, the St. Lawrence River and Lake St. Clair which rely upon imbedded hydrodynamic models and upgraded flow monitoring, water level gauging and buoy observations at a cost of $10 M over 10 years.

**Footnotes** (33) – Refer to Appendix D on the hydrology and meteorology of the open lake for tasks on the expansion of the water level gauge and buoy networks.

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**Task 34:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to evaluate the impacts of land use modifications on adjacent habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**Without Plan** (34) – Land use and cover maps are complete although inconsistent, dated, coarse in detail and lack information on temporal changes. Situation is likely not to change.

**Minimum Investment** (34) – No additional investment considered.

**Selective Implementation** (34) – Conduct land use impact assessments on habitats adjacent to all U.S. Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River utilizing new comprehensive land use and cover mapping at a cost of $2 M over two years.

**Enhanced Implementation** (34) – Conduct land use impact assessments on habitats adjacent to all U.S. Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River utilizing new comprehensive land use and cover mapping at a cost of $2 M over two years.

**Full Implementation** (34) – Conduct land use impact assessments on habitats adjacent to all U.S. Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River utilizing new comprehensive land use and cover mapping at a cost of $2 M over two years.

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**Task 35:** The USGS, in conjunction with the USACE, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures to determine effects of sedimentation on habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**Without Plan** (35) – Sediment transport modeling exists at very few locations and is frequently out-dated. Future work will likely be only site specific.

**Minimum Investment** (35) – No additional investment considered.

**Selective Implementation** (35) – Conduct studies on the ecological impacts of sedimentation in the deltas of the Detroit and St. Clair Rivers costing $1 M over three years.

**Enhanced Implementation** (35) – Conduct studies on the ecological impacts of sedimentation in the St. Marys, St. Clair and Detroit Rivers and Lake St. Clair costing $10 M over ten years.

**Full Implementation** (35) – Conduct studies on the ecological impacts of sedimentation in all of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River costing $15 M over ten years.

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**Task 36:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to classify habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River by their hydrologic and geomorphologic characteristics.

**Without Plan** (36) – Habitats are not universally classified for each of the interconnecting waterways Lake St. Clair and the St. Lawrence River for geomorphology and hydrology.

**Minimum Investment** (36) – Classify habitat by hydrology and geomorphology for of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River at a cost of $250 K over two years.

**Selective Implementation** (36) – Classify habitat by hydrology and geomorphology for of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River at a cost of $250 K over two years.

**Enhanced Implementation** (36) – Classify habitat by hydrology and geomorphology for of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River at a cost of $250 K over two years.

**Full Implementation** (36) – Classify habitat by hydrology and geomorphology for of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River at a cost of $250 K over two years.

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**Task 37:** The USGS, in cooperation with other federal agencies, state and provincial authorities and regional academic institutions, needs to develop standard modeling procedures for evaluating abiotic changes in habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

**Without Plan** (37) – Current information base is sporadic and incomplete. Situation is likely not to change.

**Minimum Investment** (37) – No additional investment considered.

**Selective Implementation** (37) – Develop and implement standard modeling procedures for evaluating abiotic changes in the Detroit River, St. Clair River and Lake St. Clair, utilizing upgraded collection at water level gauging stations and buoys, at a cost of $1.5 M over two years.

**Enhanced Implementation** (37) – Develop and implement standard modeling procedures for evaluating abiotic changes in the Great Lakes interconnecting waterways, the St. Lawrence River and Lake St. Clair, utilizing upgraded collection at water level gauging stations and buoys, at a cost of $3 M over three years.

**Full Implementation** (37) – Develop and implement standard modeling procedures for evaluating abiotic changes in the Great Lakes interconnecting waterways, the St. Lawrence River and Lake St. Clair, utilizing upgraded collection at water level gauging stations and buoys, at a cost of $3 M over three years.

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**Tasks 38-42 (Nearshore Ecological Modeling):** The USGS, in conjunction with other federal agencies, and in cooperation with state and provincial authorities and regional academic institutions, needs to develop standard procedures for modeling hydrologic impacts on nearshore habitats of Great Lakes and shorelines.

**Without Plan** (38-42) – Significant work is underway to model water levels and flow impacts on portions of the Great Lakes shorelines, including the IJC Lake Ontario - St. Lawrence River Study and other site specific project areas. Future work will likely not be comprehensive or spatially and temporally consistent.

