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HURON-ERIE CORRIDOR SYSTEM HABITAT ASSESSMENT – CHANGING WATER LEVELS AND EFFECTS OF GLOBAL CLIMATE CHANGE

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The interpretations, conclusions and recommendations presented herein represent the opinions of the report writers, who are solely responsible for any omissions or misinterpretations of the data.

HURON-ERIE CORRIDOR SYSTEM HABITAT ASSESSMENT – CHANGING WATER LEVELS AND EFFECTS OF GLOBAL CLIMATE CHANGE

EXECUTIVE SUMMARY

This project, funded by the Great Lakes Fishery Commission through the USFWS Restoration Act and sponsored by the Michigan Department of Natural Resources, established a framework and designed a process to systematically identify, coordinate, and implement binational aquatic and fish habitat restoration opportunities in the Lake Huron to Lake Erie Corridor (Huron-Erie Corridor, HEC) within a context of long-term water-level regime changes resulting from direct anthropogenic hydromodification and/or potential effects of global climate change.

In 2005, the University of Windsor and the Ohio State University hosted three Lake Erie Millennium Network (LEMN) research needs workshops to provide guidance on current and future research needs and to develop a long-term strategy to identify and assess high-quality aquatic and fish habitats within the HEC. These experts' workshops brought together fishery biologists, aquatic ecologists, physical scientists (geologists, hydrologists), and resource managers to: 1) assess the adequacy of existing physical and biological datasets within the HEC system, identify gaps, and prioritize additional habitat research/data collection needs (Workshop 3.01); 2) explore issues associated with developing and validating robust physical and ecological models to predict current and future locations of critical aquatic and fishery habitats within the HEC system (Workshop 3.02); and 3) examine how existing data and models could be applied to a range of "transitional habitat" issues, including refinement of conceptual models of habitat succession associated with anticipated changing water-level regimes within the HEC (Workshop 3.03).

The project team developed an approach that is based on the fundamental assumption that native fish and aquatic communities have co-evolved and adapted to the physical characteristics of the system - including the distribution, pattern, and function of aquatic habitats and the timing and seasonality of the dynamic processes that create and maintain those habitats. Thus, restorative actions that shift HEC physical characteristics and processes back toward a more "natural state" will be sustainable and will benefit native fish and aquatic communities. Three major environmental zones were identified based on physical and hydrogeomorphic characteristics: the connecting channels and adjacent riparian areas of the Detroit and St. Clair rivers; the St. Clair Delta and adjacent wetland complexes; and nearshore, coastal margin, and open-water areas of Lake St. Clair.

A summary list of existing datasets and publications was compiled and is available on the LEMN web-site at http://www.lemn.org. Workshop participants also identified critical data collection and research needs, including: 1) high-resolution bathymetry and substrate distribution data in nearshore/coastal margin areas of Lake St. Clair; 2) daily and seasonal flow, circulation, and temperature distribution patterns in the connecting channels and Lake St. Clair; 3) the location, distribution, and stability of contaminated sediments; 4) seasonal data on nutrient and contaminant loadings; and 5) the need to model hydrodynamic and ecological processes throughout the entire Huron-Erie corridor. This information is critically needed to identify and map environmental characteristics that define and influence spawning and nursery habitats; the distribution of seasonal larval, YOY, and adult fish; the distribution of benthic invertebrate and aquatic macrophyte communities; and critical habitat for endangered or species-at-risk.

Climate-change models predict up to a 1-meter drop in Lake St. Clair water levels within the next 50 years. Reductions in connecting channel flows and a 1-meter drop in lake level will directly influence critical shallow-water aquatic and fish spawning and nursery habitats. For example, a 1-meter drop in lake level will shift the shoreline lakeward by up to 4 to 6 km in the St. Clair Delta area. The environmental effects of these flow and water-level regime changes

will be significant, but suitable models do not currently exist to predict potential changes in habitat distribution. To address this issue, workshop participants concluded that the most effective and economical approach is to develop an integrated 3-D hydrodynamic model that predicts flow and water levels in the HEC *as a single hydrodynamic system* rather than attempting to integrate existing models into a single modeling package. Participants also recognized the need to concurrently develop integrated ecological models for each of the three major environmental zones designed to predict changes in habitat distribution and response of vegetative and fish/benthic communities to altered flows and water-level regimes.

Based on the results of the three LEMN Research Needs Workshops, a long-term research strategy was developed that is designed to systematically 1) compare the historic distribution, pattern, and function of high-quality aquatic and fishery habitats with the current distribution of those habitats in order to assess habitat alteration and the stressors that cause those alterations; 2) develop physical and ecological models that can simulate habitat impacts resulting from potential long-term changes in water-level regime, assess the potential degree of habitat alteration, and identify potential long-term management, protection, and restoration opportunities based on historical habitat distribution, pattern, and function; and 3) provide the tools and build the capacity of key agencies, organizations, and institutions to identify and implement protection, restoration, and enhancement opportunities based on sound science as part of a long-term, binational fishery and aquatic habitat research and monitoring effort within the HEC system. As part of this strategy, six major research needs and/or actions were identified:

1) Develop an inventory of current and historical HEC datasets and publications. Identify critical data gaps and work to fill those data gaps.
2) Document the current and pre-disturbance distribution, pattern, and function of habitats within the three major HEC environmental zones using available contemporary and historical datasets.
3) Identify significant historical actions or stressors that have resulted in HEC habitat impairments.
4) Develop and apply integrated 1-D, 2-D, and 3-D hydrodynamic and ecological modeling tools to predict current, historical, and future distribution, pattern, and function of habitats for varying water-level regimes for the three major HEC environmental zones within the HEC system.
5) Establish restoration/rehabilitation targets and goals based on knowledge gained from historical comparison to current conditions.
6) Identify potential habitat restoration/rehabilitation opportunities based on qualitative and quantitative assessments of habitat distribution, pattern, and function. Establish a long-term habitat monitoring program tied to performance indicators.

These research needs/actions can be implemented by supporting ongoing efforts to assess historical and current habitat patterns and functions within the HEC by the USGS Great Lakes Science Center, Michigan DNR, Ontario MNR, and Fisheries and Oceans Canada. Ongoing efforts by the Great Lakes Regional Collaboration, NOAA, USGS, USACE, Environment Canada, and the Great Lakes Commission to develop a fully integrated 3 D hydrodynamic model for the HEC should also be supported. Given the size and complexity of the HEC, an international effort is required to implement comprehensive monitoring programs and to provide technical support and guidance to key agencies, organizations, and institutions to identify and *implement* aquatic habitat restoration opportunities at multiple scales within the HEC.

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OVERVIEW

The Lake Huron - Lake Erie Corridor system (HEC) consists of the waters and adjacent lands encompassed by the St. Clair River, the St. Clair Delta, Lake St. Clair, the Detroit River, and the western basin of Lake Erie (Figure 1). This region contains a diverse range of aquatic habitats associated with coastal wetland, riverine, deltaic, and shallow nearshore and open-lake environments including critical spawning, nursery, and forage habitats for multiple fish species. The HEC is highly productive and in 2001, accounted for 34% of Michigan's sport fish harvest and 43% of Michigan's total Great Lakes fishing effort (G. Towns, MDNR Fisheries Division). In 2001, approximately 23 hours of fishing effort per acre were expended within the HEC, which is 4 to 5 times higher than any of the five Great Lakes.

Natural lands and waters within the HEC are particularly at risk to degradation as a consequence of both terrestrial and aquatic stressors. Urban and agricultural pressures have resulted in loss of over 90% of the riparian habitat bordering the HEC (Manny 2003). The HEC system is highly responsive to changes in water level regime given the shallowness of aquatic habitats and susceptibility of those habitats to inundation or loss through subareal exposure as a consequence of relatively small changes in water levels. Connecting channel flows are driven primarily by climatic factors (mainly precipitation and evaporation in the upper Great Lakes) and are affected by anthropogenic channel modifications within the connecting channels.

Increasing development pressures and urbanization have greatly altered these habitats, especially shoreline and adjacent nearshore areas (Manny, 2003). Armoring of the coastlines and adjacent banks of connecting channels has isolated and destroyed critical wetland habitat and altered the timing and intensity of the run-off patterns. Dredging of the connecting channels for commercial navigation has altered water depth, flow, substrate distributions, and habitat structure within the connecting channels and the St. Clair Delta, and has a long-term effect on annual water levels as well (Quinn, 1985).

The establishment of invasive species such as zebra mussels (*Dreissena polymorpha*) and round gobies (*Neogobius melanostomus*) has altered water clarity and changed food web dynamics within these systems (e.g., Vanderploeg et al., 2002). In particular, emergent and submergent aquatic macrophytes have flourished and have altered nearshore and shallow-water habitats in Lake St. Clair and possibly western Lake Erie over the past two decades.

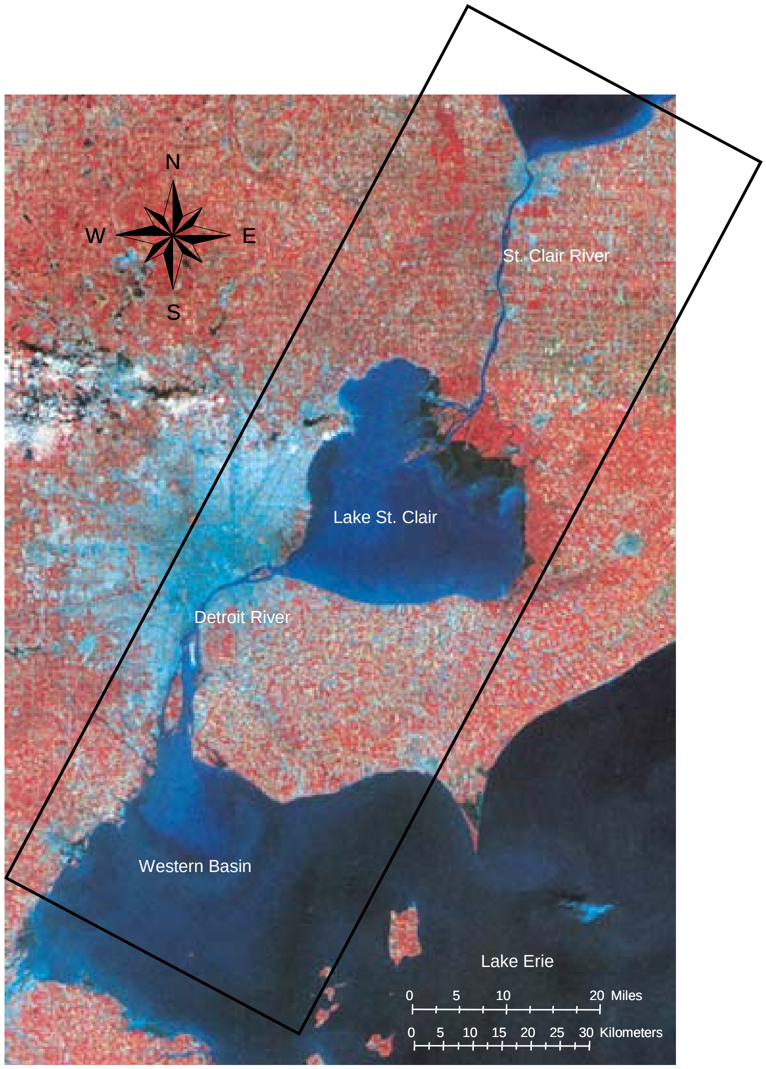


Figure 1. Location map for the Huron-Erie Corridor Project

Problem statement

There is a critical need to assess the impacts of habitat modifications on fish recruitment and fish community structure. However, our ability to understand the scale of the problem and to propose restoration strategies is limited by three factors: 1) we have insufficient knowledge of the historical and present area, type, pattern, and distribution of aquatic habitats within the HEC system; 2) we have not considered the dynamic nature of the physical processes that create and maintain critical and essential aquatic habitats within the HEC; and 3) we have a poor understanding of the spatial and temporal linkages between habitat characteristics and fish recruitment, fish community structure, and life stage.

Aquatic habitats are formed by the interaction of the biota with abiotic factors such as hydrology, substrate, and energy (Mackey 2005). Aquatic habitats are continually changing in response to dynamic interactions between physical and biological processes - which may or may not be impacted by human activity. It is due to this complexity that current habitat protection and restoration efforts are focused primarily on the terrestrial and wetland components of the coastal zone and associated improvements in water quality. However, efforts that are exclusively terrestrially based do not adequately address aquatic or fish habitat restoration needs in the HEC system. Inadequate assessments of the quality and quantity of aquatic habitat have hampered resource management efforts to maintain and improve fish community structure and sustainable populations within the HEC fishery.

Virtually all of the work that has been done to identify and classify aquatic habitats represents a static view of nearshore and coastal habitats – a snapshot in time. Even though static habitat inventories are of value, we must develop both conceptual and quantitative models that link dynamic abiotic processes to high-quality habitat structure and biological communities. This is particularly important when considering potential habitat impacts due to long-term climate change. There is a critical need for the development of strategies and models to predict and assess the current, future, and *historical* location and extent of essential coastal, nearshore, and benthic habitats and likely consequences of global warming for the long-term sustainability of the HEC aquatic food web and fishery.

Methods

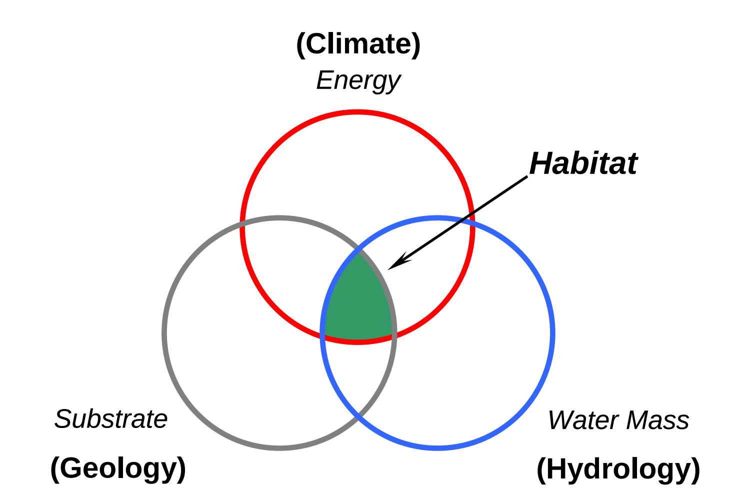
The project team used existing data, current hydrological and habitat models and initiatives, and best available climate change information to develop a long-term plan/strategy to implement system-wide assessment of high-quality HEC aquatic and fish habitats that will accommodate dynamic effects of changes in water level. Assisted and guided by three experts' workshops and drawing on the collaborative expertise of the lower Great Lakes research and management communities, the project accomplished the following objectives:

1. Compiled and assessed existing physical and biological habitat datasets within the HEC system.
2. Identified and prioritized additional habitat research/data collection needs – both physical and biological.
3. Identified key agencies and organizations currently working within the HEC.
4. Developed a process/plan that would ensure research gaps/data needs are filled/met.
5. Developed a long-term plan/strategy to implement system-wide assessment of HEC aquatic and fish habitats that will accommodate the dynamic effects of anthropogenic or climate-induced changes in water level, that includes consideration of the following elements:
   - Identification, characterization, distribution, and inventory of aquatic habitats – integration of physical and biological geospatial data (GIS).
   - Identification of impaired habitats and the stressors causing those impairments (i.e., both natural and anthropogenic).
   - Evaluation of modeling tools to predict changes in high-quality fish habitat distributions resulting from anthropogenic and/or climate-induced changes in water level over varying spatial and temporal scales (e.g. levels and flows, global climate change, connecting channel dredging/hydromodifications).
   - Development of an implementation strategy to use modeling tools to identify fish habitat protection and restoration opportunities in the HEC system.

SUMMARY OF RESULTS

1) Environmental Zone Framework

Physical processes create and maintain aquatic habitats. Aquatic habitat is defined as a range of physical, chemical, and energy conditions that can be delineated geographically that meet the needs of a specific species for a given life stage (Mackey 2005). The physical processes that create aquatic habitats act along hydrogeomorphic pathways that convey energy, water, and materials to, and through, rivers and lakes.



- *Energy* – estimated from hydraulic calculations for both oscillatory and unidirectional flows.
- *Substrate* – bedrock, composition, texture, hardness, stability, porosity, permeability, roughness.
- *Water Mass* – depth, temperature, turbidity, nutrients, contaminants, and dissolved oxygen.
- *Habitat* – physical characteristics and energy conditions that meet the needs of a specific species, biological community, and/or ecological function for a given life stage

Figure 2. Fundamental characteristics of aquatic habitat (from Mackey 2005)

From the perspective of physical integrity, *physical habitats* are defined by a range of physical characteristics and energy conditions that can be delineated geographically that meet the needs of a particular species, biological community, or ecological function for a given life stage (Mackey 2005), see Figure 2. Moreover, to be utilized as habitat, these physical characteristics and energy conditions must exhibit an organizational pattern, persist, and be "repeatable" – elements that are essential to maintain a sustainable and renewable resource (Peters and Cross 1992).

