GREAT LAKES WATER PROTECTION (SOAR 2011)

The Laurentian Great Lakes (LGL) - St. Lawrence River (SLR) system contain 20% of the world's surface fresh water and serve both water supply and waste disposal services for over 33 million residents in the United States and Canada. Technological advances have controlled the outflow of the Great Lakes at the St. Lawrence River and this has brought with it social benefits and environmental costs. The United States and Canada share the management of this resource and have shared notable success controlling environmental consequences of development yet are faced with emerging issues. The LGL/SLR system will be examined from a multidisciplinary multi-national perspective to illustrate that a shared resource can be maintained. Upon completion of this course, one will be able to understand the forces (geomorphic, biological, chemical, social, economic, and political) that shaped and impacted a globally significant resource.

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Lecture-Based Course Outline

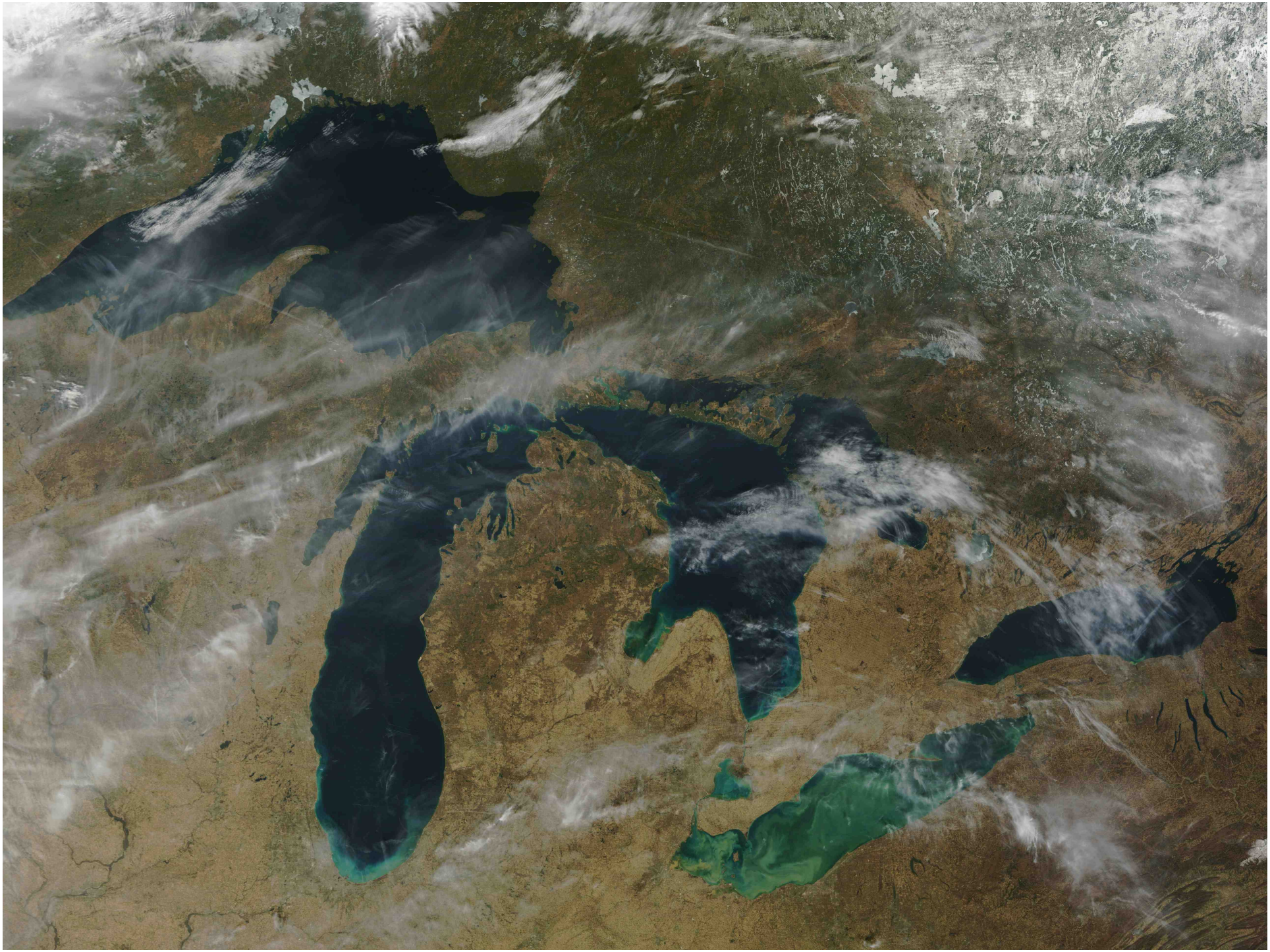
Date	Topic
May 9 (Hour 1)	○ **Introduction to the LGL-SLR System** ○ Geology of the LGL-SLR Basin ○ Physical and Chemical Limnology of the Great Lakes ○ Biological Limnology of the Great Lakes
May 9 (Hour 2)	**Early History, Exploration, Settlement, and Nation Development in the LGL-SLR Watershed** (Rush-Bagot Treaty of 1817, Boundary Waters Treaty of 1909, Great Lakes Water Quality Agreement of 1972)
May 16 (Hour 1)	**Modern Water Quality Issues and Responses** I. Great Lakes Fishery Collapse (The United States-Canadian Great Lakes Fisheries Convention II. Toxic Chemical Contamination - Areas of Concern and Remedial Action Plans: A Focus on the Massena AOC/Regionalism and Nationalism
May 16 (Hour 2)	III. The St. Lawrence Seaway and Invasive Species: Linking Geomorphology to Social Responsibility IV. Water Level Regulation and Debates V. Governance: Roles of Citizenry and Government

The Great Lakes Literacy Principles

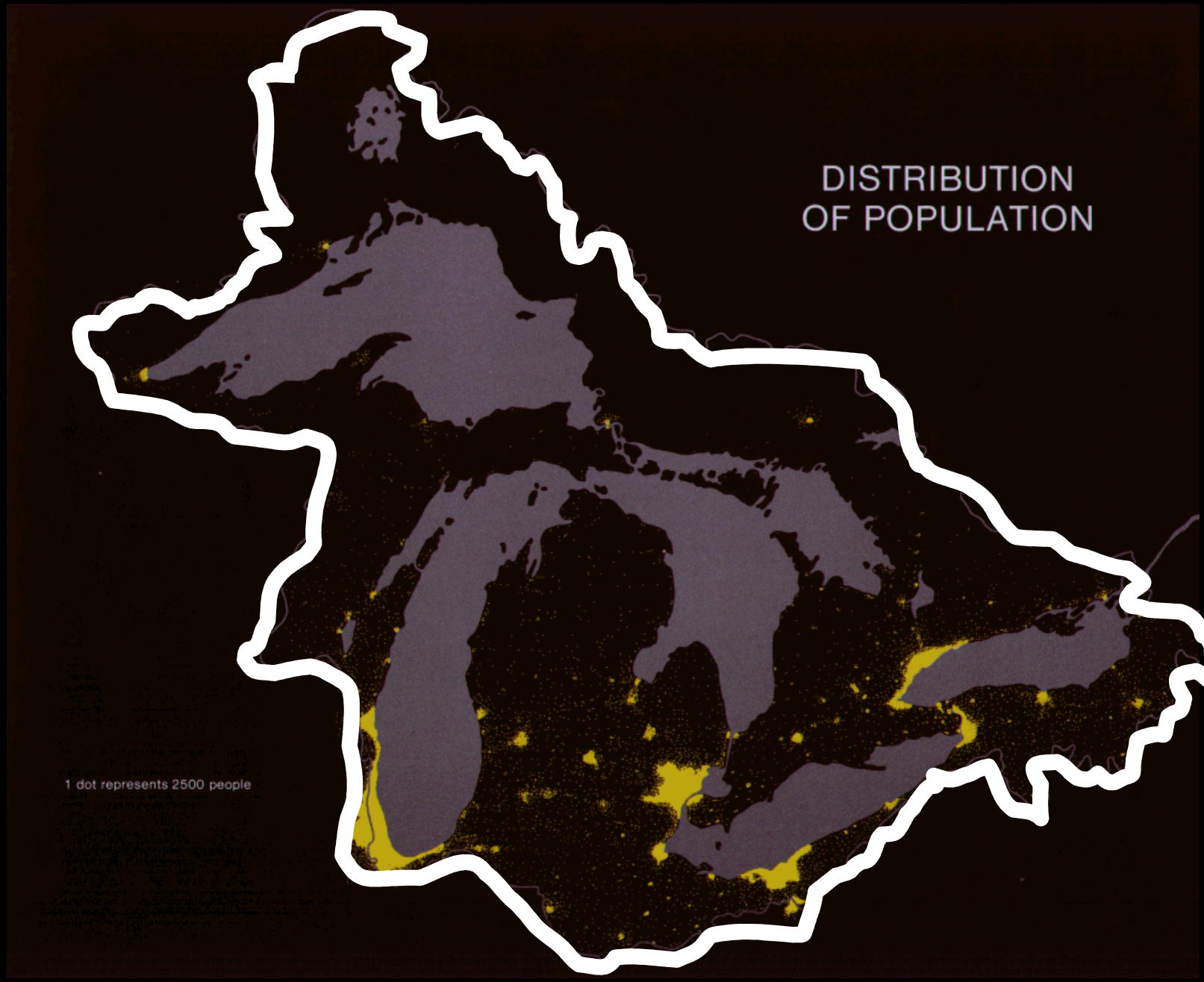
1. **The Great Lakes, bodies of fresh water with many features, are connected to each other and to the world ocean.**
2. **Natural forces formed the Great Lakes; the lakes continue to shape the features of their watershed.**
3. **The Great Lakes influence local and regional weather and climate.**
4. **Water makes Earth habitable; fresh water sustains life on land.**
5. **The Great Lakes support a broad diversity of life and ecosystems.**
6. **The Great Lakes and humans in their watersheds are inextricably interconnected.**
7. **Much remains to be learned about the Great Lakes.**
8. **The Great Lakes are socially, economically, and environmentally significant to the region, the nation and the planet.**

Source: COSEE Great Lakes

U.S. Army Corps of Engineers, Detroit District



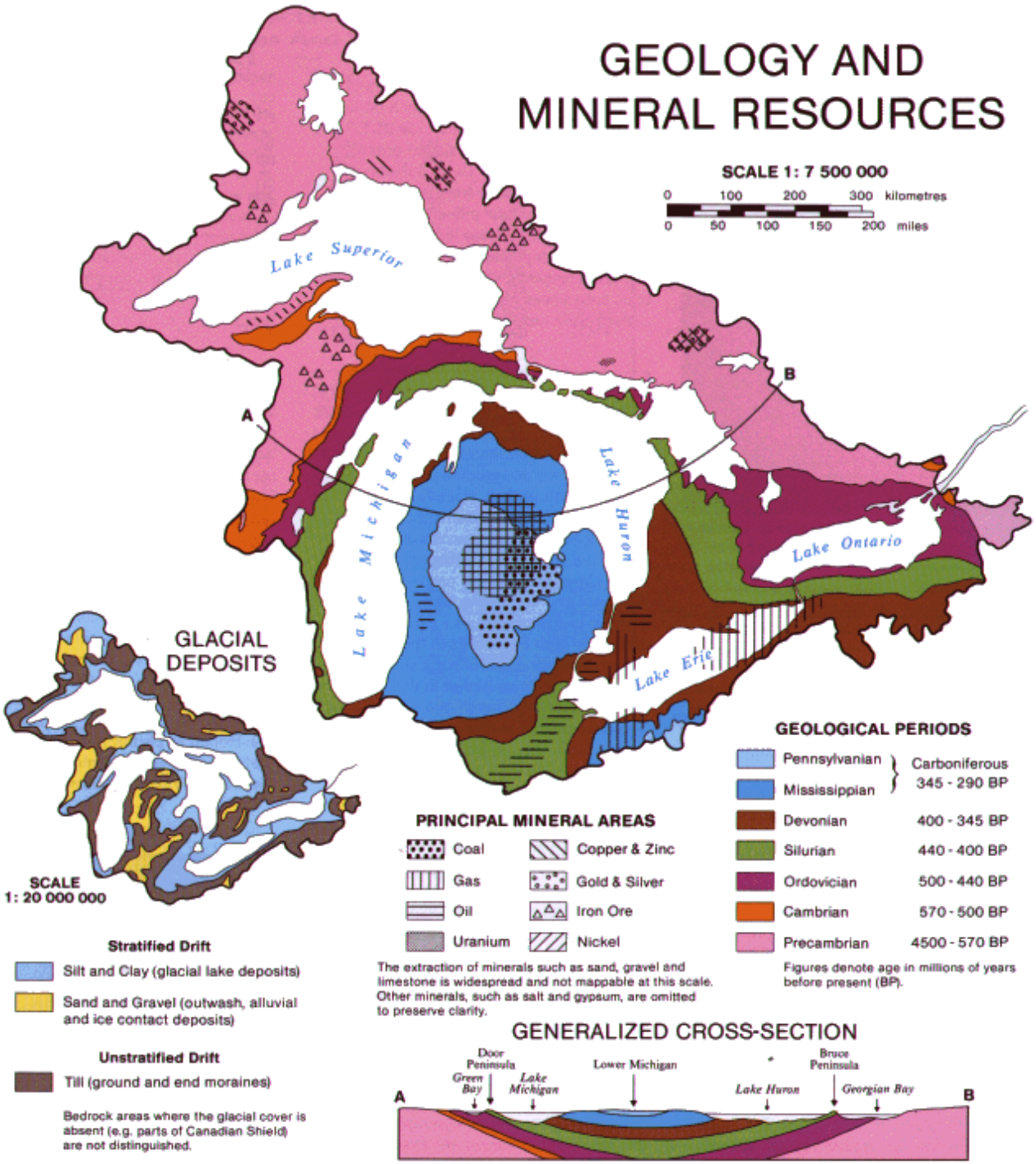
1. The Great Lakes Environment



Physical Features And Human Population in the Great Lakes-St. Lawrence River system