**Minimum Investment** (38-42) – Develop a pilot continuous circulation models and land use impact studies for Lake Michigan. Also, classify the geomorphic characteristics of nearshore habitats for all the Great Lakes excluding embayments.

**Selective Implementation** (38-42) – Develop continuous circulation models, conduct land use impact studies and classify geomorphic characteristics of nearshore habitats for all the Great Lakes excluding embayments. Also, conduct sediment transport studies for the nearshore of lakes Erie and Ontario and evaluate abiotic changes for pilot nearshore habitats along the U.S. Great Lakes.

**Enhanced Implementation** (38-42) – Develop continuous circulation models, conduct land use impact studies and classify geomorphic characteristics of nearshore habitat for all the Great Lakes including embayments. Also, conduct sediment transport studies for the nearshore of all the Great Lakes excluding embayments and evaluate abiotic changes for pilot nearshore areas along the U.S. Great Lakes nearshore.

**Full Implementation** (38-42) – Develop continuous circulation models, conduct land use impact studies, conduct sediment transport studies, evaluate abiotic changes and classify nearshore habitat for all the Great Lakes including embayments.

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**Task 38:** The USGS, in conjunction with the NOAA and the USACE, and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling tools for evaluating the hydrologic impacts of cumulative water withdrawals on nearshore habitats in the Great Lakes and their embayments.

**Without Plan** (38) – Currently most shorelines have adequate water level gauging; embayments may be lacking. Existing buoy network provides adequate coverage for marine forecasting but not for habitat modeling. Satellite monitoring of surface temperatures and upwelling events is sporadic. Circulation modeling is coarse and not continuous. Future data collection and modeling will likely be conducted piecemeal.

**Minimum Investment** (38) – Contingent upon expansion of the buoy network and improvements in satellite observations, implement an operational hydrodynamic model for Lake Michigan, excluding its embayments, with the capacity to monitor changes in nearshore circulation patterns, at a cost of $500 K over two years.

**Selective Implementation** (38) – Contingent upon expansion of the buoy network and improvements in satellite observations, develop operational continuous hydrodynamic models for all of the Great Lakes excluding embayments to monitor changes in nearshore circulation at a cost of $2.2 M over 10 years.

**Enhanced Implementation** (38) – Contingent upon expansion of the buoy network and improvements in satellite observations, develop operational continuous hydrodynamic models for all of the Great Lakes including embayments to monitor changes in nearshore circulation at a cost of $3.2 M over 10 years.

**Full Implementation** (38) – Contingent upon expansion of the buoy network and improvements in satellite observations, develop operational continuous hydrodynamic models for all of the Great Lakes including embayments to monitor changes in nearshore circulation costing $3.2 M over 10 years.

**Footnotes** (38) – Refer to Appendix D on the hydrology and meteorology of the open lake for tasks on the expansion of the water level gauge and buoy networks.

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**Task 39:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for repetitive evaluations of the impacts of land use modifications on nearshore habitats.

**Without Plan** (39) – Land use and cover mapping is complete but coarse and resolution, inconsistent between states and frequently out-dated, providing little utility for discriminating local impacts from cumulative water withdrawal impacts. This situation is not likely to change without additional investment.

**Minimum Investment** (39) – Contingent upon acquiring new detailed land use and cover mapping, conduct pilot habitat impact studies on Lake Michigan shorelines excluding embayments costing $200 K over one year.

**Selective Implementation** (39) – Contingent upon acquiring new detailed land use and cover mapping, conduct habitat impact studies on all U.S. Great Lakes' shorelines excluding embayments costing $2 M over two years.

**Enhanced Implementation** (39) – Contingent upon acquiring new detailed land use and cover mapping, conduct habitat impact studies on all U.S. Great Lakes' shorelines including embayments costing $6 M over four years.

**Full Implementation** (39) – Contingent upon acquiring new detailed land use and cover mapping, conduct habitat impact studies on all U.S. Great Lakes shorelines including embayments costing $6 M over four years.

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**Task 40:** The USGS, in conjunction with the USACE, and in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining effects of sedimentation changes on nearshore habitat.

**Without Plan** (40) – Sediment transport modeling exists at few site specific locations. Future work will expand to regional modeling, but still will not be comprehensive.