Environmental zones represent a combination of attributes that are associated with dominant processes and/or hydrogeomorphic characteristics, but are not linked to any particular species, biological community, or ecological function. The rationale for using this approach is based on the need to identify critical characteristics and processes that control the distribution, pattern, and function of aquatic habitats.

High-quality fish and aquatic habitats are created by a unique set of environmental conditions and processes that together meet the life-stage requirements of a species, biological community, or ecological function (Mackey 2005). These processes play a significant role, ultimately determining the distribution and utilization of essential fisheries habitats within the HEC system. Within the HEC, three major environmental zones were proposed based on dominant processes and the hydrogeomorphic pathways (based on hydrology and geology) along which those processes act within the system (Table 1). The environmental zone concept provides a logical way to subdivide the HEC system. Environmental zones were used to guide and focus the ensuing workshop discussions.

Huron-Erie Corridor Environmental Zones

Environmental Zone	Low Energy Areas	High energy Areas	Dominant Processes	Hydro-Geomorphology
Connecting Waters and Channels	Shallow water (bank) and backwater areas, riparian wetland	Deep water (thalweg) and main channel areas	Channelized flow, generally unidirectional	Tributary, large river/riparian system
Deltaic	Interdistributary bays, crevasse splays, delta plain, deltaic wetland	Distributary channels, delta margin nearshore	Channelized unidirectional distributary flows, wave generated delta-margin oscillatory flows	Multi-channel distributaries, Interdistributary bays, deltaic wetland, delta margin nearshore
Lake	Embayments, coastal wetland habitat, macrophyte beds	Coastal margin, nearshore, open lake	Wave generated oscillatory flows, open lake circulation	Coastal margin, nearshore, open-lake

Table 1. Environmental Zones as defined by dynamic processes within the HEC system

To summarize, the distribution, pattern, and function of aquatic habitats within the HEC are controlled by the underlying hydrogeomorphic characteristics of the system. These abiotic characteristics are likely to be (or have already been) altered by anthropogenic stressors and/or long-term changes in climate. Moreover, dominant processes acting within these zones are distinct and yield a unique response from associated biological communities. A fundamental assumption is that native fish and aquatic communities have co-evolved and adapted to the physical characteristics of the system - including the distribution, pattern, and function of aquatic habitats and the timing and seasonality of the dynamic processes that create and maintain those habitats. Thus, restorative actions that shift HEC physical characteristics and processes back toward a more “natural state” will benefit native fish and aquatic communities.

Implicit in this approach is the recognition that habitats within the HEC have been significantly affected by anthropogenic modification of physical characteristics and processes within the HEC system. Habitat restoration must consider not only water quality and contaminant issues, but physical alterations to the system as well. Significant restoration opportunities exist within the HEC to restore and enhance spawning and nursery areas by restoring natural flow regimes, reconnecting critical coastal margin, nearshore, and riverine aquatic habitats, and protecting the underlying natural physical and environmental characteristics of the HEC.

2) Existing Datasets and Current Initiatives

More than 112 databases and/or web accessible HEC datasets were identified during the three LEMN workshops. These datasets are listed and summarized on the LEMN website http://www.uwindsor.ca under “previous workshops”. This summary is based on information provided by workshop participants, and can be a considered to be a work-in-progress. Ongoing projects such as the Great Lakes Environmental Indicators Project (http://glei.nrri.umn.edu), Lake Erie Binational Map project (http://www.lemn.org), and the USGS/USFWS Huron-Erie Corridor Initiative (http://www.glsc.usgs.gov) continue to identify existing (and create new) geospatial datasets that are applicable to the HEC. Recent changes in the ways Canadian geospatial data are disseminated may also result in the potential release of Canadian Provincial and Federal datasets applicable to the HEC.

Workshop participants identified key environmental variables and processes for each of the major environmental zones within the HEC. These variables are listed below for each zone:

Connecting Channel Environmental Zone

Abiotic Parameters

- **Water Quality** – seasonal data on nutrient and contaminant loadings
- **Hydrology** – daily and seasonal flows, water-level variability
- **Thermal characteristics** – daily and seasonal water temperature distribution
- **Substrate** – substrate texture, composition, distribution, and stability; location of contaminated sediments
- **Shoreline hardening** – location, type, and composition of shore structures

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where
- **Seasonal pattern and distribution** - larval, YOY, and adult fish; benthic invertebrate and aquatic macrophyte communities; endangered or species-at-risk
- **Community structure** - resident vs. transient populations, importance of lateral and longitudinal connectivity

Deltaic Environmental Zone

Abiotic Parameters

- **Bathymetry** – high-resolution bathymetry at 10 to 15 cm vertical resolution, especially in shallow-water/coastal margin areas (< 3 m water depth). Distributary channel bathymetry is adequate.
- **Hydrology** – daily and seasonal flows, water-level variability, flow paths, and dynamic water "balance" between distributary channels
- **Thermal characteristics** – daily and seasonal water temperature distribution, 0.5 – 1 ^{o} C resolution.
- **Substrate** – substrate texture, composition, distribution, and stability in main distributaries and shallow-water/coastal margin areas (< 3 m water depth)
- **Shoreline hardening** – location, type, and composition of shore structures (riverine and coastal)

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where
- **Seasonal pattern and distribution** - larval, YOY, and adult fish; benthic invertebrate and aquatic macrophyte communities; endangered or species-at-risk
- **Connectivity** – location and type of lateral and longitudinal connectivity between active distributaries and riparian/deltaic wetlands and interdistributary bays.

<u>Open-Lake Nearshore and Coastal Margin Environmental Zone</u>

Abiotic Parameters

- **Bathymetry** – high-resolution bathymetry at 10 to 15 cm vertical resolution, especially in shallow-water/coastal margin areas (< 3 m water depth).
- **Hydrology** – Lake St. Clair water levels, water mass characteristics (turbidity, dissolved oxygen), and seasonal circulation patterns
- **Thermal characteristics** – daily and seasonal water temperature distribution, 0.5 – 1 ^{o} C resolution.
- **Substrate** – substrate texture, composition, distribution, and stability in shallow-water/coastal margin areas (< 3 m water depth)
- **Shoreline hardening and ownership** – location, type, and composition of shore structures, marinas, and navigation structures.

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where
- **Seasonal pattern and distribution** - larval, YOY, and adult fish; fish year-class strength – age class data incomplete; benthic invertebrate and aquatic macrophyte communities; endangered or species-at-risk
- **Connectivity** – location and type connectivity between coastal margin wetlands and shallow-water nearshore areas.

In addition to data collection/research needs, workshop participants identified data gaps and additional data collection needs within each of the three major environmental zones. A summary of the status of key datasets is given in Table 2. Contemporary data represent current conditions. Pre-disturbance data represent conditions that existed prior to major anthropogenic modifications to the system.

Workshop I	Connecting Channel		Deltaic		Open Lake-Nearshore-Coastal Margin	
Data	**Variable**	**Status**	**Variable**	**Status**	**Variable**	**Status**
Contemporary	Bathymetry	Yes	Bathymetry	Partial	Bathymetry	Coarse
	Substrate	Incomplete	Substrate	Partial	Substrate	No
	Flow Data	Yes	Flow Data	Yes	Flow Data	Yes
	Water Level	Yes	Water Level	Yes	Water Level	Yes
	Water Quality	Incomplete	Water Quality	Yes	Water Quality	Incomplete
	Thermal	Incomplete	Thermal	Incomplete	Thermal	Incomplete
	Habitat Util.	Incomplete	Habitat Util.	Incomplete	Habitat Util.	Incomplete
	Habitat Dist.	Incomplete	Habitat Dist.	Incomplete	Habitat Dist.	Incomplete
Pre-Disturbance	Bathymetry	Yes	Bathymetry	Incomplete	Bathymetry	No
	Substrate	Incomplete	Substrate	Incomplete	Substrate	No
	Flow Data	Incomplete	Flow Data	Incomplete	Flow Data	No
	Water Level	Yes	Water Level	Yes	Water Level	Yes
	Water Quality	No	Water Quality	No	Water Quality	No
	Thermal	No	Thermal	No	Thermal	No
	Habitat Util.	Anecdotal	Habitat Util.	Anecdotal	Habitat Util.	Anecdotal
	Habitat Dist.	Anecdotal	Habitat Dist.	Anecdotal	Habitat Dist.	Anecdotal

Table 2. Summary and status (availability) of critical HEC datasets as identified by workshop participants.

In many cases, data collection needs overlap. Within the **connecting channels,** additional data to be collected include: a comprehensive survey of connecting channel substrates; a survey of the distribution and pattern of aquatic macrophyte communities and endangered/species at risk; an assessment of lateral and longitudinal connectivity within the connecting channels; and an inventory of shore protection structures (St. Clair River, St. Clair delta, and Lake St. Clair). Data for other parameters are being addressed at a basic level (see workshop summary), but additional work will likely be needed to increase the spatial and temporal resolution of these datasets for habitat identification and assessment purposes.

Within the **deltaic environmental zone** additional data to be collected include: high-resolution bathymetric surveys in shallow-water coastal margin/nearshore areas (< 3 m water depth); substrate characterization and distribution in shallow-water coastal margin/nearshore areas; an assessment of historic and active spawning and nursery habitats; and an assessment of lateral and longitudinal connectivity between active distributaries and riparian/deltaic wetlands and interdistributary bays.

Within the **open-lake environmental zone** additional data to be collected include: high-resolution bathymetric surveys in shallow-water coastal margin/nearshore areas (< 3 m water depth); substrate characterization and distribution in shallow-water coastal margin/nearshore areas; an assessment of historic and active spawning and nursery habitats; and an assessment of aquatic macrophyte distribution and growth, and an assessment connectivity between open lake and nearshore waters (< 3 m water depth) with coastal marshes, wetlands, and embayments.

Current Initiatives

Ongoing initiatives that address some of these data needs include ongoing water-quality monitoring (including temperature) by Macomb County, Michigan DEQ, Fisheries and Oceans Canada, and Environment Canada. Water-quality data are limited to specific sampling locations and may not have appropriate spatial or temporal resolution.

Contaminated sediment distributions and resuspension potential are being investigated by a University of Windsor project supported by the Canadian Sustainability Fund (Ken G. Drouillard, P.I.). Contaminant distribution data within the HEC are also available from Dr. Chris Marvin (NWRI) and include sediment cores and annual sedimentation rates for the HEC. Hydrologic data (water level and flows) are currently collected at multiple gage sites by NOAA, USACE, USGS, and the CHS. The addition of real-time Acoustic Doppler Current Profiler (ADCP) equipment in the connecting channels and the St. Clair Delta will augment available flow datasets.

Available substrate data are spatially limited and vary in quality and resolution. Local substrate data may be adequate (especially in areas associated with USACE dredging projects). However, there are no plans currently for a comprehensive substrate survey (characterization or mapping) within the connecting channels or the St. Clair Delta.

The USGS – Great Lakes Science Center in cooperation with the MDNR is evaluating historic spawning and nursery habitats within the Detroit River, and will be sampling the lower Detroit River and Western Lake Erie to determine the dispersal pattern and distribution of larval, YOY, and adult fish derived from the HEC (B. Manny, P.I.). The University of Windsor is currently monitoring and evaluating the composition and distribution of benthic communities within the connecting channels (J. Ciborowski, P.I.). However, the spatial and temporal distribution of sampling sites is limited.

Fisheries and Oceans Canada in cooperation with Canadian academic institutions has ongoing sampling programs focused on bio-physical habitat relationships and endangered/species-at-risk in the Detroit River (N. Mandrak, S. Doka, P.Is.). This work includes sampling of aquatic macrophyte communities, but at limited spatial and temporal scales.

Ongoing fish tagging efforts by MDNR, USGS, and OMNR are designed to assess the movement of fish within and through the HEC system. Lateral and longitudinal connectivity within the connecting channels is currently not under active investigation.

In cooperation with the U.S. Army Corps of Engineers, NOAA Great Lakes Environmental Research Laboratory (GLERL), and the U.S. Geological Survey, the Great Lakes Commission is currently working to promote the development of a fully integrated three-dimensional hydrodynamic model for the HEC system (R. Gauthier, P.I.; http://www.glos.us/hec). These efforts are based on data, discussions, and recommendations from the LEMN HEC Workshops II and III described herein and recommendations within the Great Lakes Collaborative agreement. Long-term monitoring and integration of historical data are also considered to be components of this work.

Environment Canada through the National Water Resources Institute are modeling the potential impact of changing water levels and flow regimes on coastal margin wetland and nearshore fisheries habitats. This work is part of a broader strategy to identify and implement adaptation strategies that minimize potential adverse consequences of climate change (L. Mortsch et al., P.Is.; http://www.fes.uwaterloo.ca/research/aird/wetlands). The Modeling experts are developing methods to predict climate change impacts on hydrodynamics and water quality for the Great Lakes and are working to improve modelling capabilities for toxic chemicals.

3) Climate Change Summary and Potential Impacts

Regional climate change models (Canadian Centre for Climate Modeling CCGM1 and UKMO/Hadley Centre HADCM2) predict a decline in long-term annual water levels over the next 70 years for the Great Lakes (e.g. Lofgren et al., 2002; Sousounis and Grover 2002; Mortsch 1998; Mortsch and Quinn, 1996; Lee et al., 1996). Recent work by Wuebbles and Hayhoe (2003) using the HADCM3 model projects greater temperature changes for the mid-western United States than those predicted by the CCGM1 and HADCM2 models. Lee et al. (1996) predicted that a doubling of atmospheric CO_2 levels would permanently reduce long-term annual water levels in Lake Erie and Lake St. Clair by at least a meter. More recent work by David Fay and Yin Fan (Environment Canada) is summarized in a table prepared by Linda Mortsch, Environment Canada, and presented at our first workshop (Table 2). This table provides a range of predicted water levels for four different climate change scenarios. The base case represents current climatic and water-level conditions.

Even though there is a degree of uncertainty in these analyses, in all cases these models predict a general decline in Lake St. Clair annual water levels ranging from 0.2 m to as much as 1 m within the next 50 years. Similar declines are predicted for Lakes Michigan-Huron and Lake Erie. Note that these are predicted mean annual water levels and that the variability about these means (annual range) are expected to increase in three of the four cases listed in Table 3.

Predicted Lake St. Clair Water Levels (meters, IGLD 1985)

	Base Case	Warm & Dry (CGCN2 A21)	Not as Warm & Dry (CGCM2 B23)	Warm & Wet (HadCM3 A1F1)	Not as Warm & Dry (HadCM3 B22)
Lake Statistics					
Mean	175.38	174.40	174.75	174.57	175.18
Maximum	176.11	175.12	175.43	175.36	175.95
Minimum	174.38	173.37	173.72	173.46	174.05
Annual Range	1.73	1.75	1.71	1.90	1.90
Change from Base Case					
Annual		-0.98	-0.63	-0.81	-0.20
Winter		-0.95	-0.62	-0.81	-0.21
Spring		-0.98	-0.61	-0.77	-0.16
Summer		-1.01	-0.64	-0.80	-0.20
Fall		-1.01	-0.65	-0.87	-0.26
Growing Season		-1.01	-0.63	-0.78	-0.18

Table 3. Predicted changes Lake St. Clair water levels for four climate change scenarios within the next 50 years (source: David Fay & Yin Fan, Environment Canada).

However, these water-level scenarios do not take into account long-term cyclicity in Great Lakes water levels (Rob Nairn, Baird Associates, Oakville, ON, pers. communication). Incorporating these values on projected long-term lake level curves suggests for Lake St. Clair suggests that water levels will remain near current levels for the next 15 to 20 years and then may decline precipitously in response to climate change impacts superimposed on declining long-term lake levels (Figure 3). Note that the anticipated water levels are presented as a range of values that correspond to values for change from base case in Table 3. The range of anticipated water levels reflects uncertainty associated with these predictions.