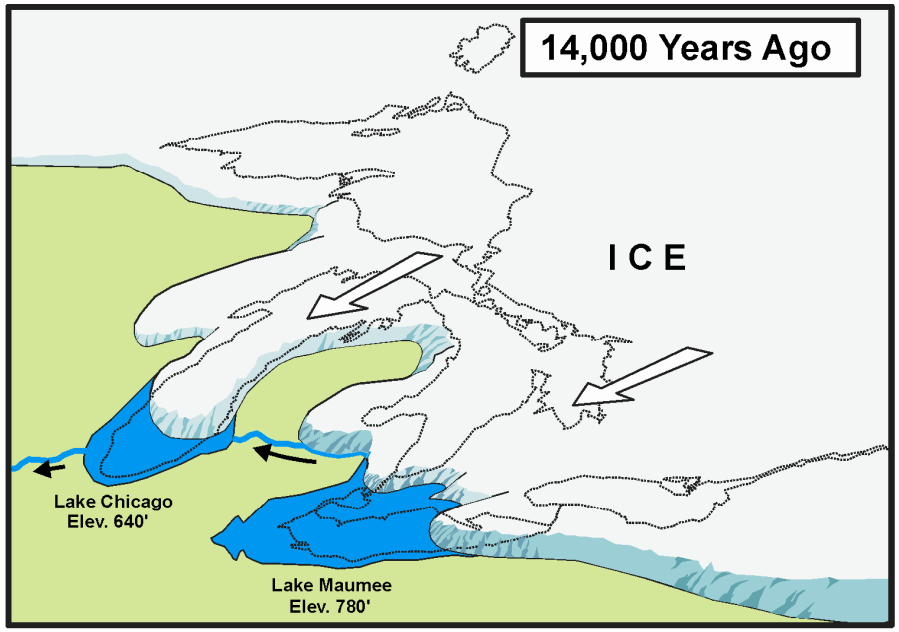
Parameter	Units	Superior	(Michigan	Huron)	Erie	Ontario	Totals
Elevation	m	183	176	176	173	74	
Length	km	563	494	332	388	311	
Breadth	km	257	190	245	92	85	
Average Depth	m	147	85	59	19	86	
Maximum Depth	m	406	282	229	64	244	
Volume	km^3	12,100	4,920	3,540	484	1,640	22,684
Water Area	km^2	82,100	57,800	59,600	25,700	18,960	244,160
Land Drainage Area	km^2	127,700	118,000	134,100	78,000	64,030	521,830
Total Area	km^2	209,800	175,800	193,700	103,700	82,990	765,990
Shoreline Length	km	4,385	2,633	6,157	1,402	1,146	17,017d
Retention Time	years	191	99	22	2.6	6	
Population: U.S.A., 1990		425,548	10,057,026	1,502,687	10,017,530	2,704,284	24,707,075
Canada, 1991		181,573		1,191,467	1,664,639	5,446,611	8,484,290
Totals		607,121	10,057,026	2,694,154	11,682,169	8,150,895	33,191,365
Outlet /Connecting Channels		*St. Marys River*	*Straits of Mackinac*	*St. Clair and Detroit Rivers*	*Niagara River*	*St. Lawrence River*	

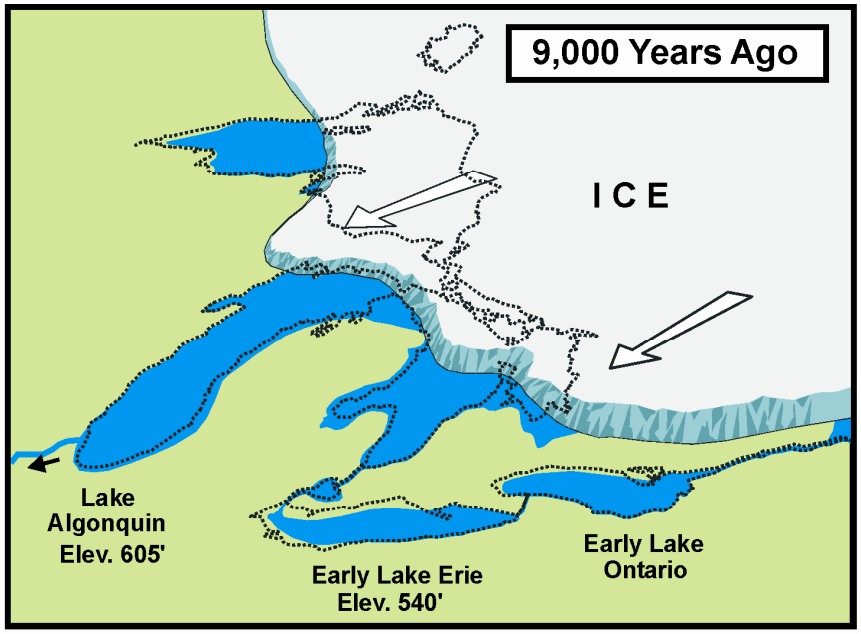
Source: Great Lakes Environmental Atlas: http://www.epa.gov/glnpo/atlas/intro.html

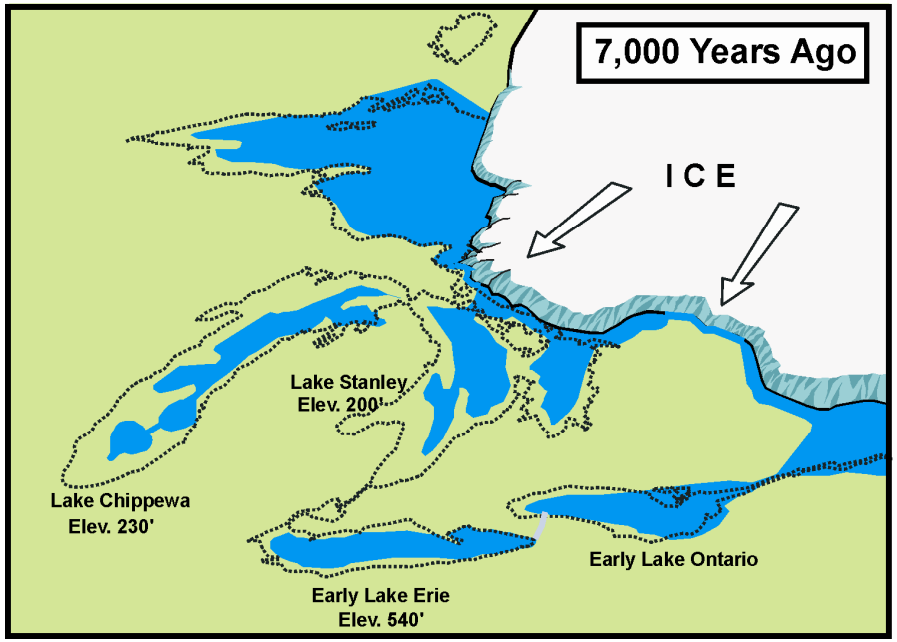


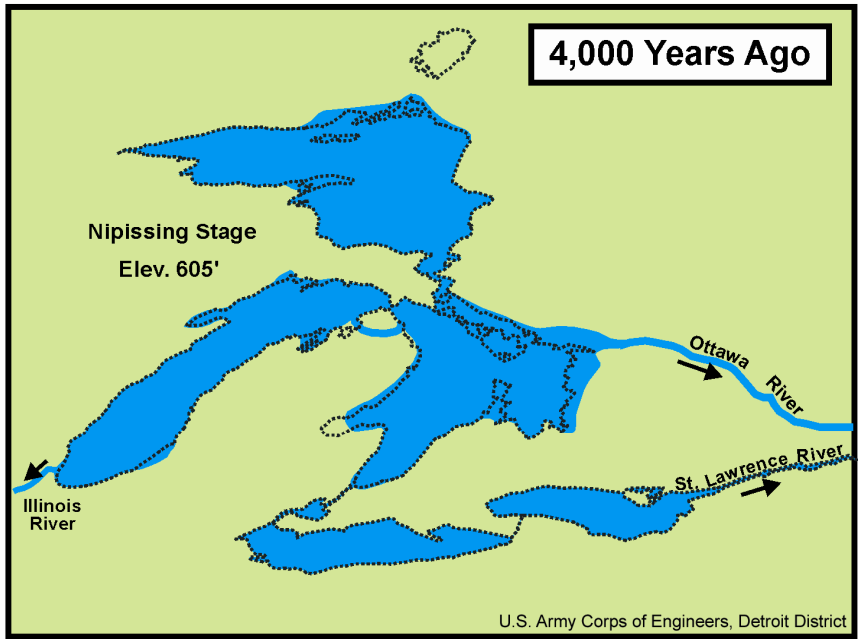
Ancient seabed
(Silurian, 444 Mya)

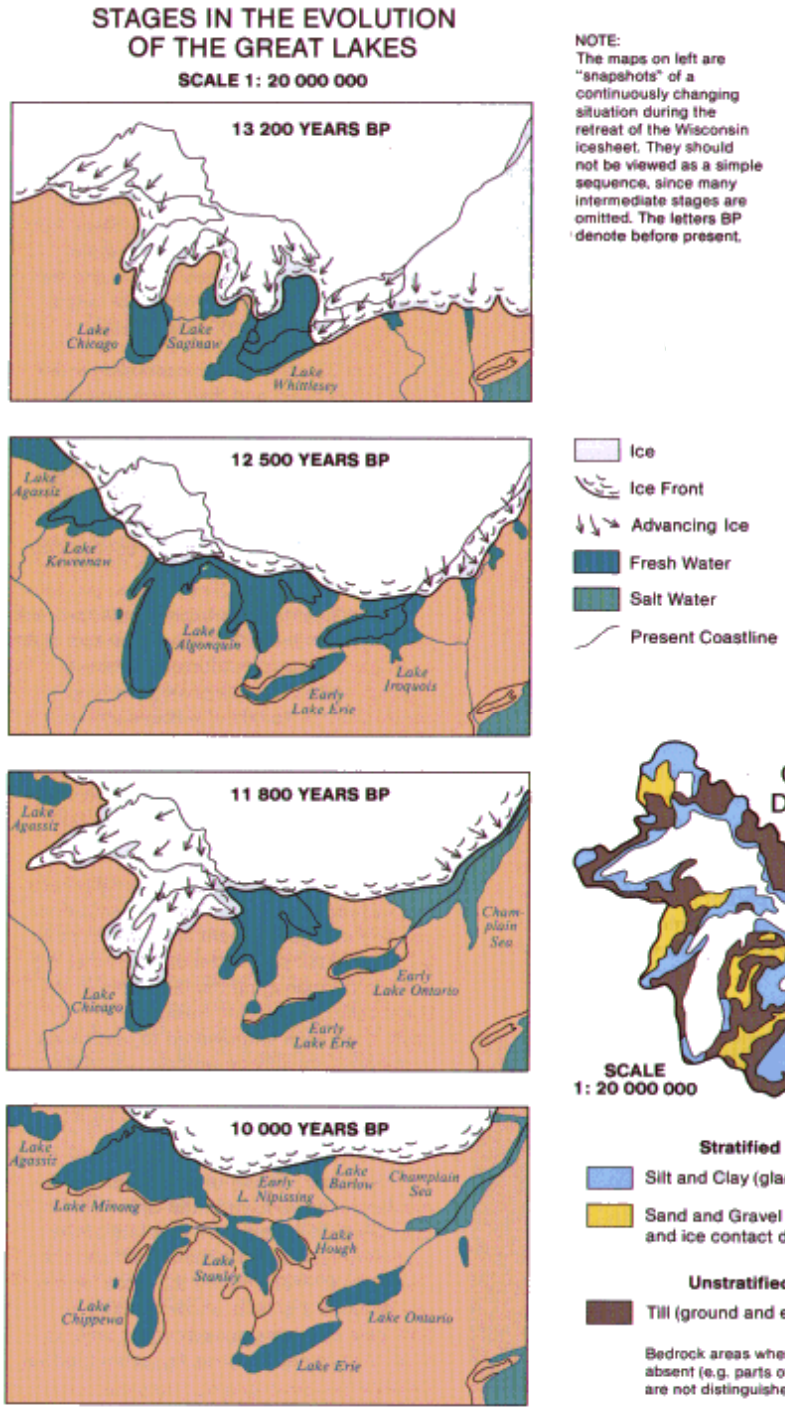
cuesta


14,000 Years Ago
ICE
Lake Chicago
Elev. 640'
Lake Maumee
Elev. 780'

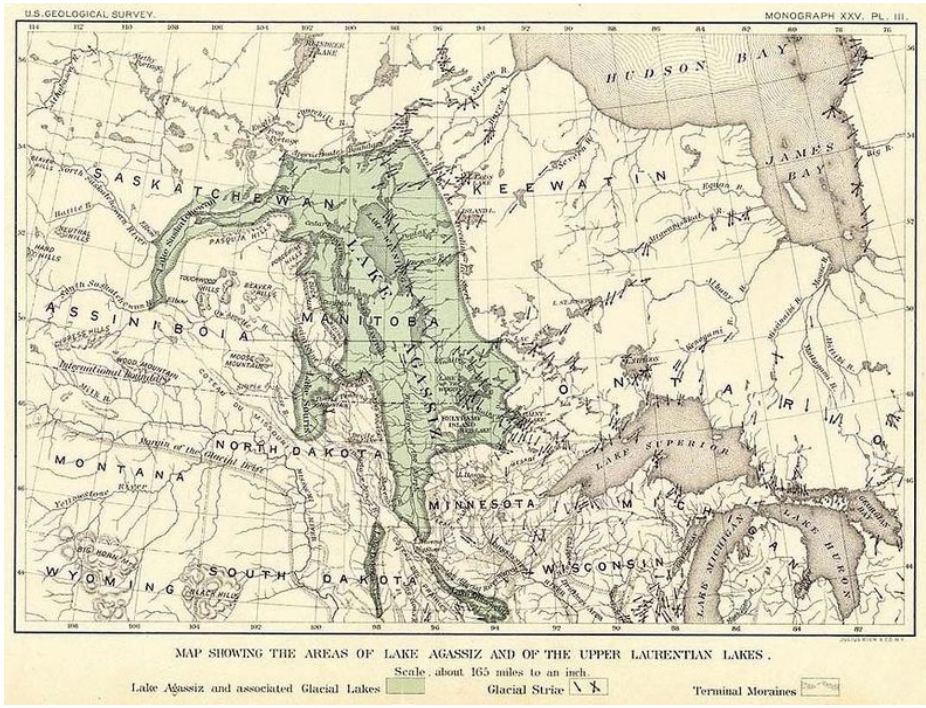

9,000 Years Ago
ICE
Lake
Algonquin
Elev. 605'
Early Lake Erie
Elev. 540'
Early Lake
Ontario