**Minimum Investment** (40) – No additional investment considered.

**Selective Implementation** (40) – Develop a prototype sediment transport studies over pilot regional areas on Lakes Erie and Ontario costing $2 M over three years.

**Enhanced Implementation** (40) – Conduct sediment transport studies over all Great Lakes shorelines excluding embayments costing $10 M over five years.

**Full Implementation** (40) – Conduct sediment transport studies over all Great Lakes shorelines including embayments costing $20 M over five years.

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**Task 41:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to classify nearshore habitats by their hydrologic and geomorphic characteristics.

**Without Plan** (41) – The U.S. Great Lakes' shorelines have been classified by their geomorphic characteristics for erosion modeling applications. However, classifications based upon prevailing hydrology and geomorphology do not exist. No development is anticipated under existing programs and funding.

**Minimum Investment** (41) – Classify habitat by hydrology and geomorphology for all U.S. Great Lakes excluding embayments at a cost of $250 K over two years.

**Selective Implementation** (41) – Classify habitat by hydrology and geomorphology for all U.S. Great Lakes excluding embayments at a cost of $250 K over two years.

**Enhanced Implementation** (41) – Classify habitat by hydrology and geomorphology for all U.S. Great Lakes including embayments at a cost of $600 K over three years.

**Full Implementation** (41) – Classify habitat by hydrology and geomorphology for all U.S. Great Lakes including embayments at a cost of $600 K over three years.

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**Task 42:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating abiotic changes in nearshore habitats.

**Without Plan** (42) – The current information base on abiotic conditions in the nearshore is sporadic and incomplete. This situation is likely not to change.

**Minimum Investment** (42) – No additional investment is considered.

**Selective Implementation** (42) – Contingent upon the collection of abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauges and the expansion and upgrades to the buoy network, conduct pilot studies on abiotic conditions at selected nearshore locations in the U.S. at cost of $1.5 M over two years.

**Enhanced Implementation** (42) – Contingent upon the collection of abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauges and the expansion and upgrades to the buoy network, conduct pilot studies on abiotic conditions at selected nearshore locations in the U.S. at cost of $1.5 M over two years.

**Full Implementation** (42) – Contingent upon expansion of water level and open lake buoy networks, develop and maintain continual monitoring of abiotic conditions in all U.S. nearshore habitats at a cost of $ 3 M over ten years.

**Footnotes** (42) – Refer to Appendix D on the hydrology and meteorology of the open lake for tasks on the expansion of the water level gauge and buoy networks.

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**Tasks 43-47 (Lowland Ecological Modeling):** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of hydrologic impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**Without Plan** (43-47)
Generic models of hydrologic impacts on wetlands exist. However, hydrologic models for other lowland habitats are sporadic and inconsistent across the region. Some improvements will be expected over time, but the accuracies of these models will still be limited by the paucity of observations needed to assess cumulative water withdrawal impacts.

**Minimum Investment** (43-47)
Conduct pilot hydrologic impact studies on Tier I priority tributaries for U.S. lowland habitats, relying upon existing data with modest improvements to the National Wetlands Inventory database.

**Selective Implementation** (43-47) – Complete comprehensive habitat modeling for selective Tier 1 priority U.S. Great Lakes watersheds with emphasis on monitoring cumulative water withdrawal impacts and predicting future changes within these domains. This modeling is contingent improvements being made in expansion of the existing water level gauging network, upgraded collection of abiotic parameters, completion of detailed studies on land use encroachment impacts and sedimentation, and completion of geomorphic classification of land characteristics.

**Enhanced Implementation** (43-47) – Complete comprehensive habitat modeling for all Tier 1 priority U.S. Great Lakes watersheds with emphasis on monitoring cumulative water withdrawal impacts and predicting future changes. This modeling is contingent upon the following tasks being completed in these watersheds: substantial expansion of the existing water level gauging network; collection of abiotic parameters at all locations; completion of detailed land use encroachment studies; completion of comprehensive sedimentation studies; and, completion of geomorphic classification of surface characteristics, and encoding of stream attributes.

**Full Implementation** (43-47) – Complete comprehensive habitat modeling for all U.S. Great Lakes lowland habitats with emphasis on monitoring cumulative water withdrawal impacts and predicting future changes. This modeling is contingent upon the following: substantial expansion of the existing water level gauging network; collection of abiotic parameters at all locations; completion of detailed land use encroachment studies; completion of comprehensive sedimentation studies; and, completion of geomorphic classification of surface characteristics, and encoding of stream attributes.