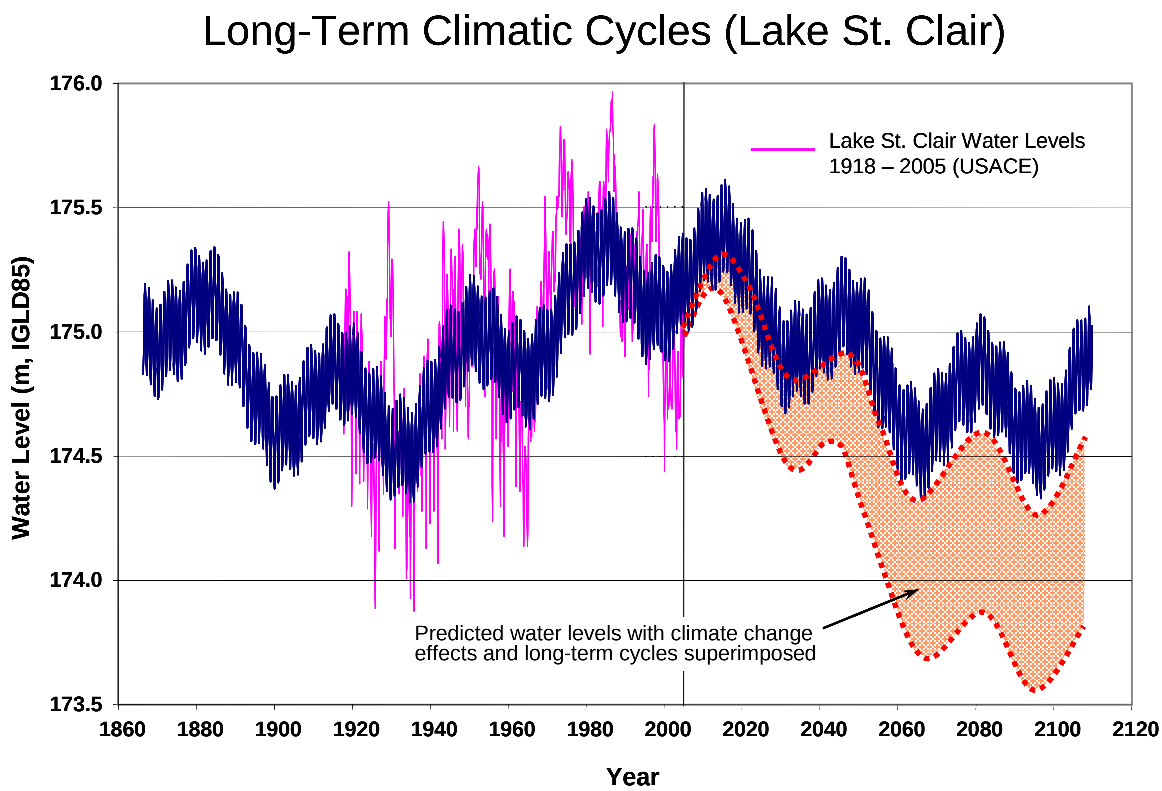


Figure 3. Future Lake St. Clair water levels will be influenced by potential climate change impacts superimposed on long-term climatic cycles. Blue band represents superimposed long-term 160-year, 33-year, and 4 to 8-year long-term cycles for Lake St. Clair (Baedke and Thompson 2000 (Source: modified from workshop presentation – Rob Nairn, W.F. Baird & Associates, 2005). Long-term declines in Great Lakes water levels may be greater than predicted by current global climate-change (GCC) models.

Even though water levels for the worst-case scenario are only slightly lower than were observed during the 1920's and 1930's, the ecological effect of these changes could be significant. The reported historic lows lasted for short periods of time (1 to 3 years) and are considered to be extreme events. These models predict <u>water-level conditions that may persist for decades and will represent a new base level to which the ecosystem will have to adapt</u>. Recent work by Burkett et al. 2005 suggests that if threshold values are exceeded, ecological responses may be rapid and nonlinear in response to markedly different physical conditions. Moreover, these ecological responses may result in effects that cascade through the system significantly disrupting established ecological processes and functions.

Potential Climate Change Impacts

HEC connecting channel flows directly influence the water levels of Lakes Michigan-Huron, Lake St. Clair, and Lake Erie (Derecki, 1985; Quinn, 1985; W.F. Baird & Associates 2005). Lake St. Clair water levels vary seasonally, and have historically fluctuated by as much as 2 m (e.g., Lenters, 2001; Quinn, 2002; Lofgren *et al,* 2002). Hydraulic connectivity, water exchange, and fish movements between coastal wetlands, embayments, and the open lake are directly related to the magnitude, timing, duration, and rate-of change of fluctuating water levels (Mackey and Goforth 2005). Coastal wetland, shoreline, and nearshore aquatic habitats are created and maintained by these natural variations in water level (e.g. Wilcox, 2004; Wilcox *et al*, 2002; 2004; Chubb *et al,* 1985).

Water depth, velocity, flow patterns, temperature, and the position of the shoreline (land-water interface) are the primary variables that most likely will be affected by potential changes in climate and water-level regime. Anticipated reductions in Lake St. Clair water levels by up to a meter over the next 50 years will significantly alter the location of the Lake St. Clair shoreline, particularly, in shallow-water areas with gentle slopes (e.g. Kling et al. 2003; Lee et al. 1996; Edsal and Cleland 1989). Based on updated bathymetry (Figure 4), up to 20% of the present surface area of Lake St. Clair area may eventually be exposed and converted into land if a 1 meter drop in lake level occurs (Table 4). In some areas, the Lake St. Clair shoreline may extend lakeward by as much as 6 km (e.g., Lee et al. 1996). As a result, the location of nearshore littoral and sub-littoral habitats will change substantially, affecting benthic and fish community distribution throughout the entire HEC system. Many of the interdistributary bay and riparian/deltaic wetland areas will become hydrologically isolated and will ultimately become exposed as water levels recede (e.g. Lee et al. 1996; Edsall and Cleland 1989)

Water Depth (m)	Area (ha)	Cumulative Area (ha)	Percent (%)
0 to 1	22,690	22,690	20.2
1 to 2	9,231	31,922	8.2
2 to 3	11,480	43,401	10.2
3 to 4	20,067	63,468	17.8
4 to 5	28,587	92,055	25.4
5 to 6	19,004	111,059	16.9
> 6	206	111,265	0.2
Navigation Channel	1,161	112,426	1.0
Total Area		112,426	100.0

Table 4. Lake St. Clair hypsography based on 20** water year (surface level of 175.?? m). More than 50% of current shallow-water habitats will be lost if Lake St. Clair water levels drop by 1 m, excluding additional reductions that may result due to loss of wetland connectivity. (Source: Scudder Mackey, University of Windsor, 2006)

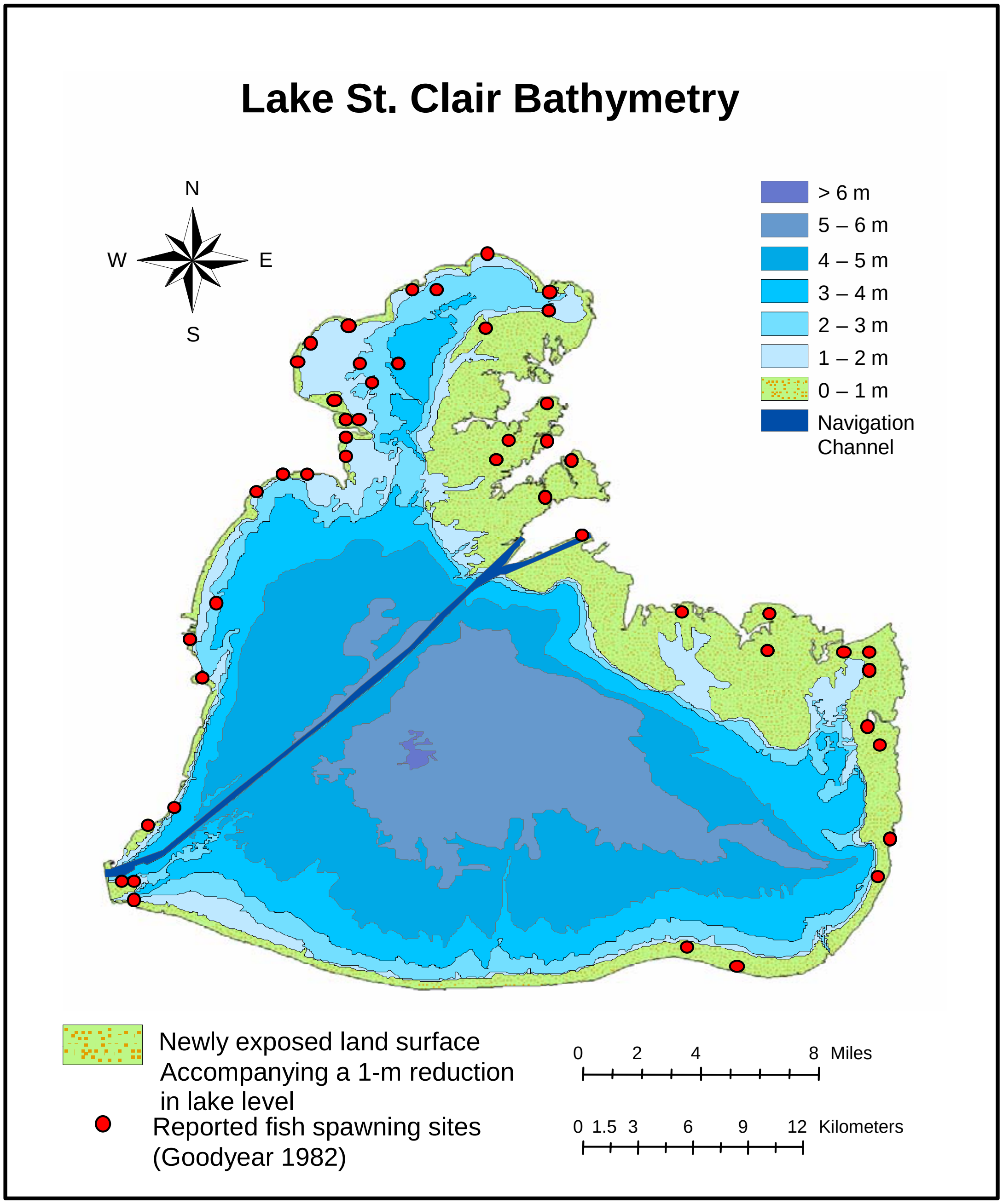


Figure 4. Lake St. Clair 1-m bathymetry, and fish spawning locations reported by Goodyear *et al.* (1982). A 1- m drop in lake level may expose up to 22,000 ha (54,000 Ac or 85 sq mi) of the lakebed by 2050. Critical fish spawning and nursery habitats will shift lakeward as water levels decline. Polygons were derived from bathymetry provided by the National Geophysical Data Center (1998). Goodyear spawning sites extracted from GLFC Lake Erie GIS (Michigan Institute for Fisheries Research). (Source: Scudder Mackey, University of Windsor, 2006)

Of significance is the fact the broad, shallow platform created by the St. Clair Delta will be exposed, reducing the currently available shallow water habitats (<1 m water depth) of Lake St. Clair by more than 50% (Table 4.). The surface area of Lake St. Clair currently 1-2 m deep comprises only 9,231 ha. Even if this area was completely suitable as ‘newly available’ shallow water habitat, it would constitute only 40% of the 22,690 ha area currently in this depth class. However, nearshore slopes adjacent to the new shoreline will be steeper, allowing more wave energy to impinge directly on the shoreline. Fine-grained sediments will be eroded and transported offshore, with remaining coarse-grained sediments redistributed into narrow beaches, bars, barriers, and spits. This process will be accelerated by cutting and removal of newly established macrophyte beds that trap and stabilize sediments in coastal margin and nearshore areas. Dewatering and compaction of sediments may also cause gradual subsidence of the delta platform. This repositioning of the shoreline will significantly alter environmental conditions within the nearshore and coastal margin areas of Lake St. Clair.

Within the St. Clair Delta, a lowering of Lake St. Clair water levels will also cause increased erosion and channel deepening as the main distributary channels equilibrate to a lower base level. The main channels will incise into the exposed platform, and eroded materials will be deposited in deeper water areas located immediately offshore from the platform edge. The distribution of St. Clair River water flow among channels will be altered, with most of the flow going through the Middle Channel, South Channel, St. Clair Cutoff, and Chenal Ecarté (Lee *et al* 1996). This will have major impacts on water circulation, water quality, and productivity - especially in Anchor Bay and other embayments associated with smaller distributary channels.

Lowering of the distributary channel bed and water-surface elevations will also alter flow paths and also contribute to the hydrologic isolation of adjacent interdistributary bay and riparian/deltaic wetland areas. Many of these wetland and estuarine areas currently provide spawning, nursery, and forage habitat for HEC fish communities (Goodyear *et al.* 1982). Moreover, altered flow paths and shifts in seasonal timing will affect the reproductive and developmental events of the fish that are adapted to the phenology of this natural range of water levels (e.g. Kling et al., 2003, Edsall and Cleland 1989).

Within Lake St. Clair, there are 43 sites used by 33 fish species identified in Goodyear *et al.* (1982). Of the 43 sites, 28 are located in shallow water (water depths less than 1 m) and would likely be dewatered and exposed as Lake St. Clair water levels decline. Table 5 lists the total number of sites per species and includes a general description of preferred spawning habitat and temperature for individual species. The combined effects of habitat loss and altered temperature regimes may adversely affect species that spawn or rely on nursery habitats in coastal wetland or shallow-water environments and are cold or cool-water species. More in-depth analyses are necessary to predict the effects of these changes on fish recruitment. Moreover, this approach illustrates the potential to integrate geospatial datasets with long-term water-level regime and climate change models in order to predict possible future locations of critical spawning and nursery habitats within the HEC system. This information is essential when developing long-term protection, rehabilitation, and restoration plans for critical HEC fish and aquatic habitats.

Note that this summary is based on historic data as reported in Goodyear *et al.* (1982). Changing environmental conditions and/or other factors may have altered habitat use by these species**.** The determination of location of active spawning and nursery habitats within the HEC was identified as a critical data collection/research need.

Reported Lake St. Clair Spawning Locations (Goodyear *et al.* 1982)

Species	Sites	Environment	Temperature	Country
Smallmouth bass	24	Intermediate	warm	US, Canada
Muskellunge	17	Intermediate	warm	US, Canada
Yellow perch	15	Intermediate	cool	US, Canada
Northern pike	14	Intermediate	cool	US, Canada
Largemouth bass	13	Coastal wetland	warm	US, Canada
Bluegill	11	Coastal wetland	warm	US, Canada
Carp	7	Intermediate	warm	US, Canada
Channel catfish	7	Intermediate	warm	US, Canada
Emerald shiner	7	Intermediate	cool	US, Canada
Rock bass	7	Coastal wetland	cool	US, Canada
Walleye	7	Intermediate	cool	US, Canada
Lake sturgeon	6	Open water	cool/cold	US, Canada
Pumpkinseed	6	Coastal wetland	warm	US, Canada
Spottail shiner	6	Intermediate	cold/cool	US, Canada
Common shiner	5	Coastal wetland	cool	US, Canada
Spotfin shiner	5	Coastal wetland	warm	US, Canada
Black crappie	4	Intermediate	cool	US, Canada
Golden shiner	4	Coastal wetland	cool	US, Canada
Longnose gar	4	Coastal wetland	warm	US, Canada
Alewife	3	Intermediate	cold	US, Canada
Goldfish	3	Coastal wetland	warm	US, Canada
White crappie	3	Coastal wetland	cool	US, Canada
Brown bullhead	2	Coastal wetland	warm	US, Canada
Lake whitefish	2	Open water	cold	US, Canada
Rainbow smelt	2	Intermediate	cold	US, Canada
Sea lamprey	2	Open water	cold	US, Canada
White bass	2	Coastal wetland	warm	US, Canada
Bowfin	1	Coastal wetland	warm	Canada
Gizzard shad	1	Coastal wetland	cool	Canada
Logperch	1	Coastal wetland	cool/warm	Canada
Trout-perch	1	Intermediate	cold	Canada
White sucker	1	Intermediate	cool	Canada

Table 5. Summary list of species that use spawning and/or nursery sites potentially affected by long-term reductions in Lake St. Clair water levels (Goodyear *et al.* 1982). Entries are ordered by the number of sites used as spawning habitat by each species. Individual sites may used by multiple species during different times of the year. Species highlighted in gray may be more severely affected by changes in water-level regime and temperature than other species. Geospatial data summarized from GLFC Lake Erie GIS (Institute for Fisheries Research). (Source: Scudder Mackey, University of Windsor, 2006)