7,000 Years Ago
ICE
Lake Stanley
Elev. 200'
Lake Chippewa
Elev. 230'
Early Lake Ontario
Early Lake Erie
Elev. 540'


4,000 Years Ago
Nipissing Stage
Elev. 605'
Ottawa River
St. Lawrence River
Illinois
River
U.S. Army Corps of Engineers, Detroit District



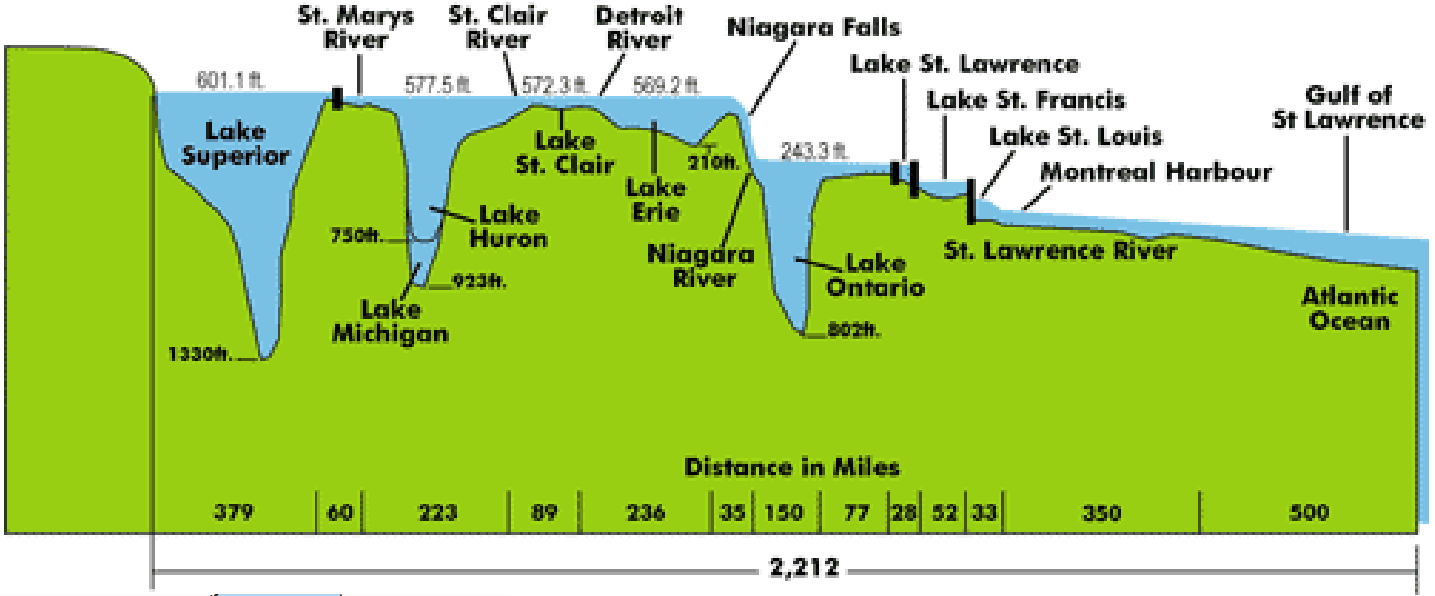
Lake Agassiz: 12,500 years ago



Potsdam New York was beneath the Champlain Sea just 10,000 years ago

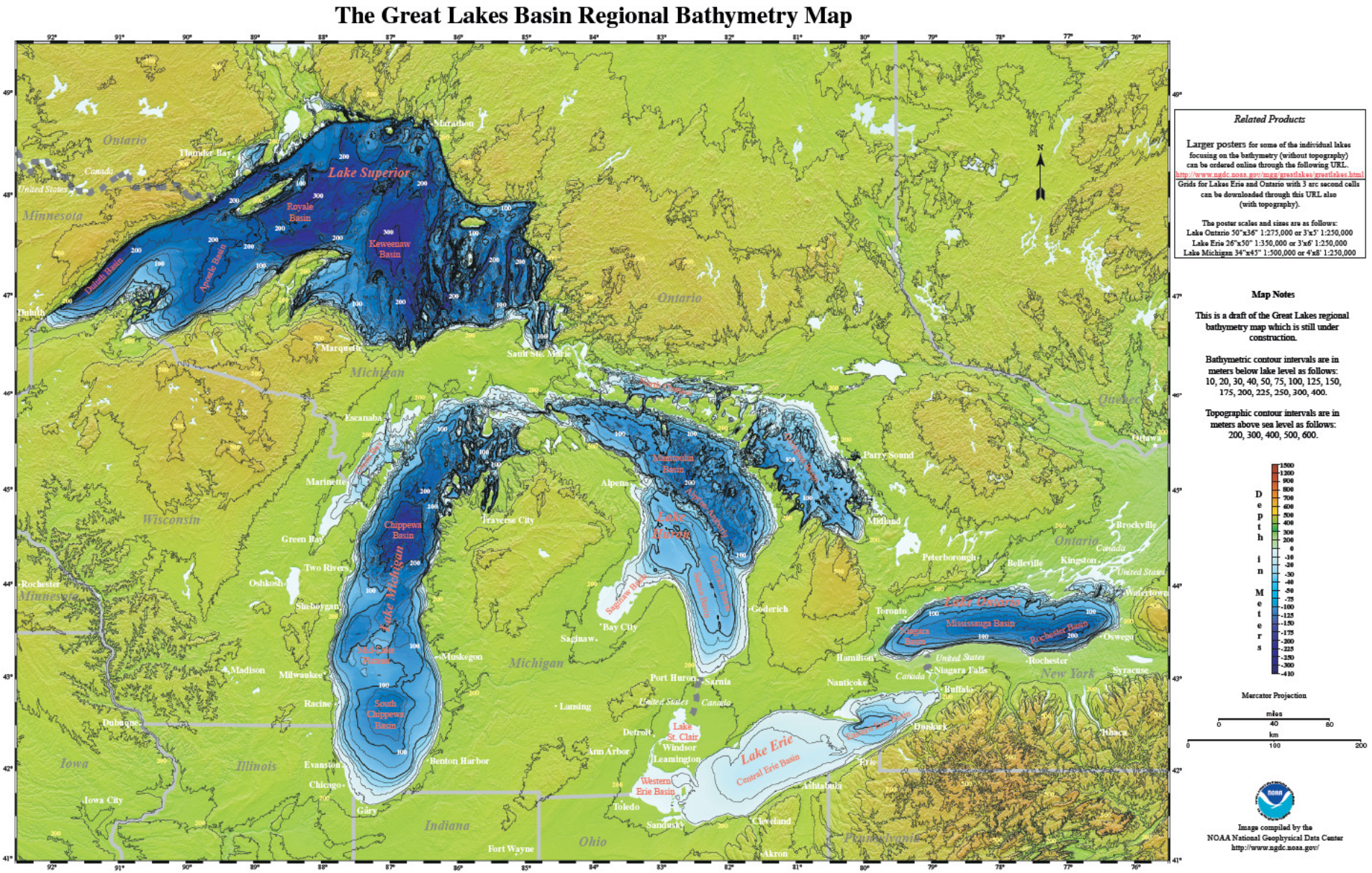
- evidence:
  - whale bones discovered in marine mud in Norfolk
  - beach dunes (Colton, Parishville)

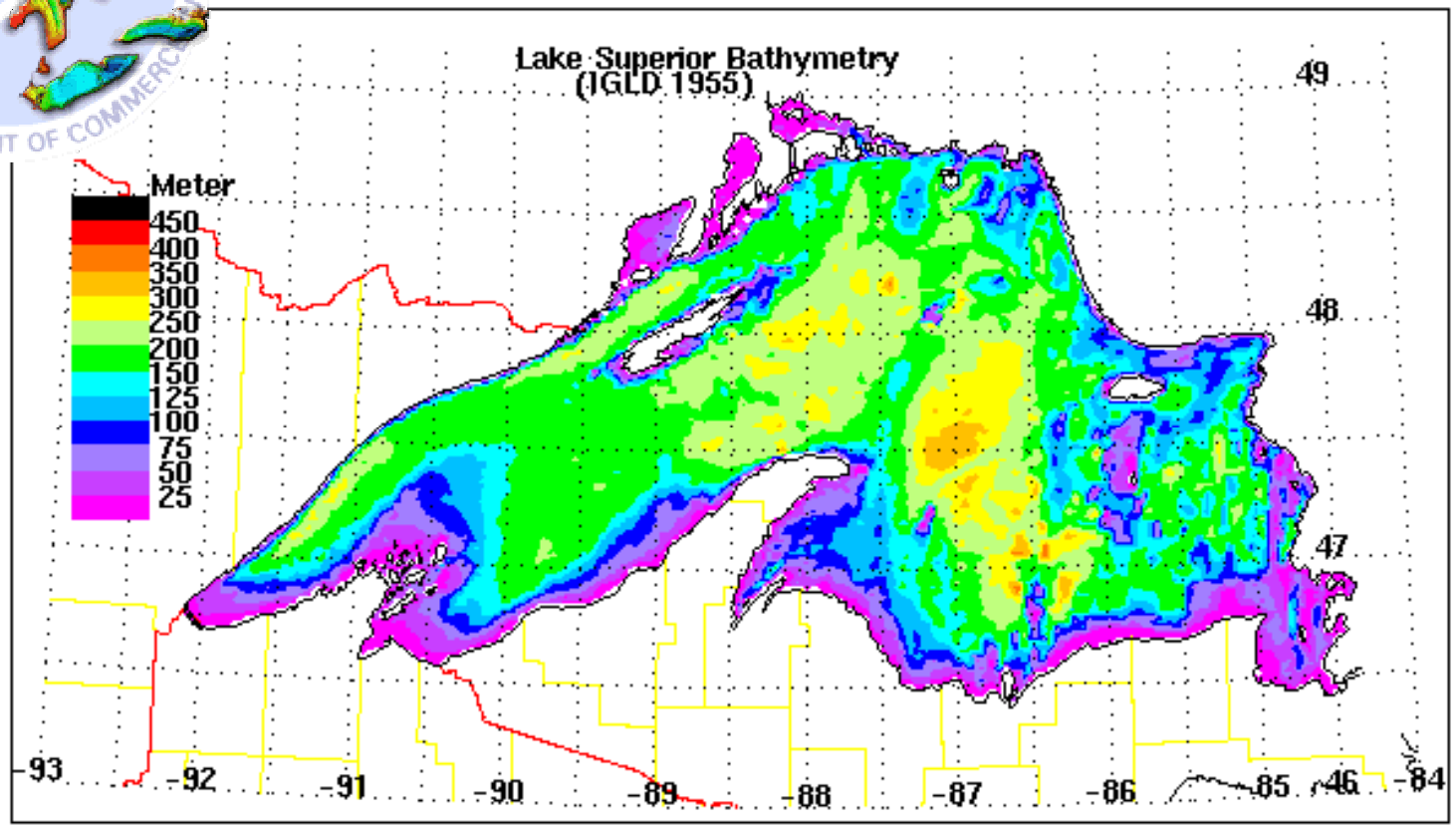
Great Lakes System Profile



U.S. Army Corps of Engineers, Detroit District

Bathymetry (topographic maps for beneath water surfaces)