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**Task 43:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating water levels and flow impacts on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**Without Plan** (43) – Currently 60 percent of the Great Lakes drainage basin is gauged. Without additional gauging, information is insufficient to evaluate cumulative water level impacts either historically or in a predictive mode.

**Minimum Investment** (43) – Conduct pilot studies on monitoring and predicting cumulative water withdrawals on the hydrology of tier 1 priority* tributaries in U.S. lowland habitats at a cost of $1 M over two years.

**Selective Implementation** (43) – Conduct pilot studies on monitoring and predicting cumulative water withdrawals on the hydrology for selective tier 1 priority* tributaries in U.S. lowland habitats at a cost of $1 M over two years.

**Enhanced Implementation** (43) – Contingent upon upgrading and expanding the current stream gauging network, develop and implement hydrologic models for all tier 1 priority tributaries at a cost of $3 M over five years.

**Full Implementation** (43) – Contingent upon upgrading and expanding the stream gauging network to provide comprehensive coverage of all the U.S. watersheds, develop and implement hydrologic models for all tier 1 and tier 2 priority tributaries at a cost of $5 M over five years.

**Footnotes** (43)* - A process to identified priority tributaries may involve input from state and local agencies. Tributaries identified as most critical are tier 1. Tier 2 and 3 correspond to tributaries in decreasing priority.

**Task 44:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for periodically evaluating the effects of land use modifications on lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**Without Plan** (44) – Land use and cover maps are inconsistent, dated and do not provide information on temporal changes or high definition. This situation is not likely to change without additional investment.

**Minimum Investment** (44) – No additional investment considered.

**Selective Implementation** (44) – Contingent upon new detailed land use and cover mapping, evaluate past anthropogenic impacts on lowland habitats and develop prediction approaches for pilot areas adjacent to tier 1* priority tributaries in U.S. lowland habitats costing $2 M over 2 years.

**Enhanced Implementation** (44) – Contingent upon new detailed land use and cover mapping, evaluate past anthropogenic impacts on lowland habitats and develop prediction approaches for all areas adjacent to tier I priority* tributaries costing $10 M over 5 years.

**Full Implementation** (44) – Contingent upon new detailed land use and cover mapping of all inland land masses within the U.S. Great Lakes - St. Lawrence River basin, evaluate past anthropogenic impacts on lowland habitats and develop prediction approaches for all lowland areas costing $50 M over 10 years.

**Footnotes** (44)* - A process to identified priority tributaries may involve input from state and local agencies. Tributaries identified as most critical are tier I. Tier 2 and 3 correspond to tributaries in decreasing priority

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**Task 45:** The USACE, in conjunction with other U.S. federal agencies, and in cooperation with state agencies and regional academic institutions, needs to develop and implement standard modeling procedures for determining the effects of cumulative withdrawals on sedimentation from lowland habitats including wetlands, inland lakes, streams, rivers and river mouths.

**Without Plan** (45) – Sediment transport models are completed or in progress for 12-15 tributaries within the 99 U.S. watersheds under the 516(e) program of WRDA 1999. Work under this program does not address the full extent of the watersheds but rather focuses on significant sub-basin areas. Future work may expand to other eligible watersheds, budget permitting.

**Minimum Investment** (45) – No additional investment considered.

**Selective Implementation** (45) – Increase funding for the 516(e) program to $25 M over 10 years and focus the attention to modeling all of the tier I priority tributaries identified by the Great Lake states.

**Enhanced Implementation** (45) – Increase funding to the 516(e) program to $50 M over 10 years and complete modeling for all of the tier I priority tributaries identified by the Great Lake states.

**Full Implementation** (45) – Model all 99 U.S. watersheds, on a prioritized basis, including all segments in a 2-D frame at a cost of $150 M over 10 years.

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**Task 46:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard procedures for classifying lowland habitats including wetlands, inland lakes, streams, rivers and river mouths by their hydrologic and geomorphologic characteristics.

**Without Plan** (46) – Considerable work has been completed or is underway under the National Hydrologic Database (NHD), the National Wetlands Inventory (NWI) and state funded habitat mapping projects to support this requirement. This work, however, is incomplete, outdated or inconsistent, compromising the quality of the analysis. It is likely that these problems will not be resolved without additional investment.