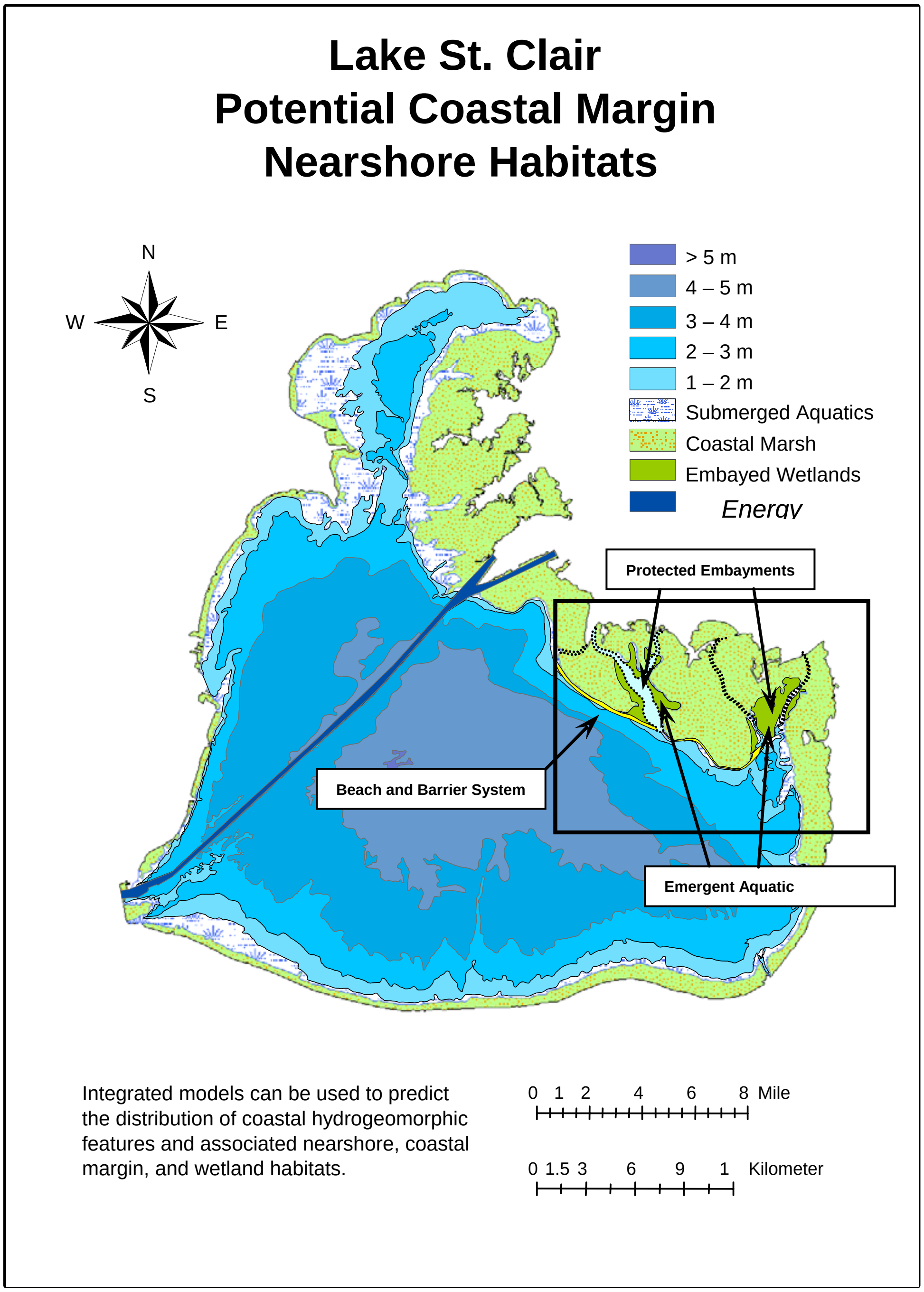


Figure 5. Example of how the Lake St. Clair coastline may change in response to a 1 m drop in water levels. Once water levels stabilize, beaches will form and the movement of sand will create protective barriers and spits at embayment mouths. The inflows from the eastern distributary channels will be diminished and locally sourced. Establishment of emergent aquatic vegetation will create embayed wetlands. Shallow-water areas will have both submergent and emergent aquatic vegetation. (Source: Scudder Mackey, University of Windsor, 2006).

To guide future management decisions, it is essential to understand how lower long-term water levels will change basin and connecting channel configurations and alter the distribution of fish and aquatic habitats within the HEC system. This is particularly important for highly productive shallow areas of the basin, especially Lake St. Clair, the St. Clair delta, and associated channels and backwater areas. Figure 5 is an example of how the hydrogeomorphic characteristics of a portion of the Lake St. Clair shoreline may change in response to altered water-level regimes. This is based, in part, on an understanding of how natural coastal processes may alter the shoreline to create new protected embayments and shallow-water habitats. The establishment of beaches and associated protective barriers and spits at embayment mouths may create new shallow-water areas conducive to the formation of embayed wetlands. This of course assumes that anthropogenic modifications to natural coastal processes are minimized and that the shoreline is allowed to naturally evolve in response to changing water-level and energy conditions.

Recent work by the Adaptation and Impacts Research Division (Environment Canada, Canadian Wildlife Service, and Fisheries & Oceans Canada) has led to the development of a set of rules-based models to predict changes in vegetative and fish communities in wetland and shallow-water nearshore waters in response to altered water-level regimes (A. Hebb, University of Waterloo, Waterloo, ON workshop presentation). These models are based, in part, on biological responses to altered abiotic and hydrogeomorphic characteristics (primarily hydrology and temperature). These models have been applied to selected sites along the Canadian coasts of Lake Ontario, Lake Erie, and within managed wetland complexes on Lake St. Clair (S. Doka, Fisheries and Oceans Canada, Burlington, ON workshop presentation). Habitat-change models combined with long-term coastal process change models can be used to develop a range of scenarios to predict potential changes in habitat pattern and distribution as a consequence of altered water level and climatic regimes (Figure 5).

Application of such models requires high-resolution bathymetry and elevation data to adequately assess potential shoreline changes and the location of transitional habitats within the coastal margin zone (< 3 m water depth). Unfortunately, high-resolution bathymetric data do not currently exist for most of Lake St. Clair or the coastal margin/nearshore areas of the delta. The acquisition of high-resolution bathymetric data within the coastal margin zone was identified as a critical data-collection/research need.

Applying the results of this work at a landscape scale will allow natural resource managers and planners to: 1) identify and protect potential pathways for critical transitional habitats (i.e. “step-stone” habitats) and assess the impact on aquatic and fish communities as water levels gradually recede, 2) identify and protect potential short-term refugia based on abiotic factors, and 3) identify existing/future anthropogenic factors or stressors that may limit the ability of the ecosystem to adapt to a new water-level regime.

4) Research Needs Strategy

Working in cooperation with resource management agency scientists and managers, a long-term strategy was developed to identify and delineate critical habitat areas necessary to maintain and/or restore sustainable fish communities within the HEC. This strategy is designed to restore habitat distribution, pattern, and function to support sustainable native aquatic and fish communities by identifying key environmental characteristics that existed historically within the HEC system; understanding how those characteristics and processes have changed through time; and then using that knowledge to guide and establish functional goals and objectives for future habitat restoration efforts. This approach is based on the fundamental assumption that native fish and aquatic communities have co-evolved and adapted to the physical characteristics of the system - including the distribution, pattern, and function of aquatic habitats and the timing and seasonality of the dynamic processes that create and maintain those habitats. Thus, restorative actions that shift HEC physical characteristics and processes back toward a more "natural state" will be sustainable and will benefit native fish and aquatic communities.

The research strategy is based on the following key elements or objectives:

- Assess the impact of past anthropogenic actions and stressors by performing a historical comparison of the distribution, pattern, and function of aquatic and fishery habitats with current conditions within the HEC;

- Develop and apply hydrodynamic and ecological models that simulate potential changes in aquatic and fishery habitats resulting from long-term changes in water-level regime and that will identify potential long-term management, protection, and restoration opportunities using historical habitat distribution, pattern, and function as a guide; and

- Establish a long-term, binational fishery and aquatic habitat research and monitoring effort within the HEC system. Provide the knowledge and science-based tools to build the capacity of key agencies, organizations, and institutions to identify and implement sustainable protection, restoration, and enhancement opportunities.

By focusing on environmental conditions (i.e., physical and chemical parameters) that create and sustain critical aquatic and fish habitats, it is possible to directly quantify the degree of habitat improvement without having to measure (or model) the more complex biological components or functions of the ecosystem.

Based on the results of the three Research Needs workshops, six major Research Needs were identified. These needs are listed below and are summarized in a flow chart linking research needs to restoration strategies and methodologies (Figure 6).

<u>Research Need</u>

1. Develop an inventory of current and historical HEC datasets and publications. Identify critical data gaps, and propose a work plan to fill those data gaps.
2. Document the current and pre-disturbance distribution, pattern, and function of habitats within the three major HEC environmental zones using available contemporary and historical datasets.
3. Identify significant historical actions or stressors that have resulted in HEC habitat impairments.

4. Develop and apply integrated 2-D, and 3-D hydrodynamic and ecological modeling tools to predict current, historical, and future distribution, pattern, and function of habitats for varying water-level regimes for the three major HEC environmental zones within the HEC system.
5. Establish restoration/rehabilitation targets and goals based on knowledge gained from historical comparison to current conditions.
6. Identify potential habitat restoration/rehabilitation opportunities based on qualitative and quantitative assessments of habitat distribution, pattern, and function. Establish a long-term habitat monitoring program tied to performance indicators.

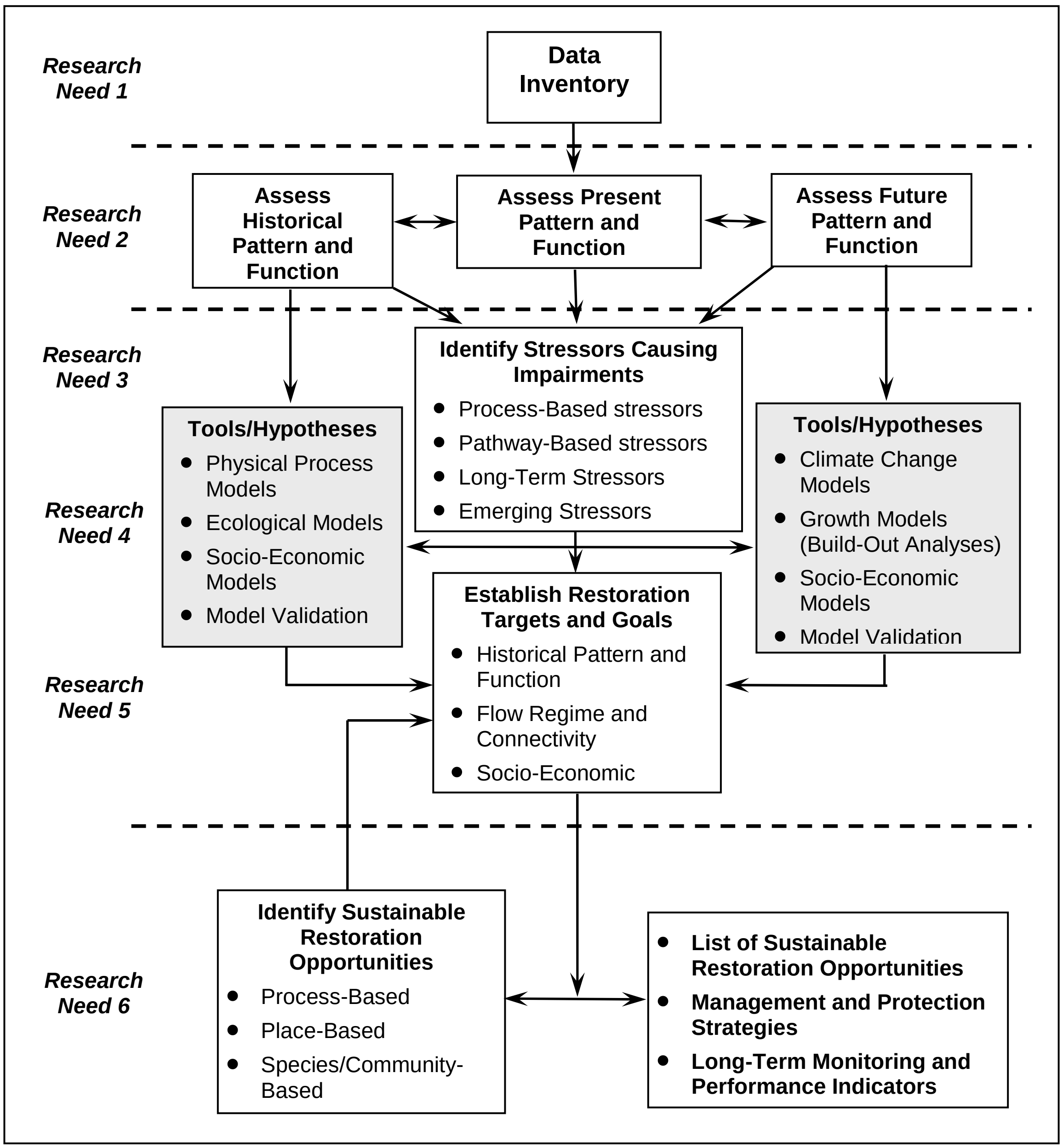


Figure 6. Flow chart linking critical research needs to restoration strategies and methodologies as identified by workshop participants.

WORKSHOP SUMMARIES

Three experts' workshops were convened by the Lake Erie Millennium Network (LEMN) to provide guidance and information as to the current status of HEC habitat science. Each workshop was modeled on the format successfully employed in previous series of LEMN Research Needs workshops. Typically, the workshops started with a series of short presentations describing the status of ongoing work and/or initiatives within the HEC. Follow-on small group discussions and/or breakout sessions were used to generate and compile additional ideas and information contributed by the participants. The intent of these workshops was to establish a common framework and to explore ways to develop and link abiotic and biotic processes within the HEC. Participants were asked to share their knowledge and experience and to identify key environmental variables and modelling tools needed to assess potential impacts of past, current, and potential future anthropogenic and climate-change scenarios on critical and essential HEC habitats. The workshops emphasized synthesis through discussion and used a strong inference approach to address problems. The workshops were international and included individuals and students from academia, binational resource management agencies, and the private sector.

OVERALL WORKSHOP OBJECTIVES AND RESULTS

1. Assess adequacy of existing physical and biological habitat datasets within the HEC system.
2. Identify and prioritize gaps and additional habitat research/data collection needs – both physical and biological.
3. Identify key agencies, organizations, methods, and approaches to fill research gaps/data needs.
4. Develop a process/plan that would ensure research gaps/data needs are filled and/or met.

Workshop No. 3.01 - Research Needs
February 2 - 3, 2005
University of Windsor

Two-day experts' workshop brought together 28 fishery biologists, aquatic ecologists, physical scientists (geologists, hydrologists), and resource managers to assess the adequacy of existing physical and biological habitat datasets within the HEC system. Specific sessions were focused on defining critical issues related to water-level regimes and habitat that included a review of existing initiatives, activities, and ongoing projects within the HEC system. Participants were asked to identify critical environmental characteristics and variables that control and define important environmental zones and associated aquatic habitats within the HEC system. Discussions were focused on the availability of appropriate expertise and geospatial datasets necessary to perform comprehensive aquatic habitat assessments within the three major environmental zones and existing data gaps that would have to be addressed before these assessments could be completed.

A series of presentations by HEC investigators and resource managers highlighted current activities and datasets within the HEC system. Copies of these presentations have been converted to pdf files are available for download and viewing from the LEMN website at http://www.LEMN.org under "previous workshops".

The project team developed a dynamic habitat classification template whereby multiple geospatial data layers are used to develop appropriate "habitat" coverages based on the intersection of a range of environmental characteristics for a particular species, community, or ecological functions of interest (Figure 7). This approach is based on the concept that physical and chemical characteristics of the system, along with the processes that link them, are the fundamental building blocks that create and maintain critical fish and aquatic habitats. These fundamental environmental characteristics (or variables) provide the mechanisms by which aquatic habitats can be rehabilitated or restored.

For individual taxa, suitable habitats can be identified by understanding the biophysical relationships that link environmental characteristics to ecological function. For example, water clarity, substrate type, fetch distance (energy), water depth, and nearshore slope can be used to describe the requirements and predict the distribution of aquatic macrophytes in nearshore environments (Minns *et al.* 1995). There will likely be a unique combination of environmental characteristics for each species, community, or ecological function under consideration. Development of environmental overlays describing those relationships for individual species was beyond the scope of this work, but this information does exist in the literature and it is up to the investigator to identify the appropriate range of values for a particular life stage or ecological function for specific biota of interest. The breakout sessions described below were, in part, designed to identify the key environmental characteristics or variables that influence or control habitat for a broad range of species.