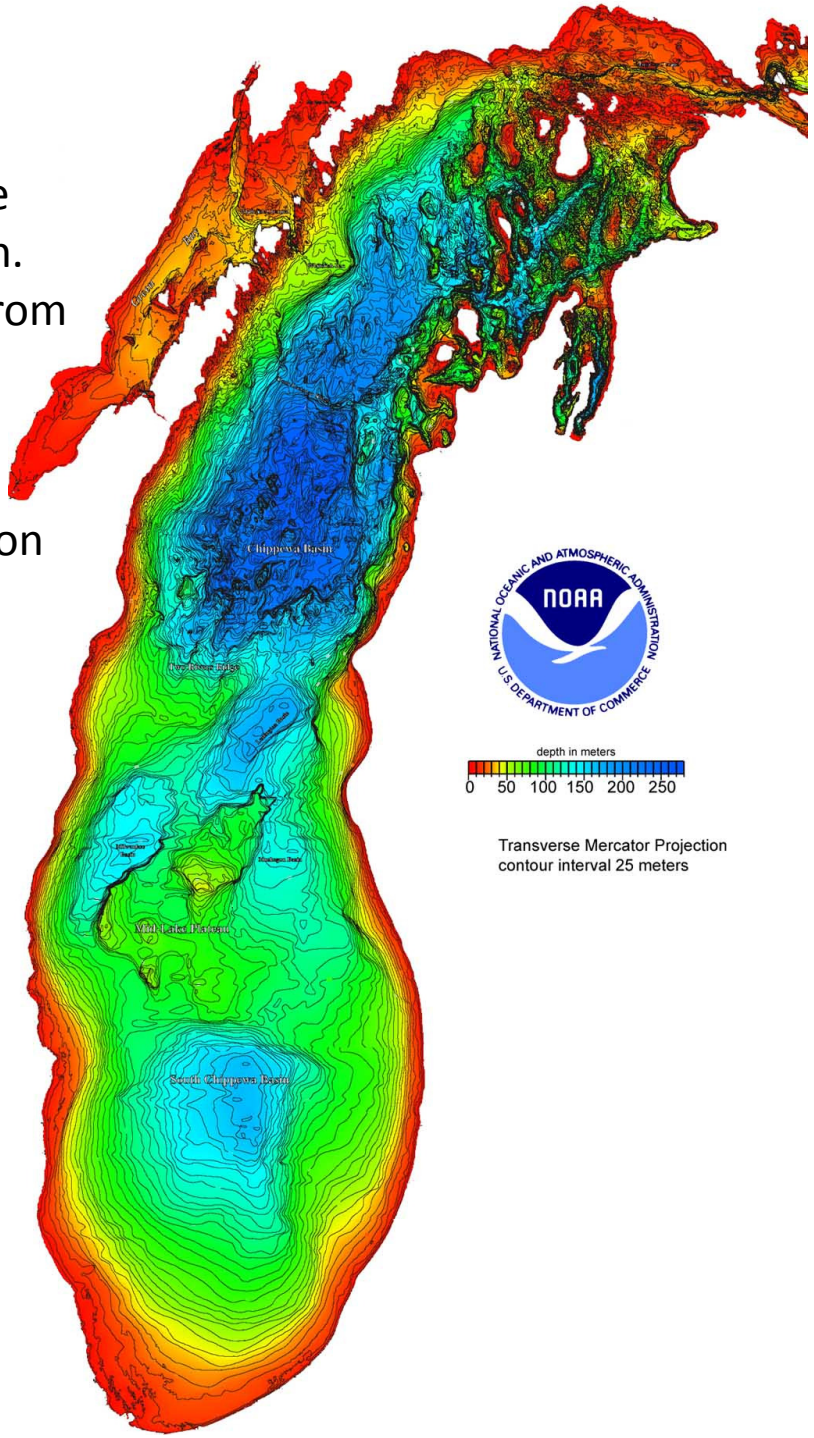




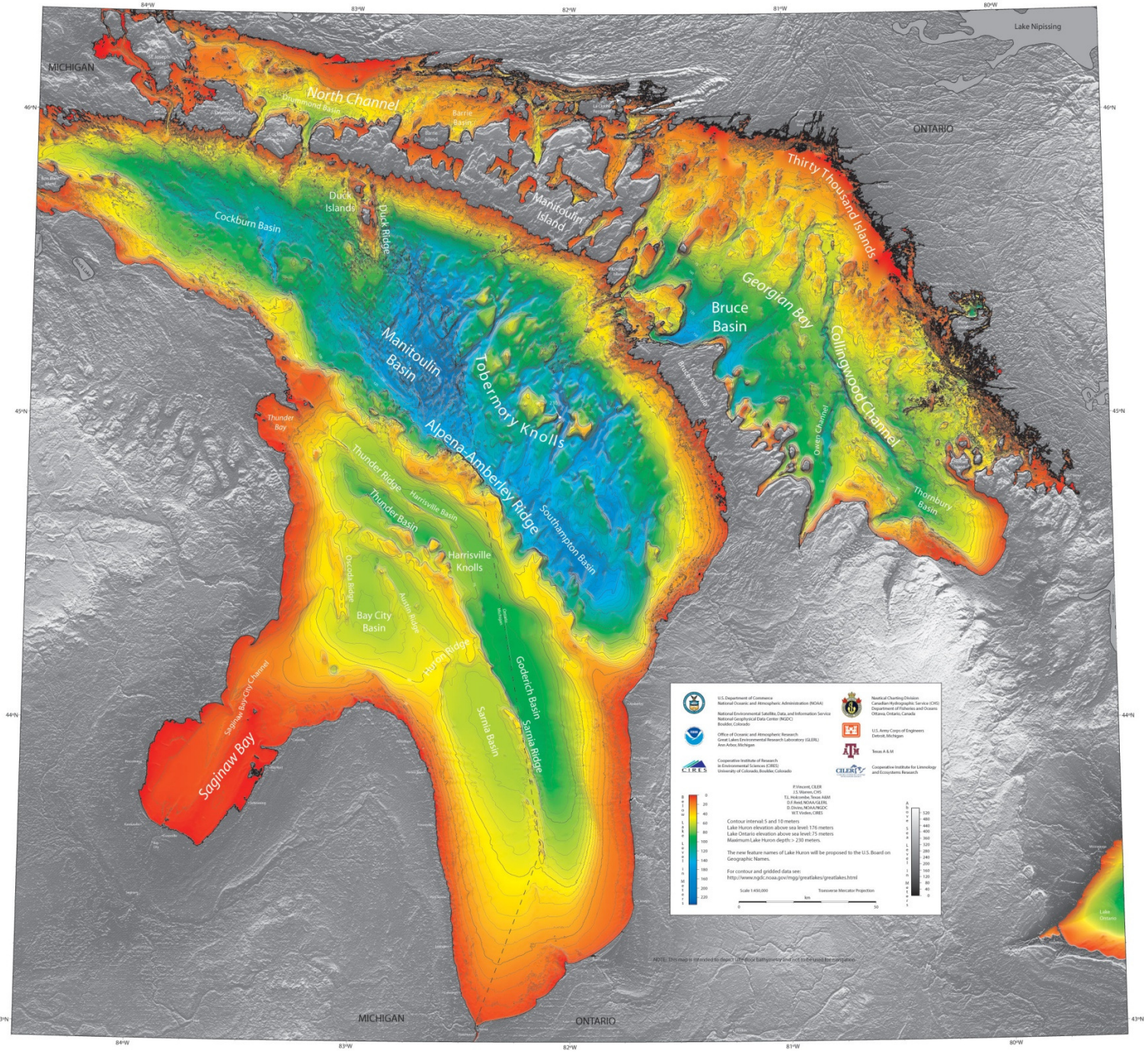
Lake Superior has tectonic origins resulting from a rift in the plate 1,000 MYA.

All other Great Lakes are primarily of glacial origin. Ice scoured the basins from bedrock and left glacial deposits (till).

Lakes Michigan and Huron are technically one lake with two basins.



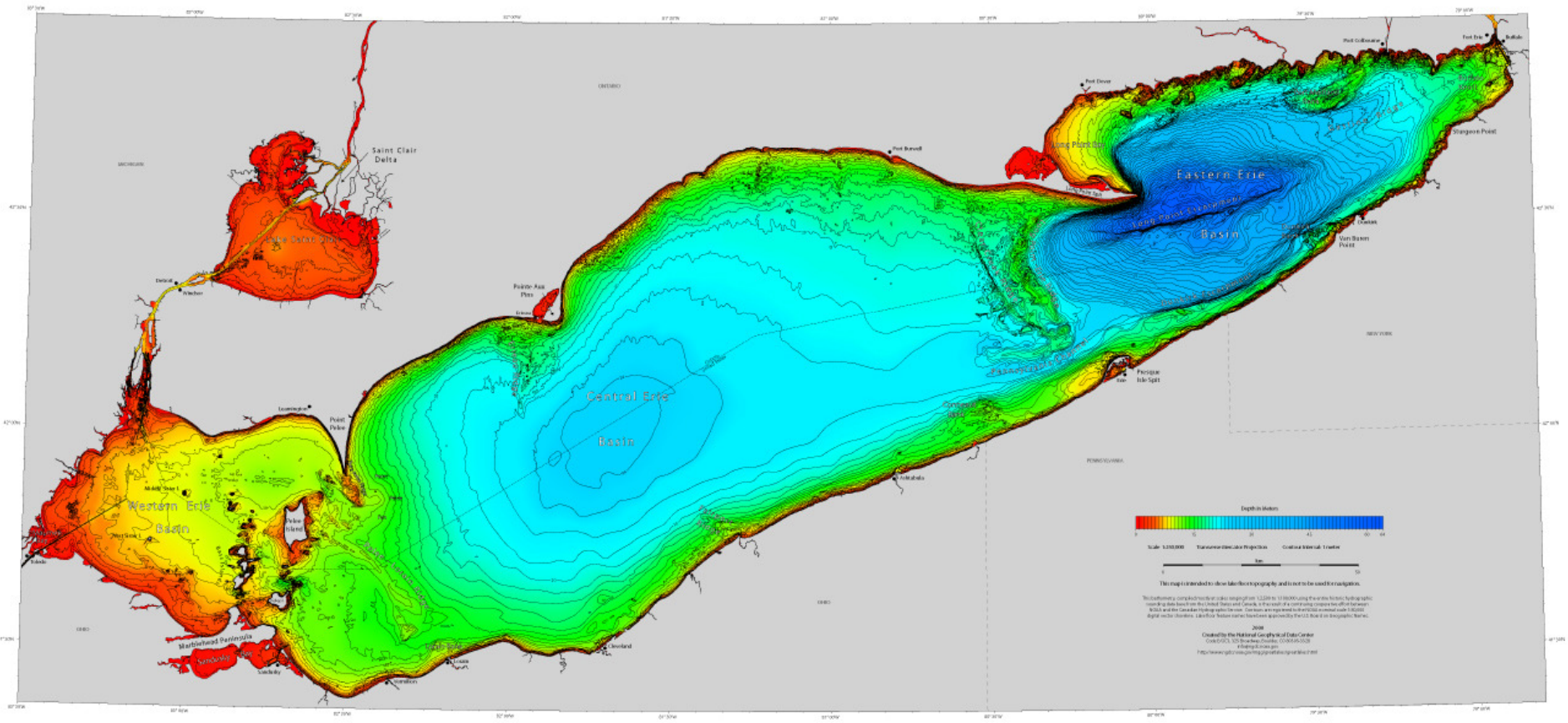
Bathymetry of Lake Huron with Topography

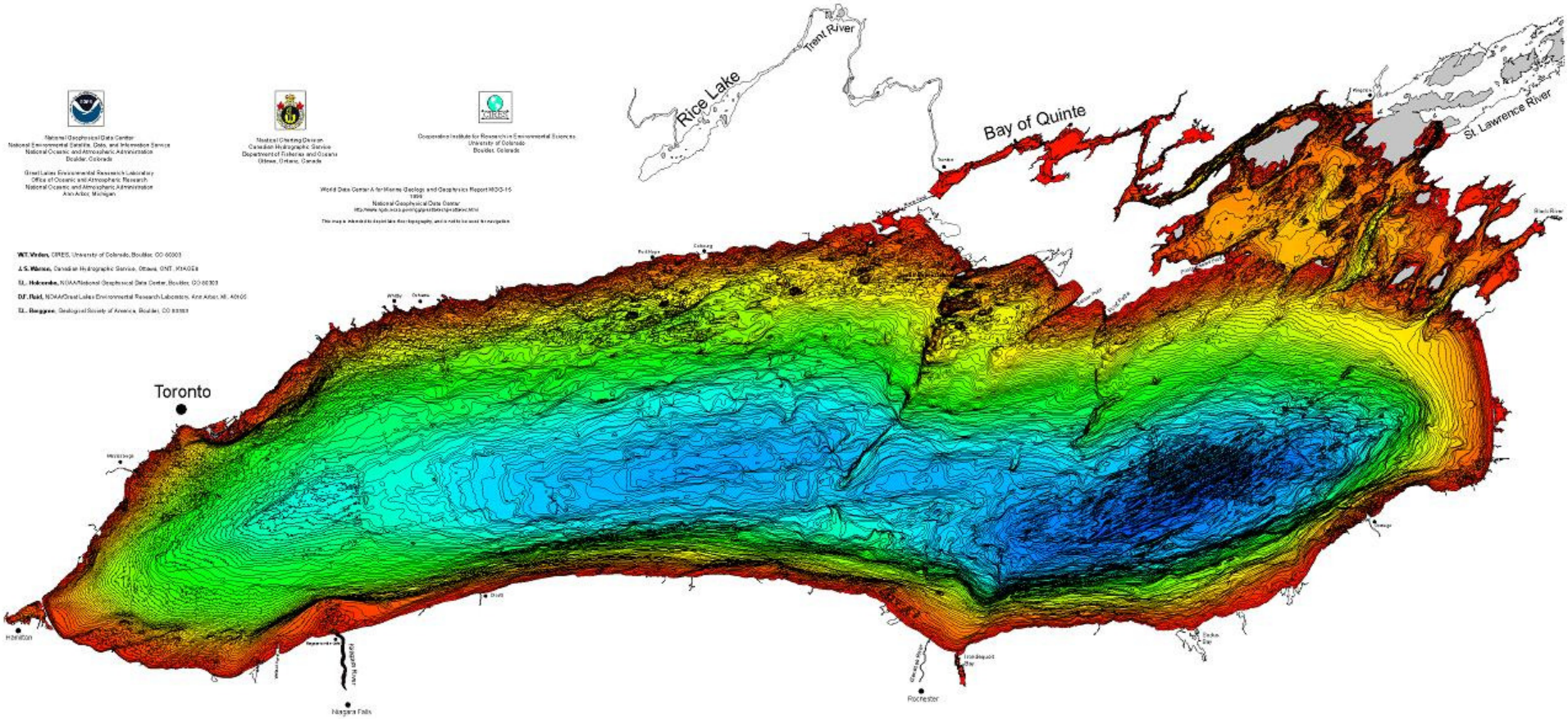


National Oceanic and Atmospheric Administration
National Geophysical Data Center,
National Environmental Satellite, Data, and Information Service /
Great Lakes Environmental Research Laboratory,
Office of Oceanic and Atmospheric Research

BATHYMETRY OF LAKE ERIE AND LAKE SAINT CLAIR

Canadian Hydrographic Service
Nautical Charting Division
Department of Fisheries and Oceans





National Geophysical Data Center
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration
Boulder, Colorado

Great Lakes Environmental Research Laboratory
Office of Oceanic and Atmospheric Research
National Oceanic and Atmospheric Administration
Ann Arbor, Michigan

National Charting Division
Canadian Hydrographic Service
Department of Fisheries and Oceans
Ottawa, Ontario, Canada

Cooperative Institute for Research in Environmental Sciences
University of Colorado
Boulder, Colorado

World Data Center A for Marine Geology and Geophysics Report MGG-15
1999
National Geophysical Data Center