**Minimum Investment** (46) – Update and improve NWI products to acceptable uniform standards and classify lowland habitats by hydrology and geomorphology for the U.S. Great Lakes - St. Lawrence River basin at an estimated cost of $1 M over two years.

**Selective Implementation** (46) – Increased federal funding is necessary to complete all NHD work at a high spatial resolution and to update and improve NWI products to acceptable uniform standards. Additional work to classify the hydrology and geomorphology is also required. Costs are estimated at $12 M over 10 years.

**Enhanced Implementation** (46) – Increased federal funding is necessary to complete all NHD work at a high spatial resolution and to update and improve NWI products to acceptable uniform standards. Additional work to classify the hydrology and geomorphology is also required. Costs are estimated at $12 M over 10 years.

**Full Implementation** (46) – Increased federal funding is necessary to complete all NHD work at a high spatial resolution and to update and improve NWI products to acceptable uniform standards. Additional work to classify the hydrology and geomorphology is also required. Costs are estimated at $12 M over 10 years.

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**Task 47:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard monitoring and modeling procedures for periodically evaluating changes in abiotic conditions in lowland areas, including wetlands, inland lakes, streams, rivers and river mouths.

**Without Plan** (47) – The current information base on abiotic conditions in lowland areas of the system is sporadic and incomplete. This situation is not likely to change without additional investment.

**Minimum Investment** (47) – No additional investment considered.

**Selective Implementation** (47) – Develop and implement standard monitoring and modeling procedures for periodically evaluating changes in abiotic conditions including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing U.S. stream gauging stations on tier I priority tributaries at a cost of $6 M over 10 years.

**Enhanced Implementation** (47) – Contingent upon expansion of water level network to cover the majority of the U.S. Great Lakes watersheds and upgrading of these stations to include abiotic sensors, develop and implement standard monitoring and modeling procedures for evaluating abiotic changes for all tier I and tier II priority tributaries at a cost of $13 M over years.

**Full Implementation** (47) – Contingent upon expansion of the water level network to directly measure streamflow for all U.S. Great Lakes watersheds and the addition of abiotic sensors to all stations, develop and implement periodic monitoring of abiotic changes for all tributaries at a cost of $20 M over years.

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**Tasks 48-51(Upland Ecological Modeling):** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to improve modeling of cumulative water withdrawal impacts on upland habitats.

**Without Plan** (48-51) – Upland habitats have not been classified by geomorphology, and therefore modeling of hydrologic impacts on uplands does not exist. Future condition is likely not to improve without additional investment.

**Minimum Investment** (48-51) – Classify upland habitats by geomorphology, conduct pilot ground water withdrawal impact studies.

**Selective Implementation** (48-51) – Classify upland habitats by geomorphology, conduct pilot ground water withdrawal impact studies and land use encroachment studies for representative upland habitat within the U.S. Great Lakes - St. Lawrence River basin. Also, develop prototype predictive models on upland habitat response to climate change.

**Enhanced Implementation** (48-51) – Classify upland habitats by geomorphology, conduct pilot ground water withdrawal impact studies and land use encroachment studies for representative upland habitat within the U.S. Great Lakes - St. Lawrence River basin. Also, develop prototype predictive models on upland habitat response to climate change.

**Full Implementation** (48-51) – Classify upland habitats by geomorphology, generate prediction tools on habitat impacts from ground water withdrawals and conduct landuse encroachment studies for all upland habitats within the U.S. Great Lakes - St. Lawrence River basin. Also, develop and apply predictive models on upland habitat response to climate change.

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**Task 48:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the hydrologic implications of ground water withdrawal on upland habitats.

**Without Plan** (48) – Currently there is little information available on ground water withdrawal impacts on upland habitats. The future condition is not likely to change without additional investment.

**Minimum Investment** (48) – Contingent upon completing the classification of upland habitat by geomorphic characteristics, conduct pilot ground water withdrawal impact studies on representative habitats costing $500 K over two years.

**Selective Implementation** (48) – Contingent upon completing the classification of upland habitat by geomorphic characteristics, conduct pilot ground water withdrawal impact studies on representative habitats costing $500 K over two years.

**Enhanced Implementation** (48) – Contingent upon completing the classification of upland habitat by geomorphic characteristics and completion of new detailed land use and cover mapping, conduct pilot ground water withdrawal impact studies on representative habitats costing $500 K over two years.