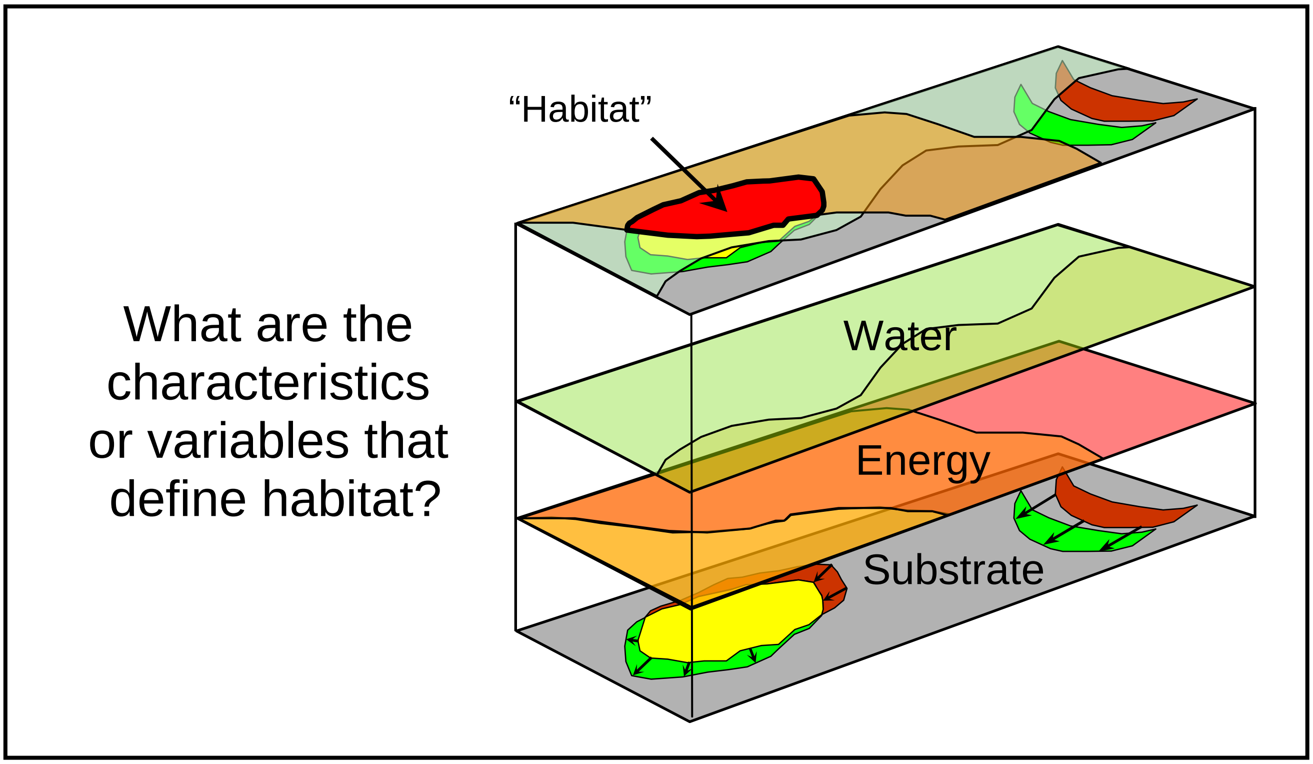


Figure 7. Dynamic habitat classification template. Aquatic habitats are three-dimensional and are spatially and temporally variable (the water column is an integral component of habitat). (Source: Workshop presentation – Scudder Mackey, University of Windsor, 2005)

Connecting Channel Breakout Session Summary

Environmental Sub-Zones

Environmental sub-zones (aquatic) include: deep and shallow water areas within the main channel (high and low energy, pools, and riffles), secondary side channels, backwater areas, channel-bank/margin areas, riparian wetland, and tributary confluences.

Environmental Variables and Processes

Key environmental variables and processes that define habitat within connecting channels include water depth and velocity, and temperature, substrate composition, distribution, and cover/structure, dissolved oxygen, and water clarity. Participants indicated that water depth and velocity are the primary variables that control or influence other key environmental variables. The distribution of aquatic macrophytes and sediment-associated contaminants, and nutrient loads are also important factors. Key inputs are source-water flows from Lake Huron and/or Lake St. Clair, tributary (or distributary) flows and loadings, and contaminant loadings from point and non-point sources. These variables are dynamic, with boundaries and interactions that are driven by riverine processes that often involve climatic/seasonal cycles that influence nutrient and contaminant loadings, hydrology, erosion and deposition, thermal characteristics, and connectivity. Habitat utilization within the connecting channels may also be limited by lateral connectivity (floodplain – wetland – channel) and longitudinal connectivity (upstream – downstream) caused by the filling of low-lying riparian wetlands, shoreline hardening, and the construction of dykes and levees along and within the connecting channels. Within the connecting channels, participants identified multiple datasets and habitat-related initiatives focused on the connecting channels. This information is summarized in the appendix.

Change in Climate and Water-Level Regime

Water depth, velocity, and temperature are the primary variables that most likely will be affected by potential changes in climate and water-level regime. Flows within the HEC are driven primarily by regional climatic factors, mainly precipitation and evaporation in the upper Great Lakes. Changes in the rates of HEC discharge directly influence water levels of Lakes Michigan-Huron, Lake St. Clair, and Lake Erie (Derecki, 1985; Quinn, 1985; W.F. Baird & Associates 2005). The movement of water through the channels sculpts and shapes the channel floor and controls the grain size of bed materials eroded or deposited within the channels and adjacent backwater areas. Temperature influences productivity and triggers seasonal biological activity, e.g. fish migration and spawning. Other habitat variables will also be indirectly affected by changes in climate and/or water-level regime, due their dependence on water level, discharge, and flow. Impacts may include altered retention time in channels and backwater areas; altered connectivity and access to riparian nearshore and channel-bank/margin areas; and changes in channel morphology and substrate distribution. Multiple species may use these substrates as spawning, nursery, and/or forage habitat. Connecting flows and flow paths may link spawning and nursery habitats. However, “one size does not fit all”, as habitat suitability characteristics will vary from species to species as will the seasonality and time period of use.

Connecting Channel Research/Data Collection Needs

Participants identified the following additional datasets/research needs for the connecting channels:

Abiotic Parameters

- **Water Quality** – seasonal data on nutrient and contaminant loadings
- **Hydrology** – daily and seasonal flows, water-level variability
- **Thermal characteristics** – daily and seasonal water temperature distribution
- **Substrate** – substrate texture, composition, distribution, and stability, location of contaminated sediments
- **Shoreline hardening** – location, type, and composition of shore structures

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where
- **Seasonal pattern and distribution** -
  - larval, YOY, and adult fish
  - benthic invertebrate and aquatic macrophyte communities
  - endangered or species-at-risk
- **Community structure** - resident vs. transient populations, importance of lateral and longitudinal connectivity

Primary data collection/research needs within the connecting channels include a comprehensive survey of connecting channel substrates; a survey of the distribution and pattern of aquatic macrophyte communities and endangered/species at risk; an assessment of lateral and longitudinal connectivity within the connecting channels; and an inventory of shore protection structures (St. Clair River, St. Clair delta, and Lake St. Clair). Other parameters are being addressed at a basic level, but additional work will likely be needed to increase the spatial and temporal resolution of these datasets for habitat identification and assessment purposes.

Deltaic Breakout Session Summary

Environmental Sub-Zones

An extensive delta system of the northeast portion or Lake St. Clair is the largest freshwater delta system in the world (Bolsenga and Herdendorf 1993). A complex network of distributary channels, interdistributary embayments, deltaic wetlands, and delta margin nearshore areas is formed and maintained by the interaction of connecting channel flows and coastal processes – natural recurring dynamic processes - that persist though time. Environmental sub-zones (aquatic) include: shallow and deep water main distributary channels with high-energy flows and colder Lake Huron waters; secondary (small) distributary channels with low-energy flows and shallower, warmer waters; backwater areas; channel bank/margin areas; riparian/deltaic wetlands; interdistributary bays and embayments; flood levees; crevasse splays (shallow channels and overwash deposits) where water flows laterally into interdistributary bays and riparian/deltaic wetlands; and delta margin (coastal-process dominated) areas (Figure 8).

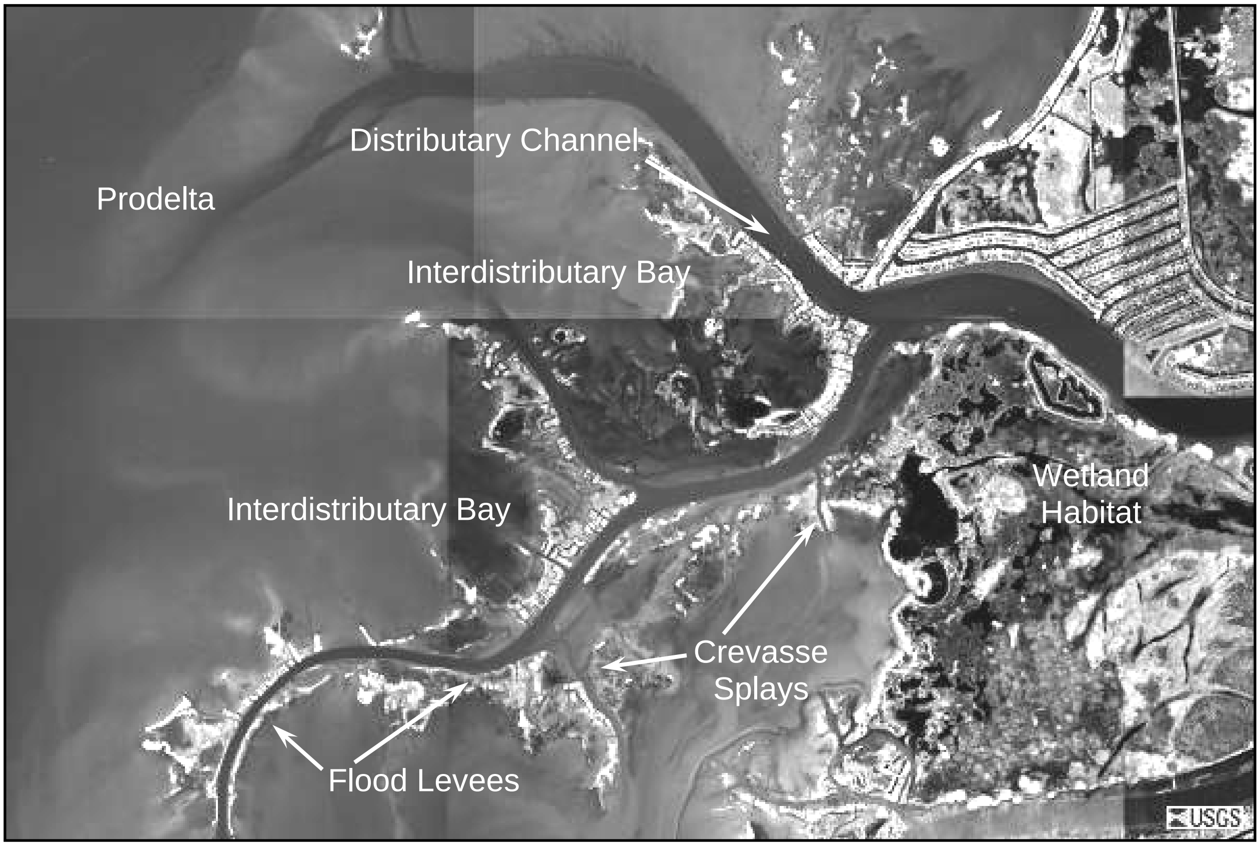


Figure 8. Deltaic environmental sub-zones. (Source: Workshop presentation – Scudder Mackey, University of Windsor, 2005)

Environmental Variables and Processes

Key environmental variables and processes that define habitat within the deltaic zone include elevation/topography/bathymetry (water depth), water velocity and temperature, dissolved oxygen, water clarity, total suspended solids (quantity and quality), and substrate composition and distribution. The processes that create and maintain the delta are a combination of strong unidirectional flows and the transport and deposition of sediments within the St. Clair delta complex. A continuous supply of both coarse and fine-grained sediment to the delta system is necessary to offset the effects of dewatering, compaction, and continued erosion. Without this sediment supply, low-lying areas of the delta will gradually disappear, altering the distribution and pattern of critical fish and aquatic habitats.

Participants indicated that both riverine and lake processes will affect deltaic environments and that variations in Lake St. Clair water levels will control which (and where those) processes are dominant. Habitats within main distributary channels will generally be less sensitive to Lake St. Clair water levels due to the dominance of unidirectional riverine flows. Habitats associated with shallow low-relief interdistributary bays and adjacent riparian/deltaic wetland, crevasse splay, and backwater sub-environments will be particularly sensitive to Lake St. Clair water-level fluctuations. The distribution of aquatic macrophytes and contaminants are also important environmental factors. Key inputs are source-water flows from Lake Huron, distributary flows and loadings, and contaminant loadings from point and non-point sources upstream from the delta.

These environmental variables are dynamic, with boundaries and interactions that are driven by both riverine and lake processes that often involve climatic/seasonal cycles that influence nutrient and contaminant loadings, hydrology, erosion and deposition, thermal characteristics, and connectivity. Habitat utilization within the St. Clair Delta may also be limited by a loss of connectivity and increase in fragmentation – both laterally (channel – wetland - delta plain) and longitudinally (upstream – downstream). This loss of connectivity is caused by the filling of low-lying riparian and deltaic wetlands, shoreline hardening, and the construction of dykes and levees along the distributary channels. Participants identified multiple datasets and habitat-related initiatives focused on the St. Clair Delta. These datasets and initiatives are summarized in the appendix.

<u>Climate Change and Water-Level Regime</u>

Water depth, flow velocity, and temperature are the primary variables that most likely will be affected by potential changes in climate and water-level regime. Anticipated reductions in Lake St. Clair water levels by up to a meter over the next 50 years will significantly alter the location of the Lake St. Clair shoreline, particularly, in shallow-water areas with gentle slopes. Many of the interdistributary bay and riparian/deltaic wetland areas will be hydrologically isolated and subareally exposed as water levels recede. In some cases, the Lake St. Clair shoreline may shift lakeward by as much as 4 to 6 km (Figure 4 - Climate Change Summary). A lowering of St. Clair water levels will also cause increased erosion and channel deepening as the main distributary channels equilibrate to a lower base level. Lowering of the distributary channel bed and water-surface elevations will alter flow paths and may hydrologically isolate adjacent interdistributary bay and riparian/deltaic wetland areas. These areas have been identified as important fish spawning and nursery habitats. High resolution bathymetry and elevation data are necessary to adequately assess potential shoreline changes and the location of transitional habitats within the coastal margin zone (< 3 m water depth). Unfortunately, high-resolution bathymetric data do not currently exist for most of Lake St. Clair or the coastal margin/ nearshore areas of the delta.

<u>St. Clair Delta Research/Data Collection Needs</u>

Participants identified the following additional datasets/research needs for the St. Clair Delta:

Abiotic Parameters

- **Bathymetry** – high-resolution bathymetry at 10 to 15 cm vertical resolution, especially in shallow-water/coastal margin areas (< 3 m water depth). Distributary channel bathymetry is adequate.
- **Hydrology** – daily and seasonal flows, water-level variability, flow paths, and dynamic water “balance” between distributary channels
- **Thermal characteristics** – daily and seasonal water temperature distribution, 0.5 – 1 ^{o} C resolution.
- **Substrate** – substrate texture, composition, distribution, and stability in main distributaries and shallow-water/coastal margin areas (< 3 m water depth)
- **Shoreline hardening** – location, type, and composition of shore structures (riverine and coastal)

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where

- **Seasonal pattern and distribution** -
  - larval, YOY, and adult fish
  - benthic invertebrate and aquatic macrophyte communities
  - endangered or species-at-risk
- **Connectivity** – location and type of lateral and longitudinal connectivity between active distributaries and riparian/deltaic wetlands and interdistributary bays.

Primary research needs within the deltaic environmental zone include high-resolution bathymetric surveys in shallow-water coastal margin/nearshore areas (<3 m water depth); substrate characterization and distribution in shallow-water coastal margin/nearshore areas (<3 m water depth); an assessment of historic and active spawning and nursery habitats; and an assessment of lateral and longitudinal connectivity between active distributaries and riparian/deltaic wetlands and interdistributary bays.

Lake St. Clair Breakout Session Summary

Environmental Sub-Zones

Lake St. Clair is a relatively shallow lake with a gently sloping bottom and water depths averaging 3 to 5 m, with the exception of the navigation channel. Participants had a robust discussion as to whether Lake St. Clair can be considered to be: 1) an “open lake” system in the classic limnological sense; or 2) a nearshore/coastal margin zone based on water clarity, water depth, and energy parameters dominated by shallow-water processes; or 3) a “wetland” based on extensive submergent aquatic vegetation. Participants did not reach a final consensus, but agreed in the interim to classify Lake St. Clair as a shallow water (<15 m deep) environmental zone that exhibits environmental characteristics similar to both nearshore and open-lake systems.

Environmental sub-zones (aquatic) within Lake St. Clair include: coastal margin and delta margin areas dominated by high-energy coastal processes (water depths generally less than 1 m), a large semi-protected embayment (Anchor Bay) and shallow-water open lake areas dominated by lower energy open-lake processes (water depths 1 to 5 m), and deep-water distributary mouth and navigation channels (water depths ~10 m).