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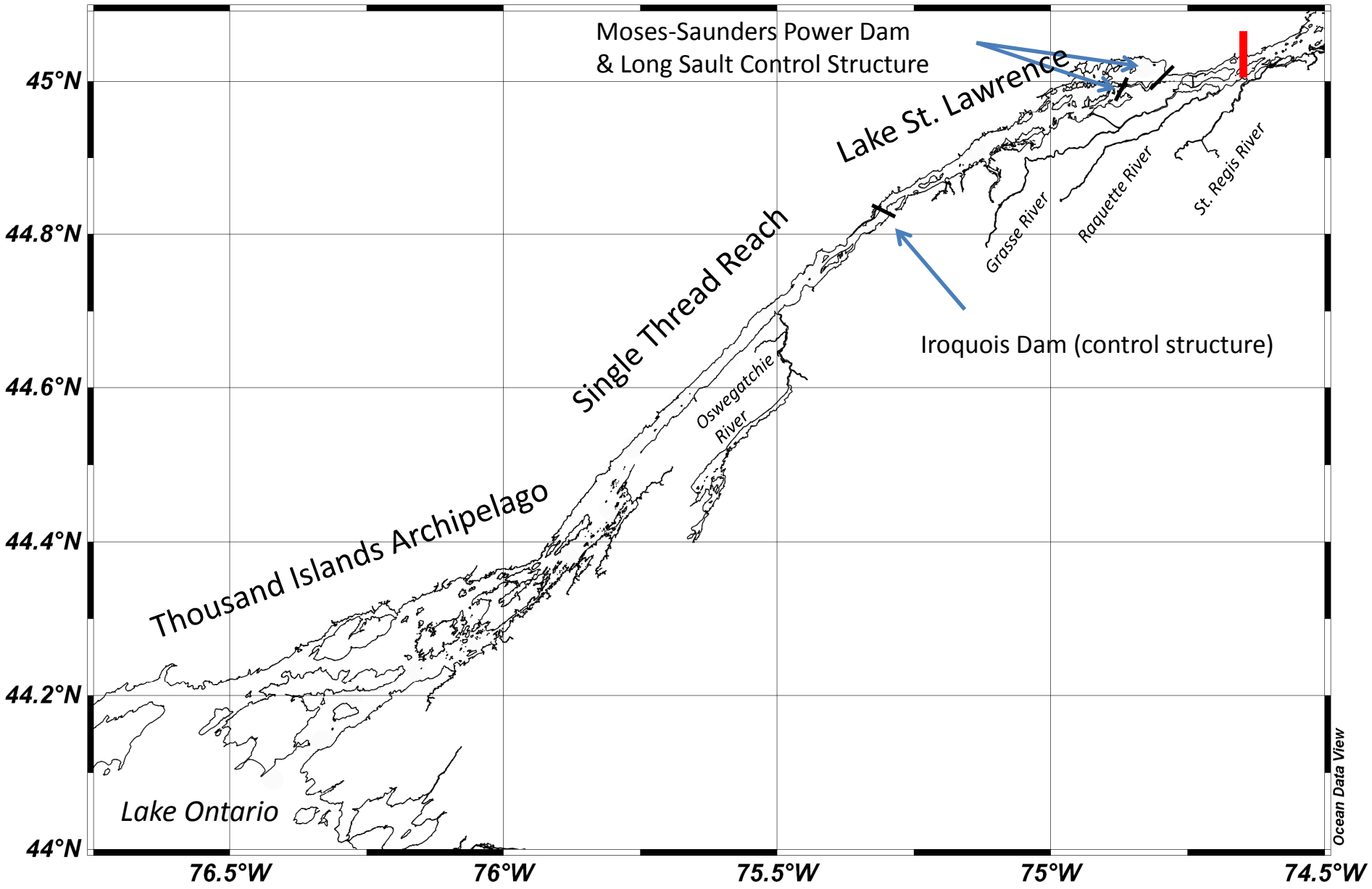

Moses-Saunders Power Dam
& Long Sault Control Structure
Lake St. Lawrence
Single Thread Reach
Thousand Islands Archipelago
Iroquois Dam (control structure)
Grasse River
Raquette River
St. Regis River
Oswegatchie River
Lake Ontario
45°N
44.8°N
44.6°N
44.4°N
44.2°N
44°N
76.5°W
76°W
75.5°W
75°W
74.5°W
Ocean Data View

U.S. Army Corps of Engineers, Detroit District

- **Physical Limnology:**
  - Light
  - Heat
  - Water movements
- **Chemical Limnology**
  - Concepts of aquatic chemistry
  - Nutrient cycles

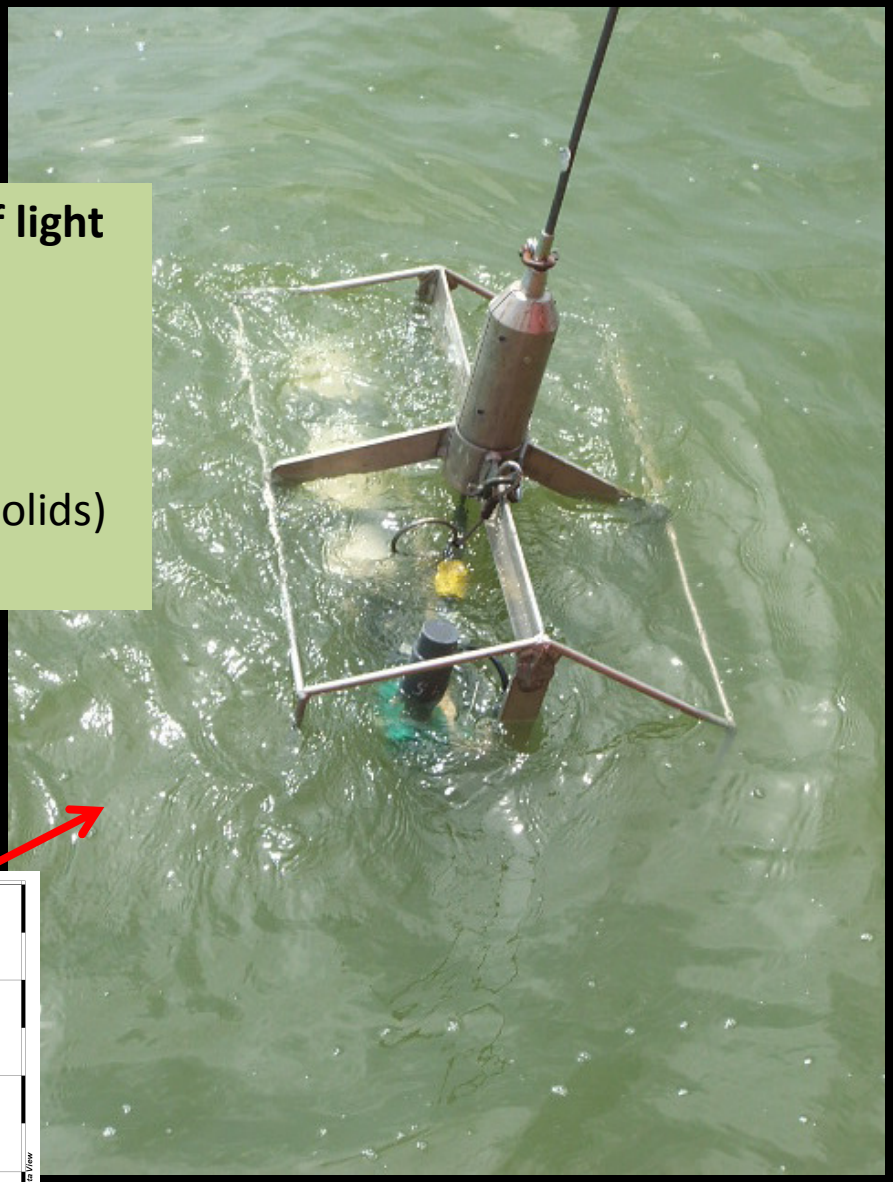
Light in Water

Importance of light:

1. Light transmittance in water is relevant to primary productivity (photosynthesis).
2. Light absorption by water is how lakes become warm and stratify.
3. Heat energy also causes currents.

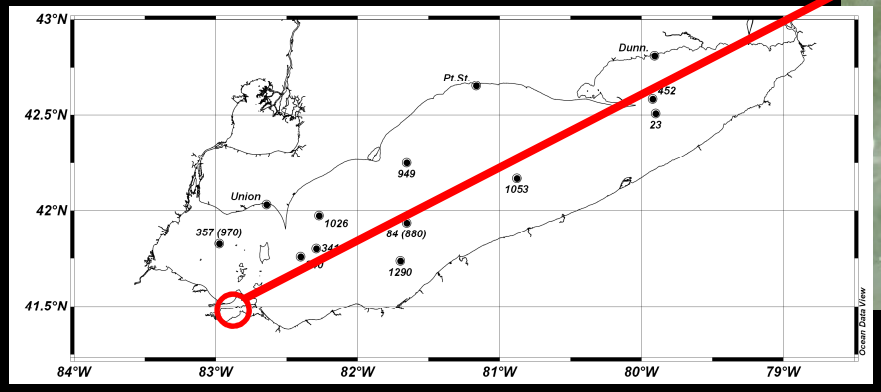
Measuring light in winter in the middle of Lake Erie (Feb 2009)

Sandusky Bay, Ohio



Absorption, transmission and scattering of light in water

Light is absorbed and reflected by
- DOC (dissolved organic carbon)
- silt, clays, calcite (inorganic colloids and solids)
- organic particles and colloids

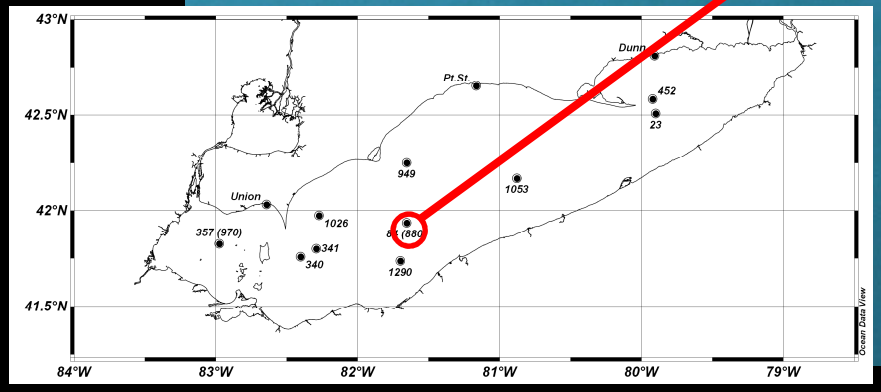


Middle of Lake Erie (25 miles northeast of Sandusky Bay)

Why is deep clear water blue?

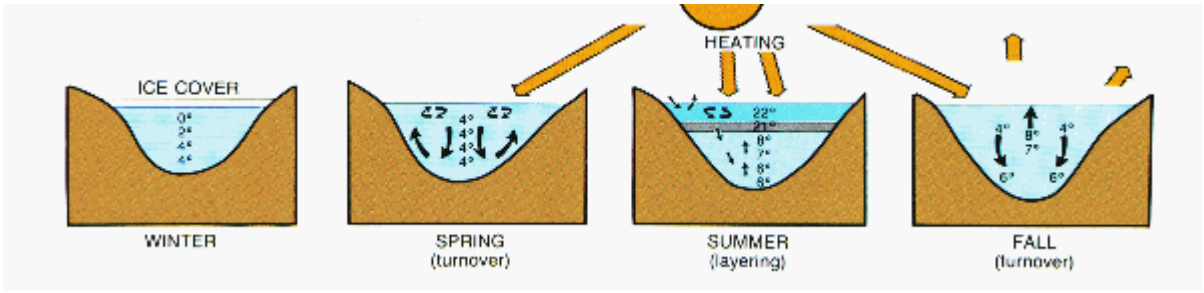
low [DOC]; red light (600-700 nm) is absorbed by water; blue light is not absorbed by water but is more prone to scattering, thus light reflected by these waters is blue or blue-green.

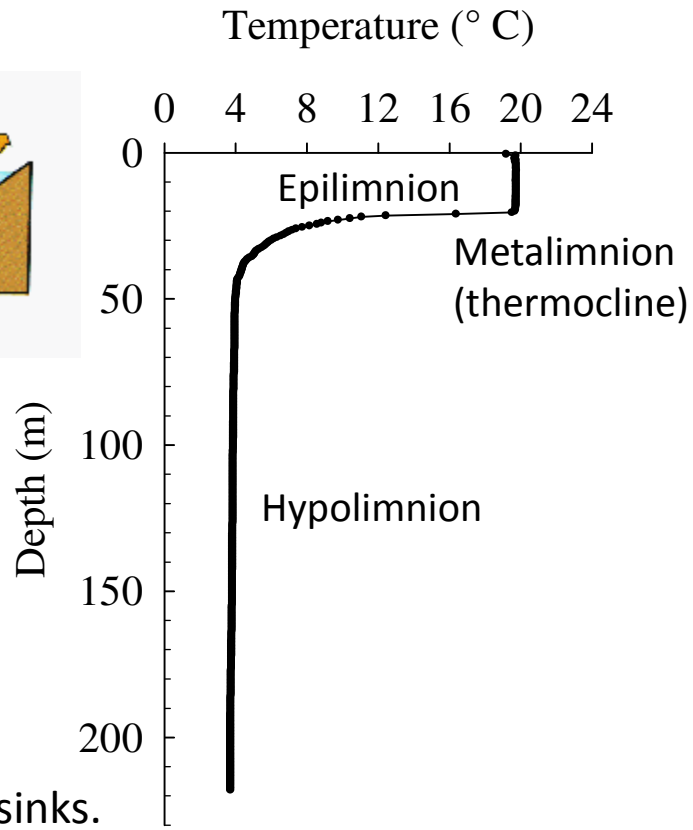
(DOC = dissolved organic carbon)

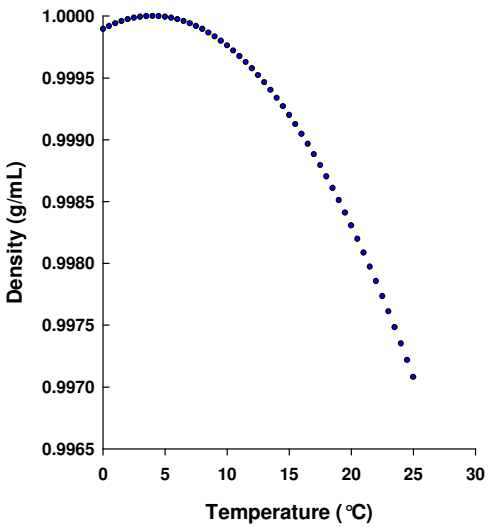


Thermal stratification

All of the Great Lakes stratify at least once per year and mix fully once per year (monomictic). Most of the Great Lakes are warm monomictic lakes; Lake Erie is dimictic (diagram).







1. Water is most dense at 4°C.
2. As water cools in autumn it sinks.
3. Cooling past 4°C causes water to float over more dense *but now warmer* water.
4. In spring as water warms it sinks until there is no density resistance to water mixing.

Water movements

- **Waves**
  - Surface gravity waves (caused by wind)
    - maximum wave height (m) = 0.332 *Fetch*(km)$^{0.5}$
    - Lake Ontario fetch = 292 km, max wave height = 5.7 m (≈ 19 ft.)
  - Internal waves (seiches; caused by wind)
- **Currents**, caused by
  - Wind
  - Sinking water masses
  - Inflows and outflows (fluvial systems)
- **Mixing** in thermal stata
  - Epilimnion
    - Well mixed, turbulent flows
  - Metalimnion
    - Convergence zone
  - Hypolimnion
    - Laminar flow

Langmuir circulation cells deepen the epilimnion.