**Full Implementation** (48) – Contingent upon completing the classification of upland habitat by geomorphic characteristics and completion of new detailed land use and cover mapping, generate prediction tools on habitat impacts from ground water withdrawals for all upland areas within the U.S. Great Lakes - St. Lawrence River basin costing $2.5 M over three years.

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**Task 49:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to develop standard modeling procedures for periodically evaluating the effects of land use modifications on upland habitats.

**Without Plan** (49) – Land use and cover maps are inconsistent, dated and do not provide information on temporal changes or high definition. This situation is not likely to change without additional investment.

**Minimum Investment** (49) – No additional investment considered.

**Selective Implementation** (49) – Contingent upon the completion of the classification of upland habitat by geomorphic characteristics and development of new detailed land use and cover maps, conduct land use encroachment studies on representative upland habitats within the U.S. Great Lakes - St. Lawrence River basin costing $1 M over two years.

**Enhanced Implementation** (49) – Contingent upon the completion of the classification of upland habitat by geomorphic characteristics and development of new detailed land use and cover maps, conduct land use encroachment studies on representative upland habitats within the U.S. Great Lakes - St. Lawrence River basin costing $1 M over two years.

**Full Implementation** (49) – Contingent upon the completion of the geomorphic classifications and development of new detailed land use and cover mapping, conduct land use encroachment studies on all upland habitats within the U.S. Great Lakes - St. Lawrence River basin costing $3 M over three years.

**Task 50:** The USGS, in cooperation with other U.S. federal agencies, state agencies and regional academic institutions, needs to comprehensively classify upland habitats by their geomorphic characteristics.

**Without Plan** (50) – Considerable work has been completed by the NRCS to map soils in high detail and by the USGS to map stratigraphy in coarser detail. Much of the NRCS soil maps still need to be digitized. Situation is likely to improve albeit slowly. However, upland habitats have not been classified by geomorphology for use in a decision support framework and this work is unfunded.

**Minimum Investment** (50) – No additional investment considered.

**Selective Implementation** (50) – Using existing digital soils and stratigraphy information, classify habitats by geomorphology for all areas where these data are available within the U.S. Great Lakes - St. Lawrence River basin at a cost of $250 K over two years.

**Enhanced Implementation** (50) – Contingent upon digital soils and stratigraphy information being fully completed, classify habitats by geomorphology for all areas within the U.S. Great Lakes - St. Lawrence River basin at a cost of $500 K over two years.

**Full Implementation** (50) – Contingent upon digital soils and stratigraphy information being fully completed, classify habitats by geomorphology for all areas within the U.S. Great Lakes - St. Lawrence River basin at a cost of $500 K over two years.

**Task 51:** The USGS, in collaboration with the NOAA and other U.S. federal agencies, and in cooperation with state, regional and academic institutions, needs to develop standard modeling procedures for monitoring upland habitat responses to climatic changes.

**Without Plan** (51) – The current information base on upland habitat responses to climate change is sparse. This situation is not likely to change without additional investment.

**Minimum Investment** (51) – No additional investment considered.

**Selective Implementation** (51) – Contingent upon completing the geomorphic classification of upland habitats, develop prototype predictive models on upland habitat response to climate change costing $1 M over two years.

**Enhanced Implementation** (51) – Contingent upon completing the geomorphic classification of upland habitats, develop prototype predictive models on upland habitat response to climate change costing $1 M over two years.

**Full Implementation** (51) – Contingent upon classifying upland habitats by their geomorphic characteristics, develop and apply predictive models for all upland habitats within the system in response to climate change costing $3 M over three years.

### *Total Costs Over 10 Years*

**Without Plan** (TOTAL) – $0 M

**Minimum Investment** (TOTAL) – $4.2 M

**Selective Implementation** (TOTAL) – $71.5 M

**Enhanced Implementation** (TOTAL) – $137.6 M

**Full Implementation** (TOTAL) – $307.0 M

## Habitat Data and Information Inventory

Presented below is the inventory of data and information holdings related to the habitats of the Great Lakes - St. Lawrence River basin. The inventory does not contain all available information on habitat types in the Great Lakes - St. Lawrence River basin, especially information generated from private industries and small academic projects. Rather, this inventory focuses on information and data holdings of federal agencies and regional conservation initiatives.

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