The circulation of Lake St. Clair is largely dominated by the flows from the St. Clair River to the Detroit River. The average river discharge is about 5,700 m^3/s. High flows and shallow water depths produce a delicate dynamic balance between hydraulically-driven and wind-driven circulation patterns within the lake. Waves are typically small in amplitude due to the lake’s relatively limited fetch length, shallow water, and gentle offshore slopes. Consequently, the waves tend to break offshore and produce relatively small littoral flows.

Within the shallow-water open lake zone, there are at least two major water masses that behave in ways analogous to larger open lake systems (Figure 9). Water temperatures in Lake St. Clair are strongly influenced by shallow water depths and the water temperature of Lake Huron and the St. Clair River, its primary contributing source. Temperatures change quickly, responding to changes in seasonal atmospheric temperature. Water is well mixed, so that temperatures are usually similar at the surface and at the bottom. The thermal influence of Lake Huron is most obvious in the western half of the lake, where Lake Huron water is discharged through the north and middle St. Clair River channels into Lake St. Clair, producing summer water temperatures about 2 to 4°C lower than occur in the eastern half of the lake (Bolsenga and Herdendorf 1993).

Work by the MDNR and others have shown that up to 80% of the bed of Lake St. Clair has been colonized by aquatic macrophytes (Haas et al. 2005). The combination of relatively shallow water depths, energy, extensive beds of submergent aquatics, and distinct water-mass characteristics create a unique and highly productive mosaic of aquatic habitats within Lake St. Clair.

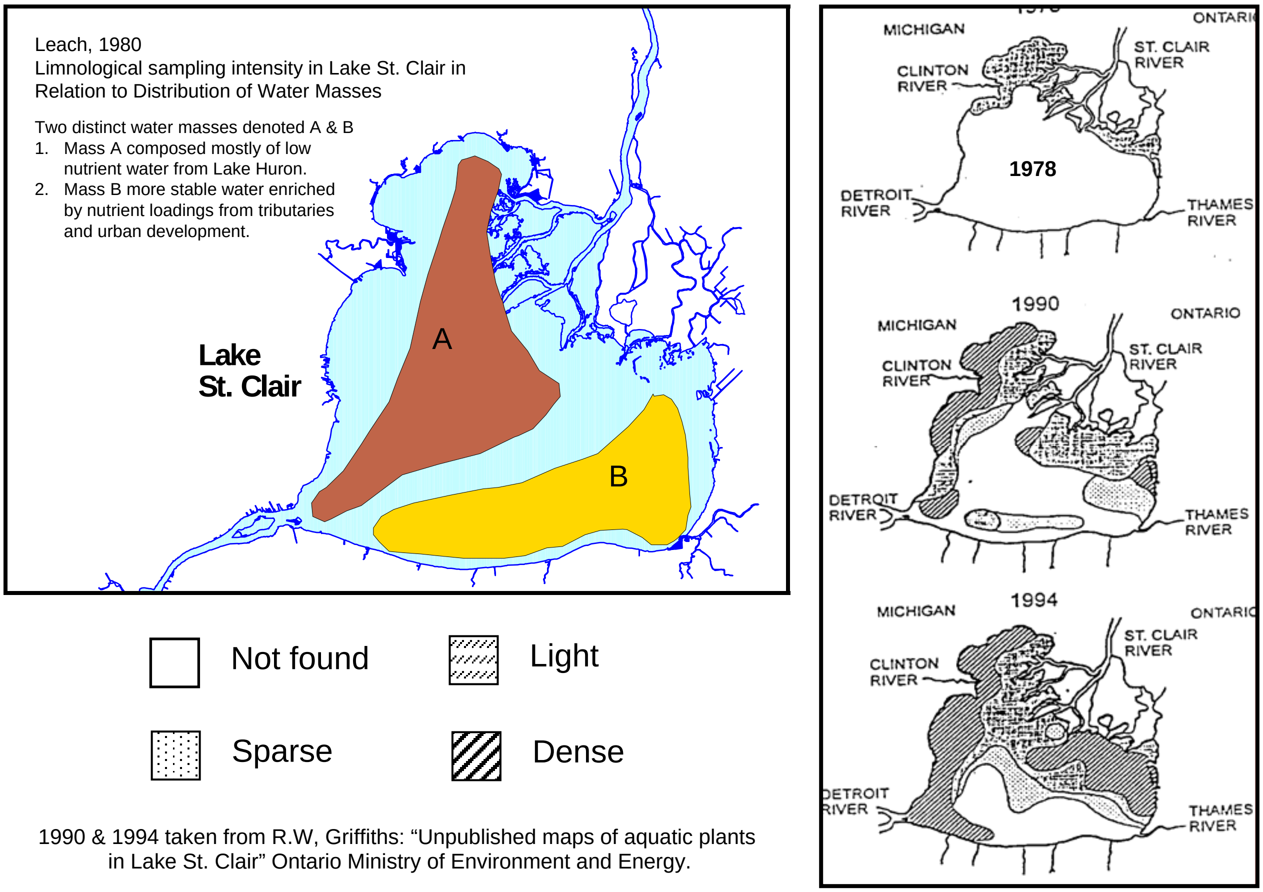


Figure 9. Lake St. Clair environmental characteristics. Water mass "A" (left above) is dominated by cool oligotrophic Lake Huron waters characterized by low nutrient levels and short residence time. Water mass "B" is dominated by warmer waters with higher nutrient levels and longer residence times. Nutrients in water mass "B" are derived primarily from tributary sources. Change in submerged aquatic macrophytes 1978 to 1994 (right above). Macrophyte distribution in 1994 is more representative of historic conditions. MDNR estimates 80% of the Lake St. Clair Lakebed is colonized by aquatic macrophytes. (Source: Workshop presentation – Robert C. Haas, MDNR, 2005)

Environmental Variables and Processes

Key environmental variables and processes that define habitats within shallow-water open lake and shallow-water nearshore zones of Lake St. Clair include elevation/topography/bathymetry (water depth), flow velocity, temperature, dissolved oxygen, water clarity, total suspended solids (quantity and quality), presence or absence of aquatic macrophytes, and substrate. Lake St. Clair water levels vary seasonally, and have historically fluctuated by as much as 2 m (e.g., Lenters, 2001; Quinn, 2002; Lofgren et al, 2002). Coastal wetland, shoreline, and coastal-margin shallow water aquatic habitats are created and maintained by these natural variations in water level (e.g., Chubb et al. 1985). Hydraulic connectivity, water exchange, and fish access among coastal wetlands, embayments, and the open lake are directly related to the magnitude, timing, duration, and rate-of-change of water levels (Mackey 2005). The timing of reproductive and developmental events of the organisms that utilize these habitats is closely adapted to the phenology of this natural range of water levels (Kling et al., 2003). The critical coastal and nearshore aquatic habitats necessary to sustain robust aquatic and fish communities depend on a unique set of environmental conditions that are structured by the region's underlying hydrogeomorphology and the sustaining effects of natural processes acting on the landscape.

Participants indicated that both riverine and lake processes will affect Lake St. Clair environments and that variations in Lake St. Clair water levels will control which (and where those) processes are dominant. Habitats associated with shallow low-relief interdistributary bays and shallow water nearshore areas will be particularly sensitive to Lake St. Clair water-level fluctuations. The distribution of aquatic macrophytes and sediment-bound contaminants are also important environmental factors. Key inputs are distributary flows and loadings of Lake Huron waters from the St. Clair River and Delta and local tributaries that drain directly into Lake St. Clair. Contaminant loadings are derived from point and non-point sources within the Lake St. Clair basin and from sources upstream from Lake St. Clair along the St. Clair River.

These environmental variables are dynamic, with boundaries and interactions that are driven by both riverine and lake processes that often involve climatic/seasonal cycles that influence nutrient and contaminant loadings, hydrology, erosion and deposition, thermal characteristics, and connectivity. Habitat utilization within the Lake St. Clair may also be limited by a loss of connectivity and increase in fragmentation. This loss of connectivity is caused by the filling of low-lying riparian and deltaic wetlands, construction of marinas, shoreline hardening, and the construction of dykes and levees. Participants identified multiple datasets and habitat-related initiatives focused on Lake St. Clair.

Climate Change and Water-Level Regime

Water depth, velocity, and temperature are the primary variables that most likely will be affected by potential changes in climate and water-level regime. Anticipated reductions in Lake St. Clair water levels by up to a meter over the next 50 years will significantly alter the location of the Lake St. Clair shoreline, particularly, in shallow-water areas with gentle slopes. Many of the interdistributary bay and riparian/deltaic wetland areas will become hydrologically isolated and subareally exposed as water levels recede. In some cases, the Lake St. Clair shoreline may shift lakeward by as much as 4 to 6 km (Figure 4). A lowering of St. Clair water levels will also cause increased erosion and channel deepening as the main distributary channels equilibrate to a lower base level. Lowering of the distributary channel bed and water-surface elevations will alter flow paths and may hydrologically isolate adjacent interdistributary bay and riparian/deltaic wetland areas. These areas have been identified as important fish spawning and nursery habitats. High resolution bathymetry and elevation data are needed to adequately assess potential shoreline changes and the location of transitional habitats within the coastal margin zone (<3 m water depth). Unfortunately, high-resolution bathymetric data do not currently exist for most of Lake St. Clair or the coastal margin/nearshore areas of the delta.

Lake St. Clair Research/Data Collection Needs

Participants identified the following additional datasets/research needs for Lake St. Clair:

Abiotic Parameters

- **Bathymetry** – high-resolution bathymetry at 10 to 15 cm vertical resolution, especially in shallow-water/coastal margin areas (<3 m water depth).
- **Hydrology** – Lake St. Clair water levels, water mass characteristics (turbidity, dissolved oxygen), and seasonal circulation patterns
- **Thermal characteristics** – daily and seasonal water temperature distribution, 0.5 – 1 ^{o} C resolution.
- **Substrate** – substrate texture, composition, distribution, and stability in shallow-water/coastal margin areas (<3 m water depth)
- **Shoreline hardening and ownership** – location, type, and composition of shore structures, marinas, and navigation structures.

Biotic Parameters

- **Spawning and nursery habitat** - location, characteristics, and use - who, when, and where
- **Seasonal pattern and distribution** -
    - o larval, YOY, and adult fish
    - o fish year-class strength – age class data incomplete
    - o benthic invertebrate and aquatic macrophyte communities
    - o endangered or species-at-risk
- **Connectivity** – location and type connectivity between coastal margin wetlands and shallow-water nearshore areas.

Primary research needs within the open-lake and nearshore environmental zones of Lake St. Clair include high-resolution bathymetric surveys in shallow-water coastal margin/nearshore areas (<3 m water depth); substrate characterization and distribution in shallow-water coastal margin/nearshore areas; an assessment of historic and active spawning and nursery habitats; water chemistry, turbidity, open-lake seasonal circulation patterns; effects of shoreline armoring and loss of connectivity on shallow-water and coastal margin habitats.

Workshop No. 3.02 – Developing and Evaluating Dynamic Habitat Models
April 13 – 14, 2005
University of Windsor

This two-day experts' workshop brought together 21 fishery biologists, aquatic ecologists, physical scientists, modelers, and resource managers to assess the adequacy of existing hydrodynamic and ecological models and to identify critical data needs and additional modeling capabilities necessary to understand and predict the distribution, pattern, and function of critical habitats within the HEC system. Specific sessions were focused on hydrodynamic and ecological modeling capabilities within the connecting waters and channels, coastal margin and open lake areas of Lake St. Clair, and the western basin of Lake Erie. Participants reviewed existing hydrodynamic and ecological modeling capabilities within the HEC system and evaluated the applicability of those models to predict potential impacts of altered water-level regimes in response to future climate change and/or anthropogenic stressors. Discussions identified the need for integrated hydrodynamic modeling tools for the entire HEC system, potential research applications, and model development and data/information requirements.

The primary objective of this workshop was to identify and assess existing physical and ecological models and to determine future modelling needs within the HEC system. A series of presentations by HEC investigators highlighted current modelling activities within the HEC system. Copies of these presentations have been converted to pdf files are available for download and viewing from the LEMN website at http://www.LEMN.org under "previous workshops".

Hydrodynamic models predict water levels and flow velocities in 1-D, 2-D, and 3-D and are usually designed to address very specific questions and/or are site specific. Most hydrodynamic models are designed to predict unidirectional (i.e. riverine) flows and/or wind-driven flows in large bodies of water such as lakes. Wave models are required to predict waves and/or their effects.

Hydrodynamic Models Developed or Applied to the HEC System

Table 6 contains a list of hydrodynamic models that were discussed during Research Needs Workshop 2 and have been applied to the HEC system. Table 6 also lists the major environmental zones for which these models have been applied.

Model	**RMA2**	**MISED**	**CH3Dsed**	**POM**	**POM**
Geographic Region	St. Clair River, Lake St. Clair, Detroit River	St. Clair River, Detroit River	Detroit River	Lake St. Clair	Lake Erie
Dimension	2-D	3-D	3-D	2-D	2-D
Grid	Finite Element	Finite Element	Finite Difference	Finite Difference	Finite Difference
Developer	USGS/USACE	Baird & Assoc.	UWindsor	UMich/GLERL	GLERL
Environmental Zone					
Connecting Waters and Channels	✓	✓	✓		
Deltaic	✓	✓	✓		
Lake	✓			✓	✓

Table 6. Hydrodynamic models currently developed and used within the HEC. The Princeton Ocean Models (POM) are not designed for riverine flows and have been applied to Lake St. Clair and the western basin of Lake Erie only. The RMA2 model has an open-lake module, that has been applied to Lake St. Clair.

One-dimensional (1-D) hydrodynamic models have been constructed for the St. Clair and Detroit rivers by the USACE and Environment Canada to support Lake Huron outflow and Lake Erie inflow simulation and forecasting. One-dimensional models are designed for a specific purpose and can not be used to predict vertical velocity profiles.

Two-dimensional (2-D) hydrodynamic models have been developed collaboratively for the St. Clair and Detroit rivers by the USGS, USACE, and Environment Canada. The RMA2 package is a finite element (flexible grid) model that uses high-resolution bathymetric data collected in 2000 by the USACE to simulate flows and track particles as part of Michigan Department of Environmental Quality (MDEQ) source-water protection program (Figure 10). The refined RMA2 model works well and has been tested, validated, and refined by flow measurements and tracking experiments performed by the USGS and USACE on the Detroit River. However, RMA2 model is finely tuned to the St. Clair and Detroit Rivers, operates at a 5 second time step, and must run for extended periods of time to produce results for longer predictive time periods. Moreover, the RMA2 model can also be used to simulate the movement suspended sediments and pollutants within the system. It can be coupled with the SED2D model to simulate bed load transport, but does not have the capability to predict changes in channel morphology or to simulate erosion.

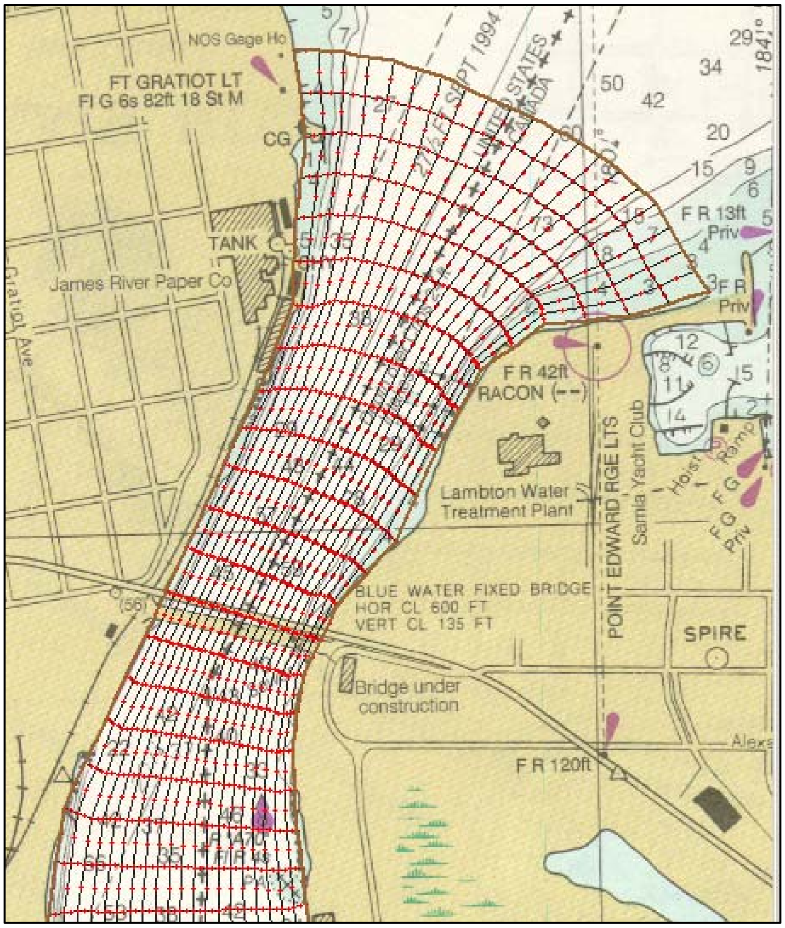


Figure 10. Refined RMA-2 finite element grid for the upper reaches of the St. Clair River near the Blue Water Bridge (Source: Workshop presentation - Dave Holtschlag, UGSS Lansing, 2005).