(video of Pancake Ice formation in East Basin of Lake Erie, Feb 2009; 25 knot winds)

Mean Circulation in the Great Lakes Dmitry Beletsky[1,*], James H. Saylor[2], and David J. Schwab[2]

J. Great Lakes Res. 25(1):78–93
Internat. Assoc. Great Lakes Res., 1999

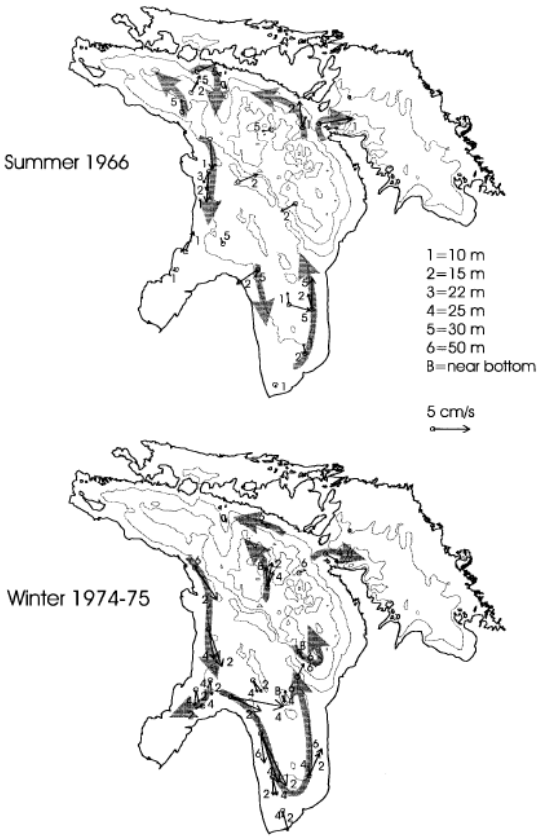
- Bathymetry and prevailing winds dominate current movements
- Winter currents are stronger than summer.
- Cyclonic (counter clockwise) in larger lakes

TABLE 2. Minimum, maximum, and average mean current speed in the Great Lakes.

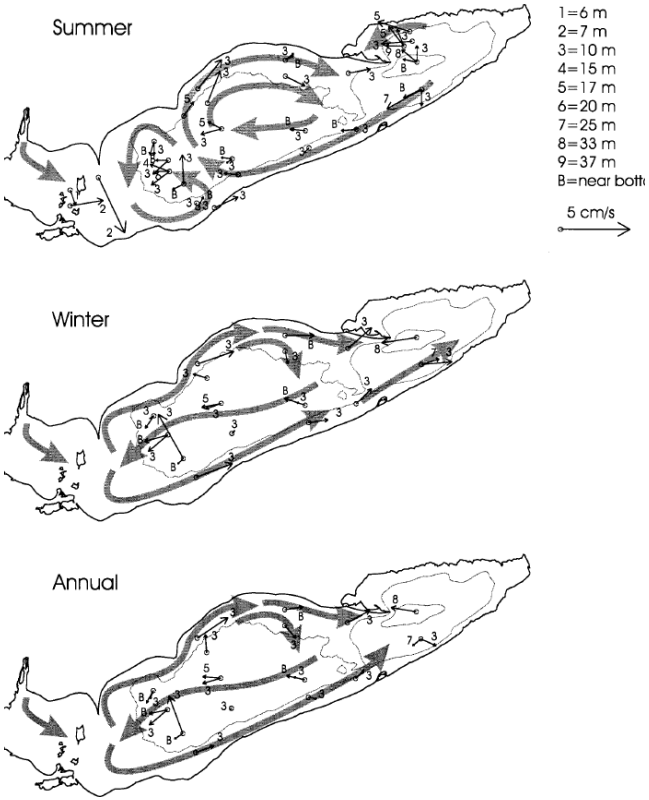
	Erie	Huron	Michigan	Ontario	Superior
Summer	0.1/4.4/1.4	0.4/4.6/2.4	0.1/4.5/1.3	0.1/2.5/1.0	0.2/7.1/2.2
Winter	0.3/3.7/1.6	0.2/7.9/2.6	0.8/4.7/2.4	0.4/9.5/2.8	
Annual	0.1/2.9/1.3		0.5/4.3/1.9	0.4/3.3/1.5	

(cm/s)

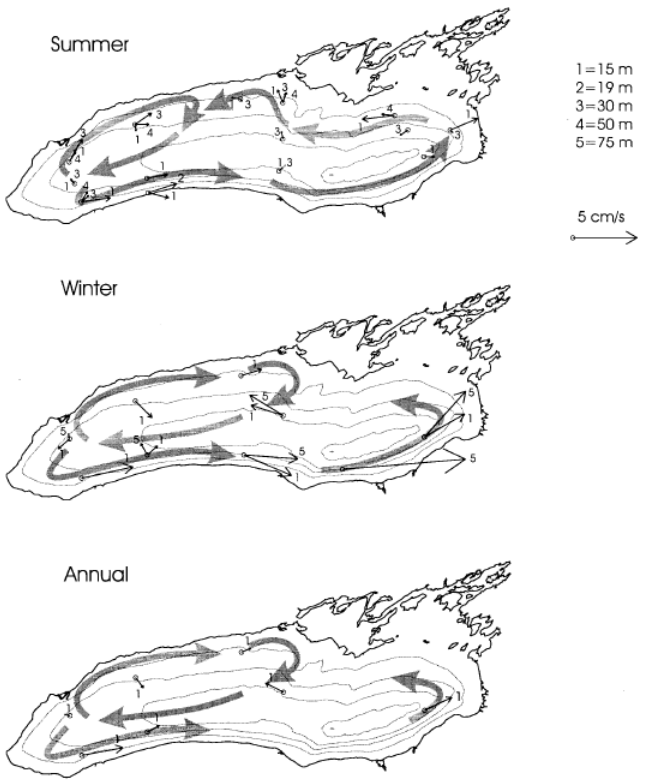
Lake Huron Averaged Currents



Lake Erie Averaged Currents, 1979-80



Lake Ontario Averaged Currents, 1972-73

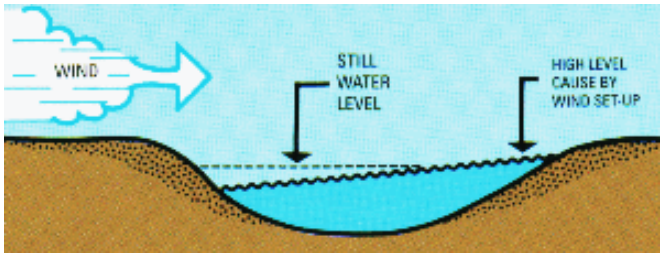


SEICHES (pronouced 'saysh')

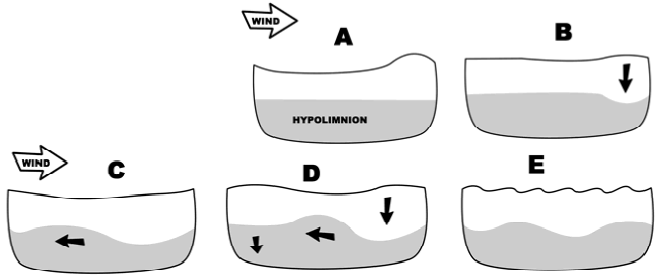
"High winds cause Lake Erie 'seiche,' stranding boats in western basin"

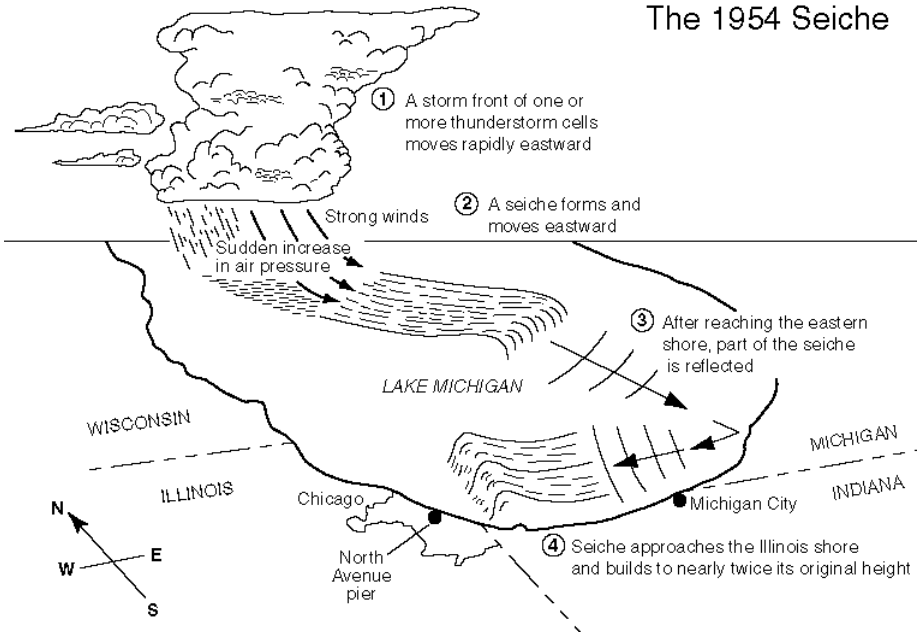
***Cleveland Plain Dealer*, Tuesday, September 29, 2009**

Surface Seiche



Internal Seiche



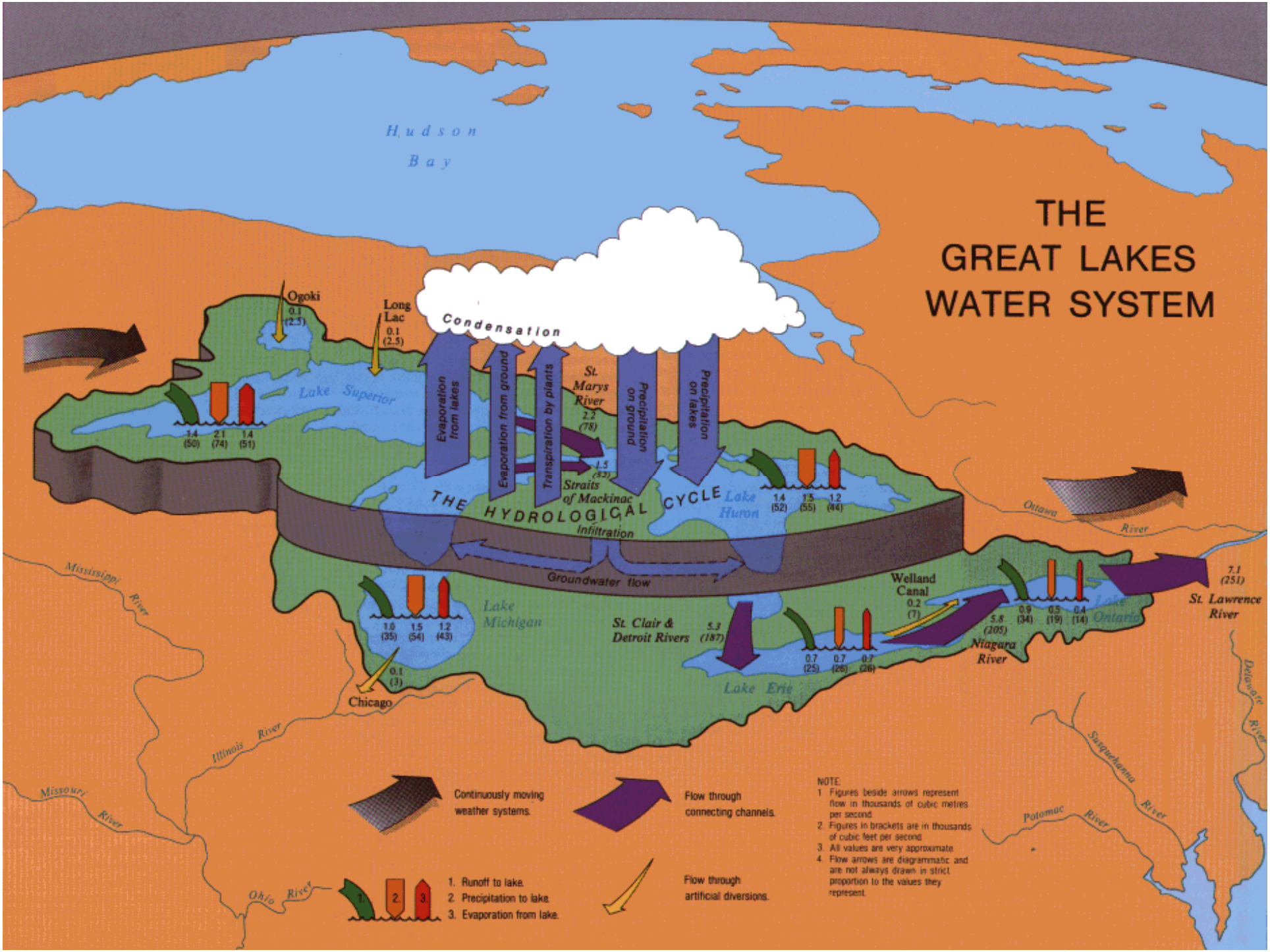


<u>Seiches have been deadly</u>:

Lake Erie: May 1942 - storm surge **killed seven people** in Northeast Ohio when a wall of water slammed into the shore.

1844 - a seiche wiped out a shantytown on the shore of Buffalo, **killing at least 78 people**; a storm surge in 1926 **took 11 lives**.

Lake Michigan: Chicago lakeshore at 9:30 a.m. Saturday, June 26, 1954. A seiche approached from the southeast and struck the entire Illinois coast with a wave about 2–4 feet high, swelling as it approached to 10 feet. Fishermen were swept into the lake, **eight drowned**.