Three-dimensional (3-D) models have been applied to selected reaches of the St. Clair and Detroit rivers for specific purposes, primarily to examine the impacts of shoreline structural modifications to flow and transport processes and/or impacts of lake-driven water level changes (seiches) in the lower Detroit River. Existing 3-D models that have been applied to the Corridor include the CH3DSed model package developed by the University of Windsor for the lower reaches of the Detroit River to simulate the effects of seiche driven changes in water level of flows and potential for resuspension of contaminated sediments in the lower Detroit River. The CH3DSed package is a curvilinear finite difference model but doesn't have water quality module or muddy sediment capabilities. The MISED model is a proprietary package developed by Baird and Associates and has been used to simulate flow and sediment transport around structures in the upper reaches of the St. Clair and Detroit Rivers. This model was used to simulate changes in bathymetry associated shoreline structural modifications and to model channel erosion and downcutting in the headwaters of the St. Clair River (Figure 11). A brief summary of other 2- and 3-D models that could be applied to the HEC system is presented in Table 7.

Summary of 2-D and 3-D Hydrodynamic Models

***RMA2** – USACE/EC/USGS
- 2-D model, FE, 1970s vintage, public domain
- Covers full system, hydrodynamics, designed for particle tracking, not linked sediment/morphology
- SED2D is sediment module (sand only), not directly linked

***POM** - University of Michigan, NOAA, many others
- 2-D model, FD, applied to Lake St. Clair, public domain, Univ. Michigan
- 2-D model (possibly 3-D), applied to Lake Erie, GLERL
- Has sediment and ecological models, 1970s
- Not suited to rivers but there is ECOMSED, now public domain (good sediment/morphology but 2D)

***CH3DSed** – University of Windsor (Univ. of FL, USACE, Univ. of Iowa)
- 3-D model of Detroit River, hydrodynamics and particle tracking (has morphologic component)
- Sediment transport only for sand
- 1980s vintage, FD curvilinear

***MISED** – Baird & Associates in-house (proprietary)
- late 1990s vintage, FE, 3-D, unconditionally stable
- Time steps 10-20x greater (or more) than other models
- Sediment (sand and silt/clay), morphologic
- Setup for parts of St. Clair and Detroit
- Particle tracking – settling velocity and vectors – larval and YOY fish

EFDC (USEPA)
- 3-D, FE, sand/clay, morphologic, early 1980s
- Links to WASP for water quality
- Public domain (set up for lower Clinton River by USACE)

MIKE3 (DHI)
- FE and FM (Flexible Mesh version), 2-D and 3-D
- Sediment and some morphologic
- Fully coupled to a water quality/ecologic model (contaminants, eutrophication, zebra mussels, etc)
- Ecologic model can be customized
- Now setup for Lake Simcoe including ecological model
- Commercial and expensive, but for good reason

DELFT3D (Delft Hydraulics)
- 3-D, FD curvilinear, sand/clay, morphologic, mid-1990s
- Excellent morphologic
- Water quality and ecologic functions
- Commercial and expensive, but for good reason

TELEMAC (LNH/Sogreah, France)
- FE, 3-D, hydrodynamic, limited sediment capabilities, no ecological functions (this may be changing)
- Probably the only 3-D hydrodynamic model specifically developed for rivers
- Commercial and expensive, but for good reason

Table 7. Summary of 2-D and 3-D hydrodynamic models and their capabilities. (Source: Workshop presentation - Rob Nairn, W.F. Baird & Associates, 2005)

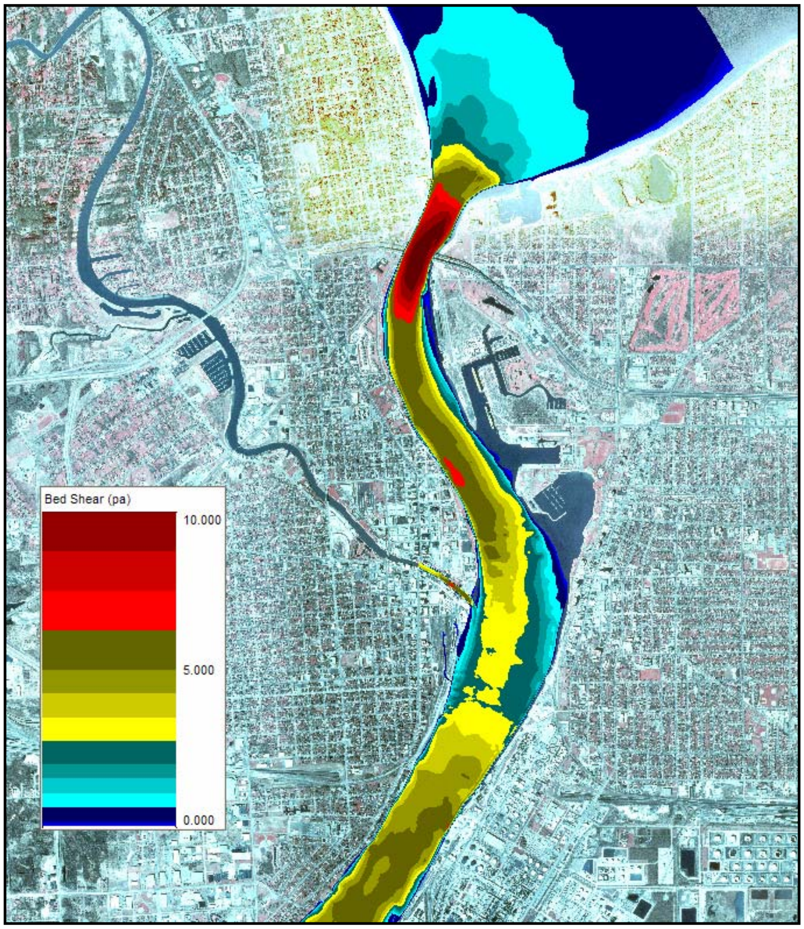


Figure 11. Erosion potential at the headwaters of the St. Clair River based on 3D flow simulation. Colors represent calculated bed shear stress that can be used to predict grain size of transported and/or deposited materials on the riverbed (Source: Workshop presentation - Rob Nairn, W.F. Baird & Associates, 2005).

The Princeton Ocean Model (POM) is a finite difference model (fixed grid size) that has been applied to Lake St. Clair and the western basin of Lake Erie. These models are used to predict flow and circulation patterns in response to changing weather patterns (i.e. wind forces) acting across the surface of the lake. These models can also incorporate the effects of tributary inflows on open-lake circulation patterns as well. The POM model developed jointly between NOAA GLERL and the University of Michigan has been used for particle tracking and backcasting circulation patterns in order to identify possible sources of *E. coli* contamination related to beach closings on the U.S. side of Lake St. Clair. These 2-D models can be extended to 3-D but are computationally intensive and require substantial computing resources to run.

The existing models described above are functional for the purposes for which they were designed, and the potential for their use in habitat evaluations has yet to be explored. However, during the workshop discussions, it became clear that limited spatial coverage and lack of model integration between riverine, deltaic, and lake systems severely limits the applicability of these models for use in regional habitat assessments. Workshop participants discussed the possibility of linking existing models to produce an integrated model for the HEC system. However, differing time-step, computational, and framework issues between existing models make integration difficult. Based on anticipated efficiencies and estimated costs, the consensus of workshop participants was to encourage the development of a new, fully integrated 3-D hydrodynamic model for the entire HEC system. A new fully integrated 3-D hydrodynamic model would provide more complete coverage of nearshore areas and St. Clair Delta - areas that were identified by participants in Workshop I as critically important habitat areas within the HEC system.

Hydrodynamic Model Requirements for Habitat Modeling in the HEC

Participants articulated a need to develop and/or apply existing hydrodynamic models to predict current, historical, and future patterns of flow and sediment transport in response to changes in water-level regime and/or anthropogenic channel modifications. Workshop participants discussed how these hydrodynamic models could be applied to assist in the identification, characterization, and restoration of aquatic and fish habitats within the HEC. Ecological models could then be used to predict historical, current, and future habitat pattern, distribution, and function based on environmental characteristics predicted by the hydrodynamic models.

Workshop participants were also very interested in sediment transport and water quality/chemistry predictions, which aren't available with all existing models. If the integrated model is applied to shallow-water nearshore and coastal margin areas, provision needs to be made for the addition of a wave model to simulate nearshore water movement, sediment transport, and potential boat-wave impacts. It was suggest that the integrated 3-D model be designed with additional modules that could be used for habitat modelling and prediction, spill and contaminant modeling, particle tracking, water-level and flow modelling, and sediment transport modelling. Specific requirements include:

Dimensionality – Integrated model should be 3-D. 1-D models are insufficient to model nearshore embayments and river-lake confluences. 2-D models do not adequately capture depth gradients in flow and temperature, which may be particularly important in river-lake confluences and in Lake St. Clair. Only a 3-D model can incorporate all of the factors necessary to model the critical environmental characteristics that influence habitat pattern, distribution, and function within the HEC.

Spatial resolution and model framework – Finite element models are preferred as grid spacing can be adjusted to focus on areas of biological interest. For example, a fine spatial resolution of 2 m could be applied to nearshore areas and in confluence zones where delta distributaries flow into Lake St. Clair. Conversely, a coarse spatial resolution of 200 m may be appropriate to model open-lake circulation and thermal processes within Lake St. Clair. Workshop participants suggested that the initial model be developed at a coarse scale and then adapted to finer scales in areas of biological interest. Zones of interest mentioned by workshop participants include:

- Boundary zones between rivers and lakes, especially the St. Clair Delta/Lake St. Clair, Detroit River/Lake St. Clair, and Detroit River/Lake Erie interfaces;
- Nearshore areas such as embayments and eddies or tributary confluences near river banks;
- Anthropogenic modifications or features, especially dredged areas such as the shipping channel in Lake St. Clair and large shoreline structures along the banks of the St. Clair and Detroit Rivers; and
- Dynamic areas with high/persistent erosion or deposition.

Time scale – Workshop participants identified a range of time scales that would be useful for habitat analyses and modeling. Time scales ranged from daily, seasonal, annual, and decadal. Daily information on flow, circulation, and thermal structure was thought to be important for fish life stage and distribution studies. Longer-term seasonal and annual patterns were also considered to be important because aquatic and fish communities respond to seasonal changes in flow and water temperature. The longest time scale of interest was decadal, where changes in historical patterns and abundance could be compared to broad-scale regional factors such as anthropogenic modifications, water-level regime, and climate.

Additional Capabilities – The integrated model should have the capability to add sediment transport, turbidity, water quality/chemistry, and ecological/habitat modules.

Visualization Capabilities – Models must be able to clearly display results in a meaningful format. Visualization should include ability to generate geographically referenced plan views at varying scales and resolution, and an ability to generate depth slices and/or vertical cross sections to illustrate 3-D components of flow within channels, confluence zones, and the open lake.

Research Topics/Hydrodynamic Model Applications

Specific applications suggested by workshop participants include:

- Impacts of recreational and commercial boat traffic on water quality, sediment resuspension, ecological functions
- Patterns of sediment transport and sediment resuspension
- Historical analyses based on pre-disturbance channel morphology (bathymetry) and sediment patterns
- Drift of fry after spawning (Similar to particle tracking exercise)
- Distribution of aquatic macrophytes in Lake St. Clair; transport and fate of decaying macrophytes in autumn

Ecological Models Applied to the HEC System

The Adaptation and Impacts Research Division from Environment Canada and Fisheries & Oceans Canada have developed a suite of models to predict how vegetative and fish communities may respond to changes in water-level regime (i.e., climate change) in coastal margin and nearshore areas of Lake Erie and Lake St. Clair. Details were provided in Workshop 3.02 presentations by Andrea Hebb (Environment Canada, Waterloo) and Susan Doka (Fisheries & Oceans Canada, Burlington). The approach used to model changes in the distribution and structure of vegetative communities is as follows (Figure 13):

1) For each wetland site, topographic models are constructed using best available bathymetry
2) A rule-based vegetation community response model (or matrix) is constructed that considers water depth and duration of hydrologic condition (length of time submerged vs. exposed). The response model is validated using historical wetland data.
3) The response model is then applied to a range of water-level regime (i.e., climate change) scenarios to model future vegetation response to altered hydrologic conditions.

Figure 12 illustrates an example vegetation community response model (or matrix) based on water depth and hydroperiod. Specific responses (i.e., the expected type of vegetative cover in a cell) are determined empirically from contemporary data and comparisons with historical site data to validate the vegetative response model. Results from the vegetation community response model are then combined with substrate, bathymetric, and simulated temperature data to predict the distribution of aquatic and fish communities to a range of water-level regime (i.e. climate change) scenarios in coastal margin and nearshore areas.

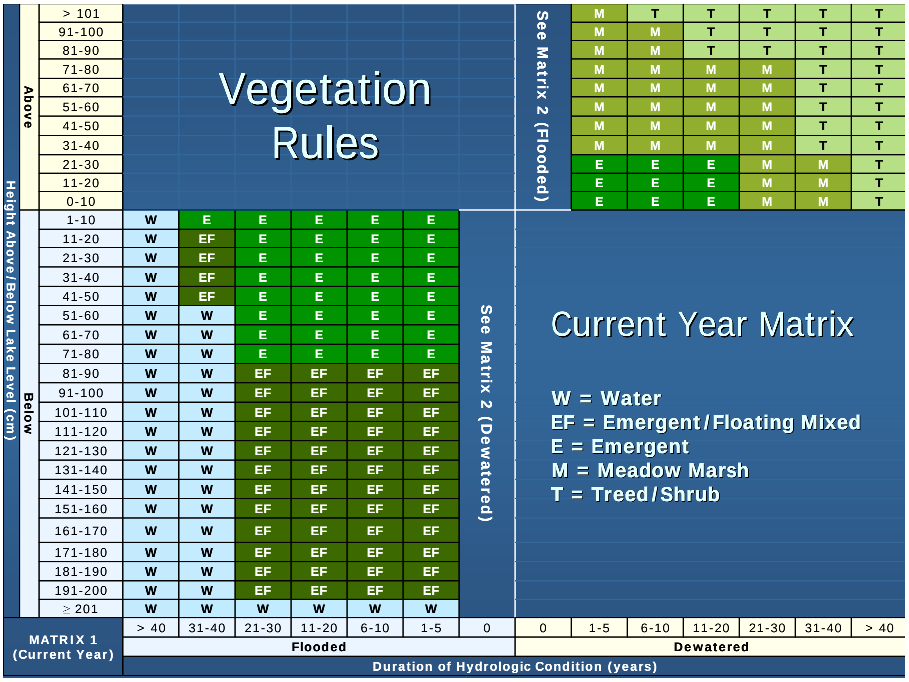


Figure 12. Example of rule-based vegetation response matrix used to determine vegetative community composition and structure based on water depth and hydroperiod, i.e. length of time submerged or exposed. The matrix is validated using historical data of vegetative communities. (Source: Workshop presentation – Andrea Hebb, Environment Canada, Waterloo, 2005)

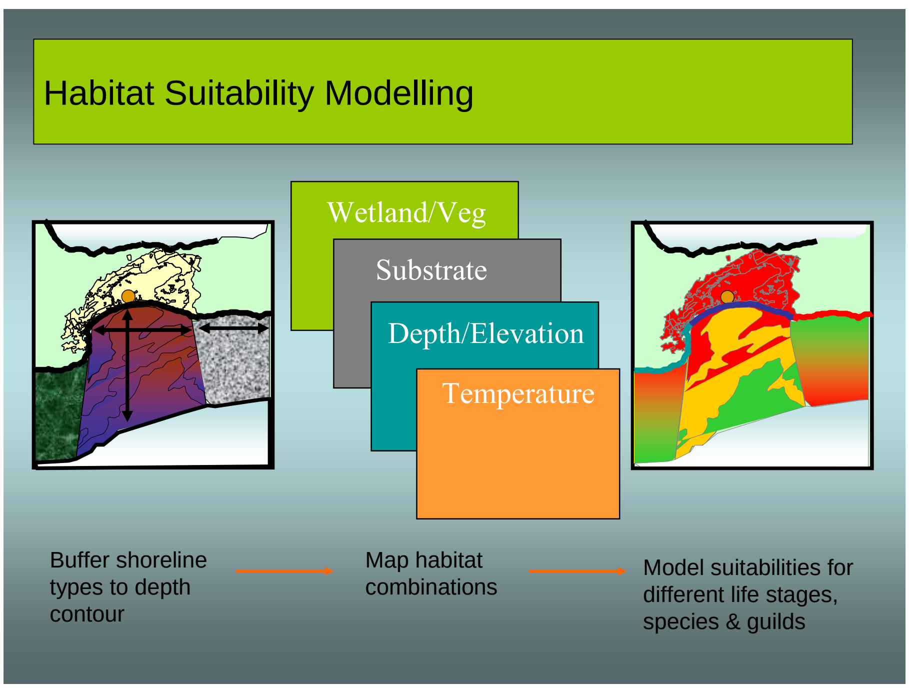


Figure 13. Predicted vegetative community structure is integrated with substrate, bathymetry, and predicted temperature data to geospatially map environmental characteristics and infer habitat suitability for different fish life stages, species, and guilds. (Source: Workshop presentation - Susan Doka, Fisheries & Oceans Canada, 2005)

Data Needs for Habitat Modelling

Hydrodynamic models could help to predict many of key environmental variables identified by Workshop participants in Research Needs Workshop 1. For example: flow, circulation, and turbulence; shear stress; sediment transport, erosion and deposition; DO; water chemistry; and contaminant dispersal. Hydrodynamic models could also be used to predict changes in environmental conditions due to changes in water level-regime and channel morphology due to dredging, erosion, or other anthropogenic actions.