THE GREAT LAKES WATER SYSTEM
Hudson Bay
Condensation
Evaporation from lakes
Evaporation from ground
Transpiration by plants
Precipitation on ground
Precipitation on lakes
THE HYDROLOGICAL CYCLE
Infiltration
Groundwater flow
Ogoki 0.1 (2.5)
Long Lac 0.1 (2.5)
Lake Superior
1.4 (50) 2.1 (74) 1.4 (51)
St. Marys River 2.2 (78)
1.5 (53)
Straits of Mackinac
Lake Huron
1.4 (52) 1.5 (55) 1.2 (44)
Ottawa River
Welland Canal 0.2 (7)
Lake Ontario
0.9 (34) 0.5 (19) 0.4 (14)
7.1 (251)
St. Lawrence River
5.8 (205)
Niagara River
St. Clair & Detroit Rivers 5.3 (187)
Lake Erie
0.7 (25) 0.7 (26) 0.7 (26)
Lake Michigan
1.0 (35) 1.5 (54) 1.2 (43)
0.1 (3)
Chicago
Mississippi River
Illinois River
Missouri River
Ohio River
Susquehanna River
Potomac River
Delaware River
Continuously moving weather systems.
Flow through connecting channels.
Flow through artificial diversions.
1. Runoff to lake.
2. Precipitation to lake.
3. Evaporation from lake.
NOTE:
1. Figures beside arrows represent flow in thousands of cubic metres per second.
2. Figures in brackets are in thousands of cubic feet per second.
3. All values are very approximate.
4. Flow arrows are diagrammatic and are not always drawn in strict proportion to the values they represent.

Aquatic chemistry

- Same principles as chemistry, uses water as the matrix (solvent).
- Useful terminology:
  - **Dissolved: less than 0.2 or 0.45-µm filter cut-off**
    - Solutes are not retained on a filter
    - May contain colloids
  - **Particulate: >0.2-0.45-µm**
    - Suspended particulate matter (SPM)
  - **Inorganic versus Organic**
    - Anything containing organic carbon is organic

      e.g. particulate organic carbon (POC) is material retained by a filter that is organic

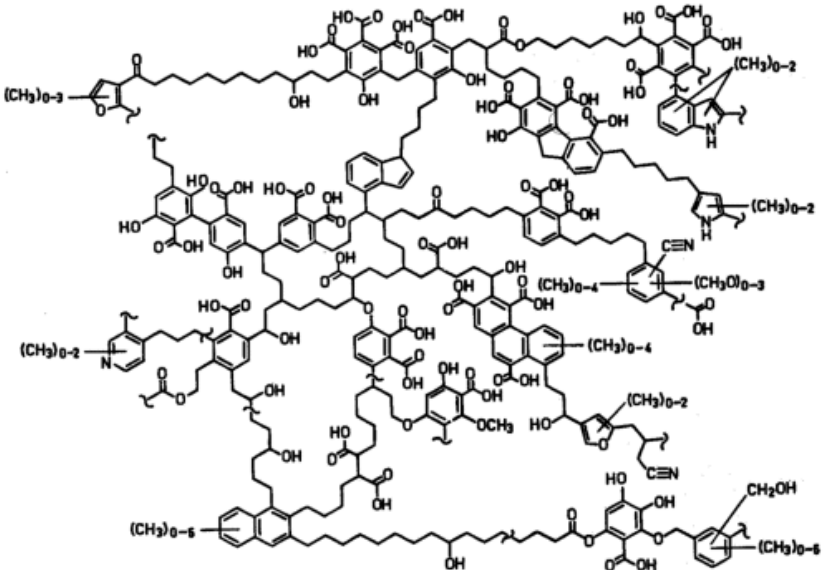
Inorganic chemicals

- Inorganic chemicals originate from the watershed geology.
  - Bedrock weathering releases ions
  - Freeze-fracturing increases surface area; carbonic acid from rain (pH 5) dissolves solutes-as do organic acids
- Base ions (concentrations ≈ 10^{-4} to 10^{-6} mol/L)
  - anions (Cl^-, HCO_3^-, SO_4^{2-}, NO^{3-}, PO_4^{3-} , SiO_4^{2-}, OH^-)
  - cations (pH, Ca^{2+}, Mg^{2+}, K^+, Na^+); pH of LGL-SLR is 7.5-8.5
- Trace elements (< 10^{-7} mol/L): nutritive and toxic
  - Fe, Cd, Zn, Cu, Ni, V, Ag, Hg, Tl, etc.

Dissolved Organic Carbon(DOC) in Great Lakes Water

- aka DOM, CDOM, FA, HA
- **Sources:**
  - Inputs from watersheds
    - Degraded organic detritus
    - Recalcitrant organic matter
  - In situ production
    - Decomposition in water column
    - Release from sediments

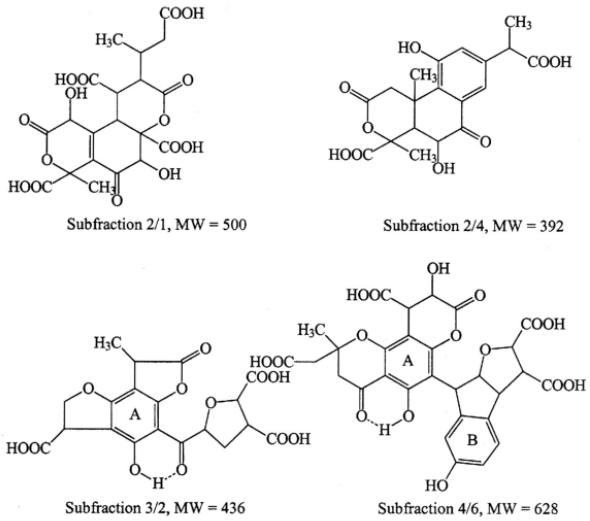
- **Sinks**
  - Precipitation from water column to sediment
  - Photo-oxidation
  - Microbial degradation



Humic and Fulvic Acids (HA & FA):

Dissolved Organic Matter (DOM)

Chromogenic Dissolved Organic Matter (CDOM)



Can. J. Fish. Aquat. Sci. Vol. 54, 1997

Campbell et al.

Table 1. Some recognized roles of natural dissolved organic matter (DOM) in the aquatic environment.

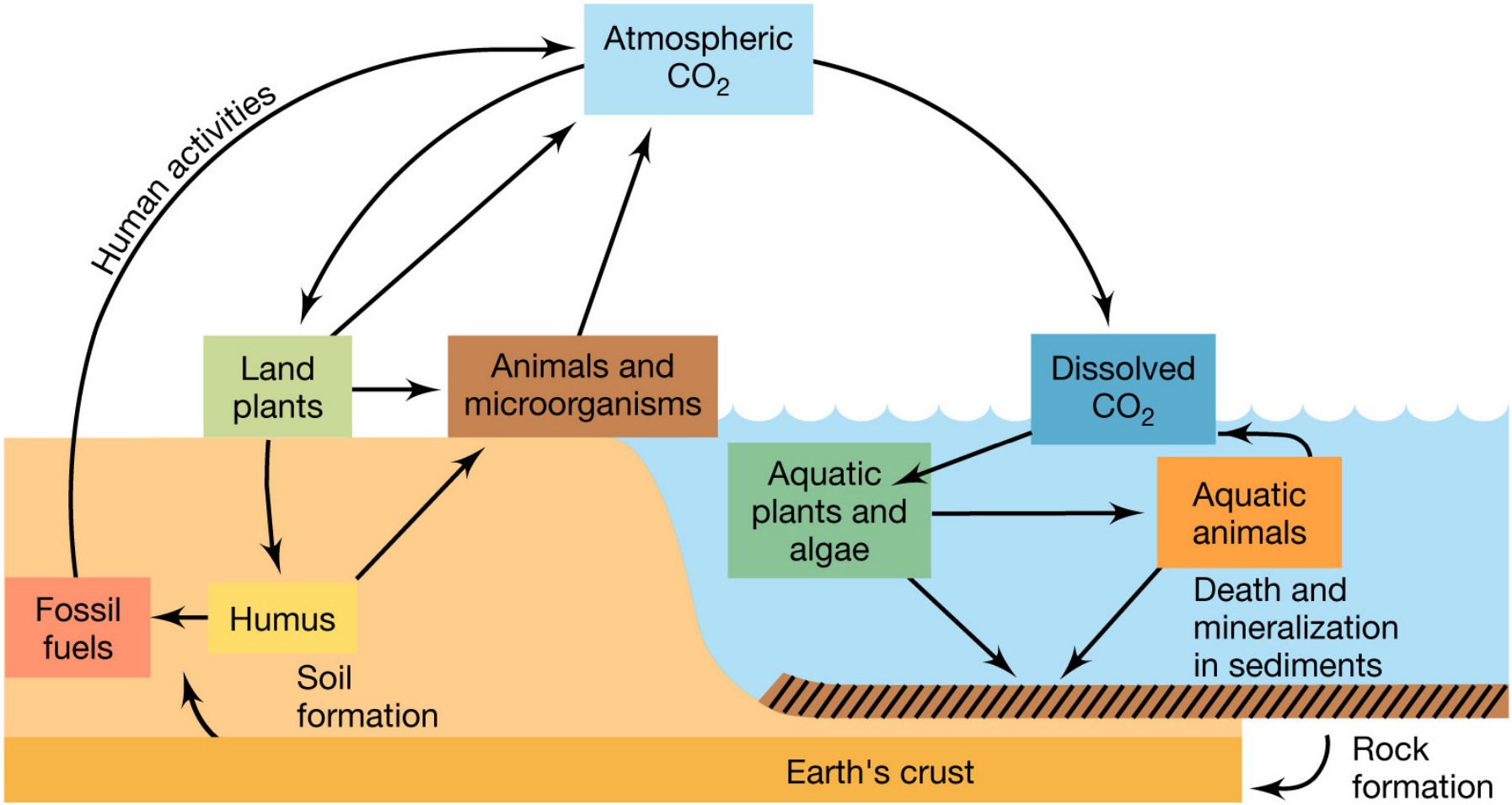
Chemical property	Biogeochemical role	Reference(s)
Acidic functional groups (carboxylic acids, R-COOH; phenols, Ø-OH)	Contribution to surface water acidity	Oliver et al. 1983
	Metal complexation	Buffle et al. 1990
	Involvement in P cycling (mixed ligand DOM–Fe–phosphate complexes)	Sunda 1994; Cotner and Heath 1990
Electron-accepting groups (quinones)	(Photo)reduction of metals (Fe, Mn)	Waite and Morel 1984; Stone and Morgan 1984
Presence of chromophores, excitable π-electrons	Photosensitized oxidation of other organic molecules	Zepp 1988; Weiner and Goldberg 1985
	Light attenuation in surface waters	Scully and Lean 1994
Presence within the macromolecule of hydrophobic structures	Adsorption/complexation of small hydrophobic organic molecules	Chiou et al. 1986
Coexistence within the macromolecule of both hydrophilic and hydrophobic domains	Accumulation of humic substances at air–water and water–particle interfaces	Hunter 1980; Tipping 1981; Davis 1982


St. Lawrence River
CDOM = 2.4 mg/L
St. Lawrence River
Sucker Brook
CDOM = 28.5 mg/L

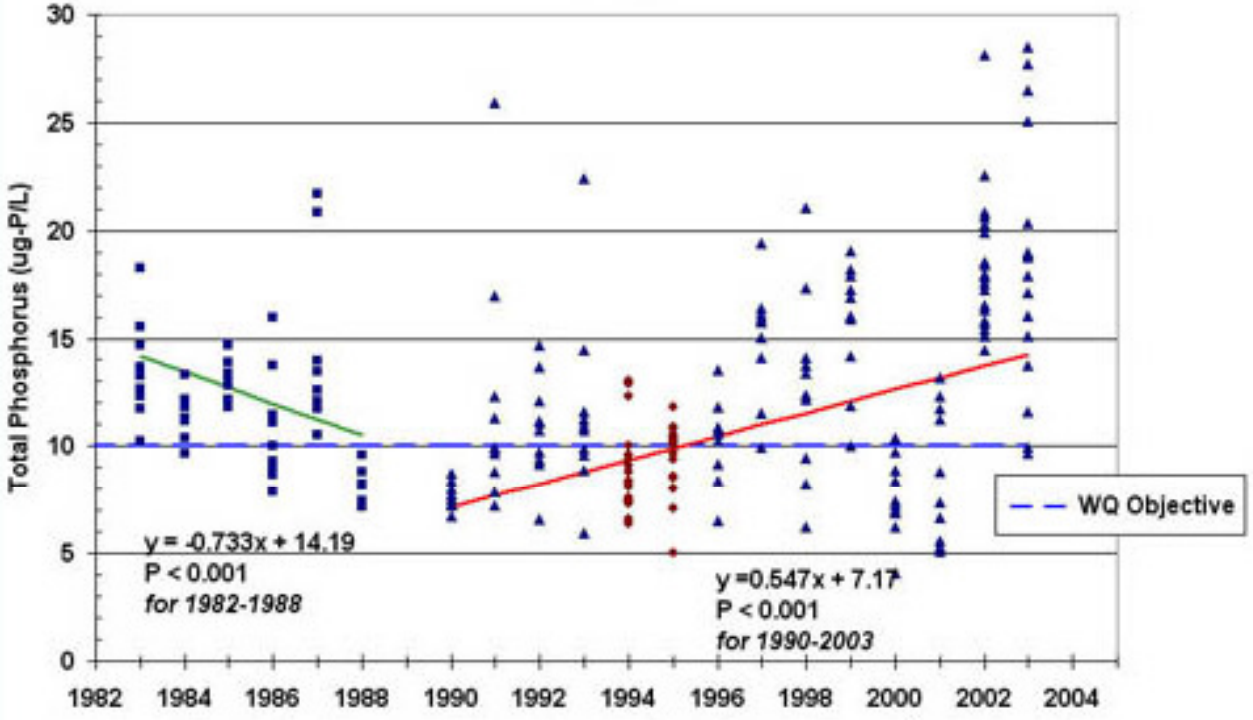
Nutrient Cycles: Carbon, Nitrogen, Phosphorus

- **Carbon**
  - Inorganic: $CO_2(g)$, $HCO_3^-(aq)$
  - Organic: (CH_2O), protein, humic and fulvic matter
- **Nitrogen**
  - Inorganic: $N_2(g)$, $NO(g)$, $N_2O(g)$, $NO_2^-(aq)$, $NO_3^-(aq)$
  - Organic: combined and free amino acids, protein
- **Phosphorus**
  - Inorganic: $PO_4^{3-}(aq)$, associated with FeO(OH)x
  - Organic: organo-phosphates (humic and fulvic matter)

The Carbon Cycle



Phosphorus in Lake Erie



Goal: Total Phosphorus in Lake Erie Central Basin should be at or below IJC Water Quality Objective of 10 µg/L

Status: Goals is not being met.