The data needed for predicting velocities and water levels for hydrodynamic models, even at a fine scale, are adequate for much of the HEC. However, additional flow and circulation data are needed to validate predictions for open-water areas in Lake St. Clair and the western basin of Lake Erie. For future water quality and sediment modules, additional data may be needed with respect to vertical water quality profiles, substrate, and grain size of lake and/or river bed materials.

As identified in Research Needs Workshop 1, bathymetry in many nearshore areas is inadequate, especially in Lake St. Clair. High resolution (10 cm or less) bathymetric data are needed to model vegetative community responses to changes in water-level regime. More detailed information on substrate type and distribution are also needed not only to perform sediment transport calculations, but to model the response of vegetative and fish communities to changing water-level regimes as well. However, the amount of detail can vary as a function of substrate heterogeneity. High-resolution substrate data will likely be required in nearshore shallow-water areas, but lower-resolution substrate data will be adequate in more homogeneous deep-water areas.

There are major gaps in available suspended sediment and water quality data. However, workshop participants suggested that it may be possible to obtain long-term data from water supply intakes. New remote sensing (satellite) tools are now available that may provide additional information on suspended sediment concentrations, turbidity, and light penetration for many areas within the HEC.

Workshop participants also recognized that our limited understanding of biophysical linkages between environmental characteristics and biological functions severely limits our ability to develop effective biological and ecological models. Hydrodynamic data can provide sufficient information to answer a limited range of biological questions, but workshop participants stated that there is a lack of information (and knowledge) to model or predict habitat selection/ distribution for many species of interest. This was identified as a major limiting factor. It was hoped that development of a robust 3-D hydrodynamic model and associated module would stimulate additional research focused on developing biophysical linkages between habitat and the organisms that use those habitats.

Workshop No. 3.03 – Long-term Strategic Research Plan
October 17, 2005
U.S. EPA Great Lakes Laboratory Grosse Ile, Michigan

Participants attending this one-day workshop explored a range of "transitional habitat" issues (Saxon 2003) and further evaluated available tools and datasets that could be used to predict potential habitat impacts of changing water-level regimes resulting from regional climate change and/or anthropogenic stressors. The results of the two prior workshops were also reviewed as part of a process to develop a long-term habitat restoration approach/strategy for the HEC system. Discussions identified the need to develop realistic, process-based restoration/rehabilitation targets based on comparisons of current and historical habitat distribution, pattern, and function within the HEC system. Participants also identified the need to apply hydrodynamic and ecological models not only to simulate historical water-level regimes and resulting environmental conditions, but to predict future water-level regimes and resulting environmental conditions in order to identify the most likely future locations of high-quality fish habitat, which would be the best candidate areas for protection and restoration in the HEC system as well. Finally, participants discussed the need for an international approach that includes the Great Lakes Fisheries Commission; the International Joint Commission; First Nations; The Lake Erie LAMP; various Federal, State, Provincial, and local resource management agencies; academia; and the Lake Erie Millennium Network.

Working in cooperation with resource management agency scientists and managers, a long-term strategy was developed to identify and delineate critical habitat areas necessary to maintain and/or restore sustainable fish communities within the HEC. This strategy is designed to restore habitat distribution, pattern, and function to support sustainable native aquatic and fish communities by identifying key environmental characteristics that existed historically within the HEC system; understanding how those characteristics and processes have changed through time; and then using that knowledge to guide and establish functional goals and objectives for future habitat restoration efforts. This approach is based on the fundamental assumption that native fish and aquatic communities have co-evolved and adapted to the physical characteristics of the system - including the distribution, pattern, and function of aquatic habitats and the timing and seasonality of the dynamic processes that create and maintain those habitats. Thus, restorative actions that shift HEC physical characteristics and processes back toward a more "natural state" will be sustainable and will benefit native fish and aquatic communities.

Long-Term Research Strategy

Fundamental components of the long-term research strategy include:

- **Assessment of the impact of past anthropogenic actions and stressors by performing a historical comparison of the distribution, pattern, and function of aquatic and fishery habitats with current conditions within the HEC.**

  Support ongoing efforts to assess historical and current habitat patterns and functions within the HEC by USGS Great Lakes Science Center, Michigan DNR, Ontario MNR, and Fisheries and Oceans Canada. Use existing datasets, historical reports and data, and models to summarize historical and current HEC aquatic and fish habitats and the environmental conditions and *natural processes* that create and maintain them. For each major environmental zone, use modelling tools and best professional judgment (expert knowledge) to assess how *processes, pathways,* and *habitat characteristics* have been impaired by historical anthropogenic and/or climatic stressors. Use historical and current data to determine the biophysical linkages between habitats and the organisms that use those habitats.

- **Development and application of hydrodynamic and ecological models to simulate potential changes in aquatic and fishery habitats resulting from long-term changes in water-level regime and to identify potential long-term management, protection, and restoration opportunities using historical habitat distribution, pattern, and function as a guide; and**

  Support ongoing efforts by the Great Lakes Regional Collaboration, NOAA, USGS, USACE, Environmental Canada, and the Great Lakes Commission to develop a fully integrated 3-D hydrodynamic model of the HEC including the St. Clair River, St. Clair Delta, Lake St. Clair, Detroit River, and western basin of Lake Erie. The model should be designed with the capability to incorporate ecological and habitat modules that use hydrodynamic and sediment transport data to predict the pattern and distribution of current, past, and future environmental characteristics that create and maintain critical aquatic and fisheries habitats within the HEC.

- **Establishment of a long-term, binational fishery and aquatic habitat research and monitoring effort within the HEC system. Provide the knowledge and science-based tools to build the capacity of key agencies, organizations, and institutions to identify and implement sustainable protection, restoration, and enhancement opportunities.**

  Support efforts to work cooperatively with other agencies/programs to implement comprehensive monitoring programs within the HEC. Provide technical support and guidance to key agencies, organizations, and institutions to identify and *implement* aquatic habitat restoration opportunities at multiple scales within the HEC.

Major Research Needs

Based on the three Research Needs workshops, workshop participants developed an aquatic habitat characterization/mapping strategy that integrates abiotic and biotic processes and environmental characteristics with existing data sets on instream, riparian nearshore, and open-water aquatic habitats. Through the application of historical analyses and physical and ecological modelling, this strategy can be applied to identify potential place-based, species-based, and process-based restoration opportunities within each of the major environmental zones within the HEC. Six major Research Needs steps were identified based on discussions with workshop participants.

Research Need 1 - Develop an inventory of current and historical HEC datasets and publications. Identify critical data gaps and work to fill those data gaps.

Research Need 2 - Document the current and pre-disturbance distribution, pattern, and function of habitats within the three major HEC environmental zones using available contemporary and historical datasets.

- Use these data to compare pre-disturbance and current conditions to assess and quantify changes or impairments in habitat distribution, pattern, and function.

Research Need 3 - Identify significant historical actions or stressors that have resulted in HEC habitat impairments.

- Identify specific events or actions that resulted in significant HEC habitat impairments.
- Assess historical thresholds and time lags associated with stressors and resulting impairments.

Research Need 4 - Develop and apply integrated 1-D, 2-D, and 3-D hydrodynamic and ecological modeling tools to predict current, historical, and future distribution, pattern, and function of habitats for varying water-level regimes for the three major HEC environmental zones within the HEC system.

- Apply these modeling tools to assess current habitat conditions. Validate models using currently available datasets.
- Apply these modeling tools to pre-disturbance conditions to assess bio-physical linkages. Validate models using historical data where available.
- Compare results to quantify and validate habitat degradation (or improvement) resulting from specific historical actions of stressors.
- Assess impacts and prioritize historical actions or stressors causing those impacts.

Research Need 5 - Establish restoration/rehabilitation targets and goals based on knowledge gained from historical comparison to current conditions.

- Develop an overall vision and set of goals for habitat protection and restoration within the HEC that includes all ecological integrity elements – physical, chemical, and biological.
- The overall vision and set of goals should be based upon historical analysis of inferred habitat distribution, pattern, and function.

Research Need 6 - Identify potential habitat restoration/rehabilitation opportunities based on qualitative and quantitative assessments of habitat distribution, pattern, and function. Establish a long-term habitat monitoring program tied to performance indicators.

- Working at multiple scales, evaluate ways to reverse or mitigate significant historical events or actions that resulted in HEC habitat impairments. Identify a comprehensive suite of sustainable restoration projects designed to restore aquatic habitat distribution, pattern, and function within the HEC system.
- Use modeling tools to predict system response and sustainability in anticipation of future changes to water-level and thermal regimes based on expected anthropogenic or natural stressors (e.g. climate change)
- Implement a comprehensive monitoring program to assess physical, chemical, and biological response to restoration/rehabilitation efforts.

A flow chart relating critical research needs to restoration strategies is provided in Figure 6 in the Summary section of the report.

Aquatic habitat restoration opportunities probably exist at multiple scales within the HEC system, and implementation of these research needs will require international cooperation between agencies and programs within the HEC system.

REFERENCES

-Baedke, S.J., and Thompson, T.A., 2000. A 4,700-year record of lake level and isostasy for Lake Michigan. Journal of Great Lakes Research, . 26(4): 416-426.

-Bolsenga, S.A. and Herdendorf, C.E., 1993, Lake Erie and Lake St. Clair handbook, Wayne State University Press, Detroit, MI. 467 p.

-Burkett, Virginia R., Douglas A. Wilcox, Robert Stottlemyer, Wylie Barrow, Dan Fagre, Jill Baron, Jeff Price, Jennifer L. Nielsen, Craig D. Allen, David L. Peterson, Greg Ruggerone, and Thomas Doyle. 2005. Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. *Ecological Complexity* 2(4): 357-394.

-Chubb, S and C.R. Liston. 1985. Relationships of water level fluctuations and fish. Pages 121-140 *in* H.H. Prince and F.M. D'Itri, editors. Coastal Wetlands. Lewis Publishers, Inc., Chelsea, Michigan.

-Derecki, J.A. 1985. Effect of channel changes in the St. Clair River during the present century: *Journal of Great Lakes Research*, 11(3): 201-207.

-Edsall, T. and J. Cleland. 1989. Effects of altered water levels and flows on fish in the Great Lakes connecting channels. IJC Water Levels Reference Study, Task Group 2, Task 202-4 Report. USFWS, National Fisheries Research Center, Ann Arbor, MI. 164 p.

-Goodyear, C.D., T.A. Edsall, D.M. Ormsby-Dempsey, G.D. Moss, and P.E. Polanski. 1982. Atlas of spawning and nursery areas of Great Lakes fishes. USFWS, Report FWS/OBS-82/52, Volumes 1-14, Washington, DC.

-Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson. 2003. Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems: Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C., 105 p.

-Leach, J. H. and R. C. Herron. 1992. A review of lake habitat classification: *in* Busch, W. D. N. and P. G. Sly, eds. The development of an aquatic habitat classification system for lakes. Boca Raton, FL: CRC Press. p. 27-58.

-Lee, D.H., R. Moulton, and D.A. Hibner. 1996. Climate change impacts on Western Lake Erie, Detroit River, and Lake St. Clair water levels: Great Lakes – St. Lawrence Basin Project, Environment Canada and NOAA, GLERL Contribution #985, 44 p.

-Lenters, J.D., 2001, Long-term Trends in the Seasonal Cycle of Great Lakes Water Levels: *Journal of Great Lakes Research,* 27(3): 342-353.

-Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes Water Resources based on climate scenarios of two GCM's: *Journal of Great Lakes Research*, 28(4): 537-554.

-Mackey, S.D. 2005. Physical Integrity of the Great Lakes: Opportunities for Ecosystem Restoration. Report to the Great Lakes Water Quality Board, International Joint Commission, Windsor, ON.

-Mackey, S.D. and R.R. Goforth, 2005, Great Lakes Nearshore Habitat Science: *in* Mackey, S.D. and R.R. Goforth, eds. Great Lakes nearshore and coastal habitats: Special Issue, Journal of Great Lakes Research 31 (Supplement 1): 1-5.

-Manny. B.A. 2003. Setting priorities for conserving and rehabilitating Detroit River habitats. *in* J.H. Hartig, eds. Honoring our Detroit River: Caring for our Home. Cranbrook Institute of Science, Bloomfield Hills, MI. p. 121-139.

-Mortsch, L.D. 1998. Assessing the impact of climate change on the Great Lakes shoreline wetlands: *Climate Change* 40: 391-416.

-Mortsch, L.D. and F.H. Quinn. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies: *Limnology and Oceanography* 41: 903-911.

-National Geophysical Data Center. 1998. Bathymetry of Lake Erie and Lake Saint Clair. In World Data Center for Marine Geology and Geophysics report #MGG-13. L.A. Taylor, P. Vincent, and J.S. Warren, editors. National Geophysical Data Center. Boulder, CO.

-Peters, D.S. and F.A. Cross. 1992. What is coastal fish habitat? Pages 17-22 In Richard H. Stroud (ed.), Stemming the tide of coastal fish habitat loss. Proc. of a Symposium on Conservation of Coastal Fish Habitat, Baltimore, MD. Published by the National Coalition for Marine Conservation, Inc., Savannah, GA.

-Quinn, F.H. 2002. Secular Changes in Great Lakes Water Level Seasonal Cycles: *Journal of Great Lakes Research,* 28(3): 451-465.

-Quinn, F.H. 1985. Temporal effects of St. Clair River dredging on Lakes St. Clair and Erie water levels and connecting channel flow: *Journal of Great Lakes Research*, 11(3): 400-403.

-Saxon, E.D. 2003. Adapting ecoregional plans to anticipate the impact of climate change. in Drafting a Conservation Blueprint – A Practitioner's Guide to Planning for Biodiversity: C.R. Groves, editor. The Nature Conservancy, Island Press. p. 345-365.

-Sousounis, P.J. and E.K. Grover. 2002. Potential future weather patterns over the Great Lakes region: *Journal of Great Lakes Research*, 28(4): 496-520.

-Vanderploeg, H.A., Nalepa, T.F., Jude, D.J., Mills, E.L., Holeck, K.T., Liebig, J.R., Grigorovich, I.A., and Ojaveer, H. 2002. Dispersal and ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 59: 1209-1228.

-W.F. Baird & Associates. 2005. Regime change (man made intervention) and ongoing erosion in the St. Clair river and impacts on lake Michigan-Huron lake level. Final Report to the Georgian Bay Association, W.F. Baird & Associates, Oakville, Ontario. 141 p.

-Wilcox, Douglas A. 2004. Implications of hydrologic variability on the succession of plants in Great Lakes wetlands. *Aquatic Ecosystem Health & Management* 7(2): 223-231.

-Wilcox, Douglas A., James E. Meeker, Patrick L. Hudson, Brian J. Armitage, M. Glen Black, and Donald G. Uzarski. 2002. Hydrologic variability and the application of Index of Biotic Integrity metrics to wetlands: a Great lakes evaluation. *Wetlands* 22(3): 588-615.

-Wuebbles, D.J. and K. Hayhoe. 2004. Climate change projections for the United States Midwest: Mitigation and Adaptation Strategies for Global Change, XX. p. 1-29.

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