Trends: Total phosphorus levels have been increasing since the early 1990s

Issues: *Increasing phosphorus loads and disruptions of food web by aquatic nuisance species may cause future problems in Lake Erie's Central Basin.*

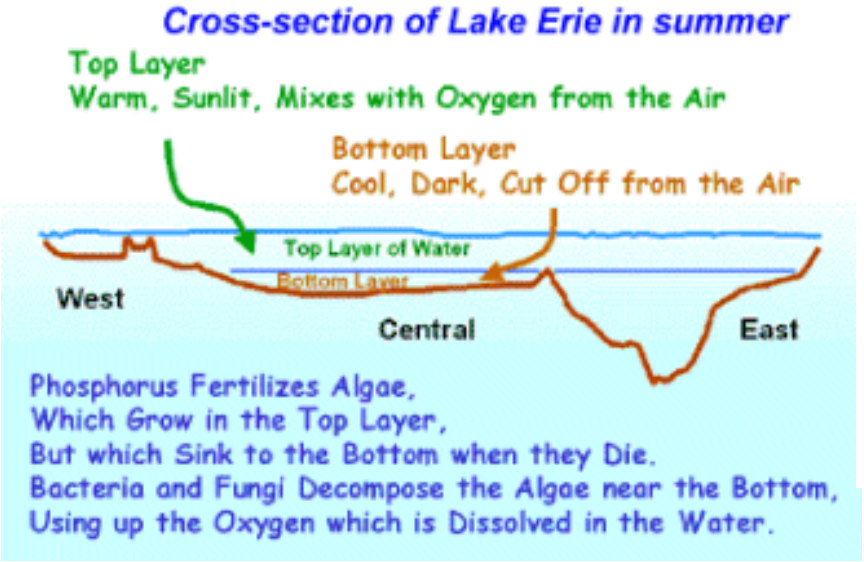
Source: USEPA GLNPO/ http://www.epa.gov/glindicators/water/phosphorusa.html

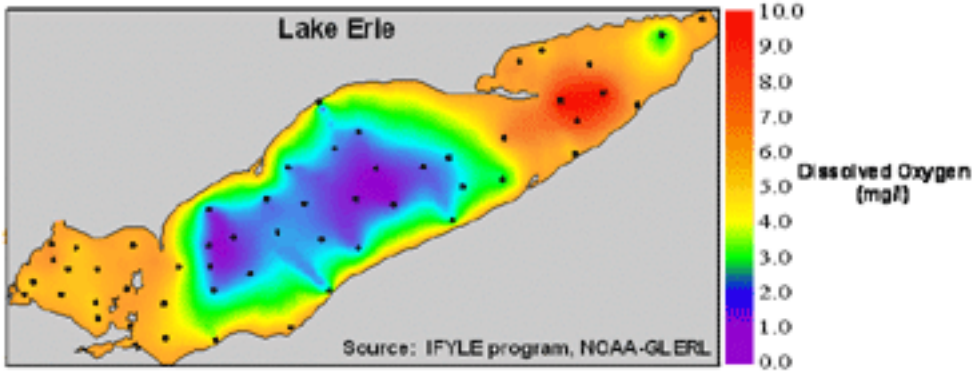
Gases dissolve in lake water

- **Sources:**
  - Atmosphere
    - Increased flux by wind action (turbulence)
  - Biota
    - Sediments are sources of dissolved gases (e.g. methane, CO, NO, H_2 resulting from microbial activities)
    - Phytoplankton release oxygen

- **Sinks:**
  - Atmosphere (degassing)
  - Consumption *in situ*
    - Use by microbes in respiration
    - Abiotic reactions (e.g. oxygen oxidizing reduced metals)

The Lake Erie 'dead zone'





- Solubility of oxygen is a function of temperature (and pressure). DO = dissolved O_2
- DO < 2 mg/L is stressful to fish
- The 'Dead Zone' forces fish to use less preferable habitat
  - Deep water fish prefer low light, cold temperatures
  - Seiches will shift hypolimnion faster than fish can move
  - Anoxia will kill insect invertebrates that fish need for food

Biological Limnology of the Laurentian Great Lakes-St. Lawrence River Ecosystem

Biological Limnology of the LGL-SLR Ecosystem: *Lecture outline*

1. Ecosystems

2. Biota
    - Microbes
    - Zooplankton
    - Macroinvertebrates
    - Fish
    - Birds

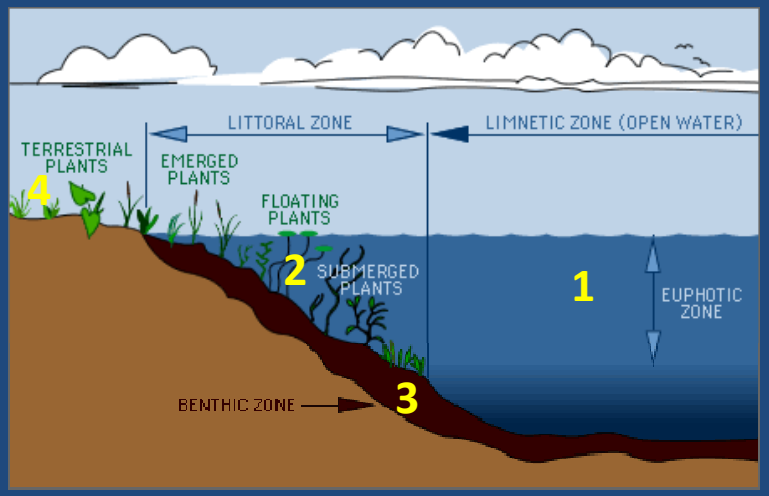
3. Wetland biomes

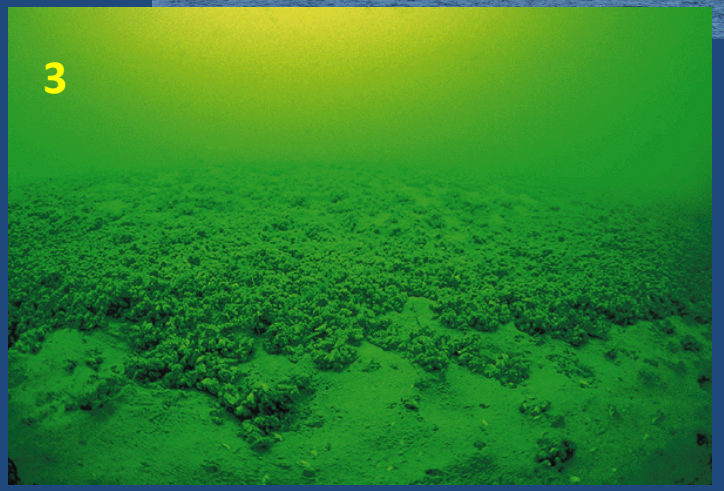
4. Contaminant transfers in food webs

5. Invasive and introduced species

Ecosystems:

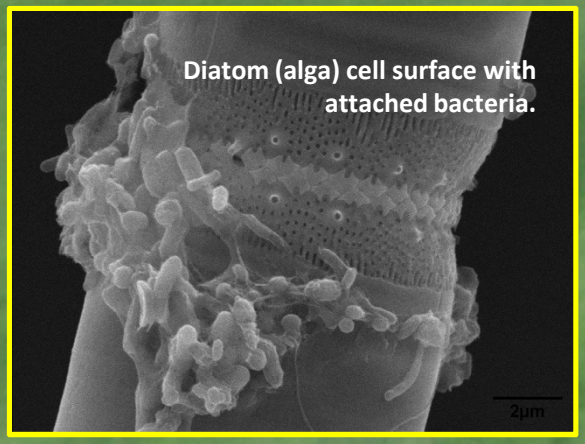
1. Open water (pelagic)
2. Nearshore (littoral)
3. Sediment (benthic)
4. Wetland (land-water interface)

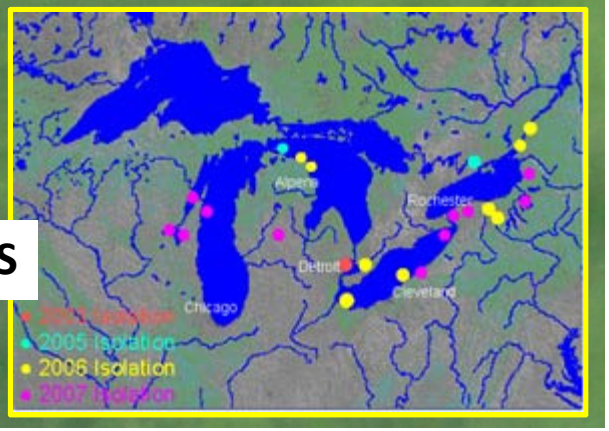




Microbes (invisible to the unaided eye) BIOTA

- **Bacteria**: prokaryotic, heterotrophic, decomposers, 1-2 µm size, simple morphology, diverse metabolism
- **Protozoa**: eukaryotic, heterotrophic, consumers
- **Phytoplankton**: autotrophic (photosynthetic)
  - Algae: eukaryotic, diverse morphology, 2-200 µm size, some macroscopic forms, e.g. *Cladophora*
  - Cyanobacteria: a.k.a. blue-green algae, prokaryotic, some are toxin producers (e.g., *Microcystis*), some can fix nitrogen (convert N_2 to $-NH_3$), 1-200 µm size
- **Fungi**: eukaryotic, heterotrophic, decomposers, single celled and filamentous forms, > 4 µm in size
- **Viruses**: infect all living organisms; are not cells but affect them and play important ecological role, e.g. Viral Hemorrhagic Septicemia (VHS) is a deadly fish virus.





"Rulers of Lake Erie" – Carbon Pools

[DOC = 1,452,000 tonnes]

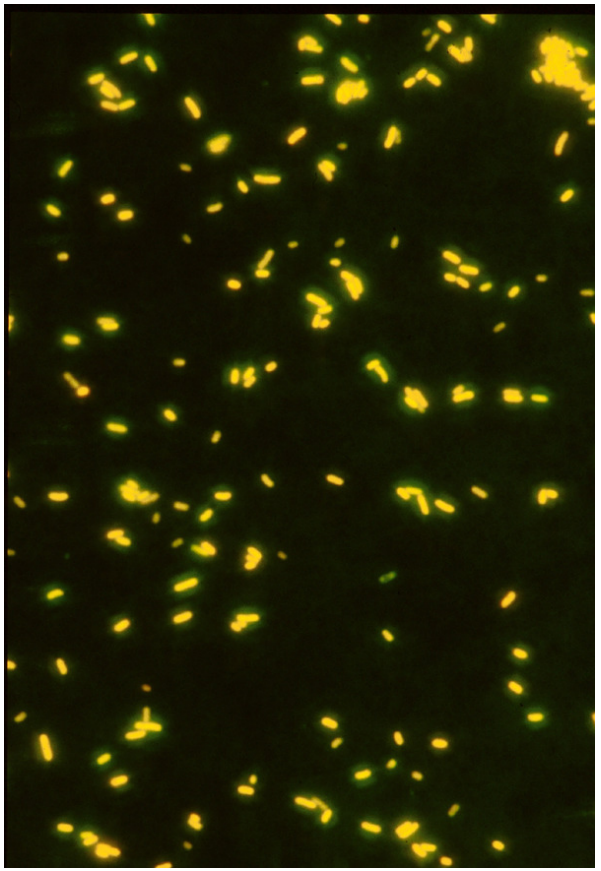
Annual Fish Catch

(5, 000 tonnes C)

www.fishontario.com

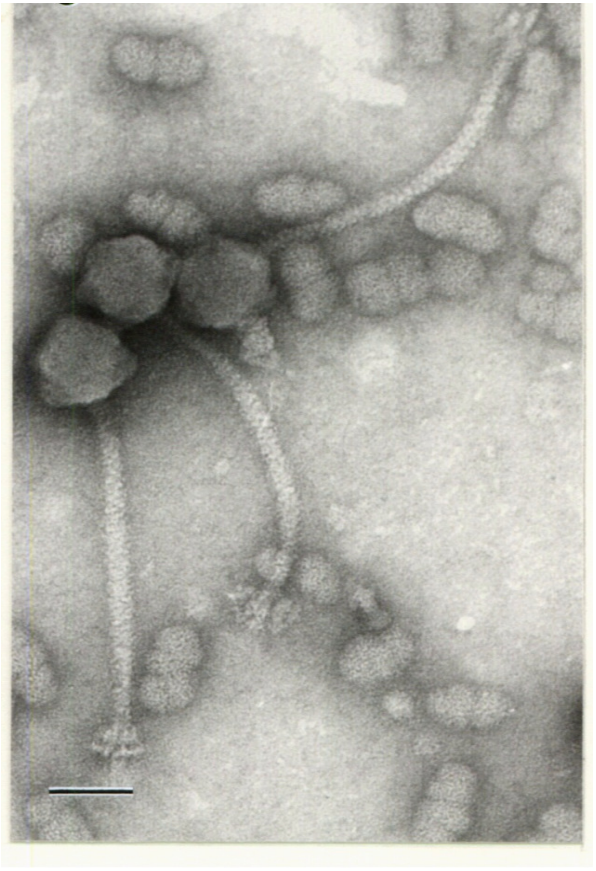
Bacterial stock

(41, 000 tonnes C)



Virus stock

(7,900 tonnes C)

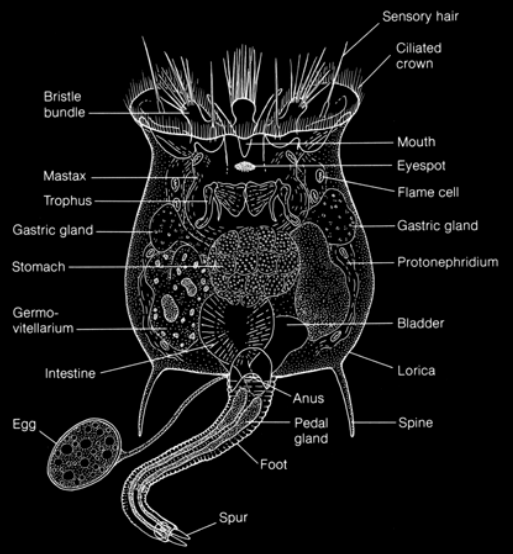


Source: S.W. Wilhlem, Ph.D. (Univ. Tennessee-Knoxville)

BIOTA

Zooplankton - found in all LGL-SLR ecosystems; some are sessile (attached to surfaces); consume protists & bacteria

- **Rotifers:** 100-1000 µm in size; metazoans; rapid reproduction potential

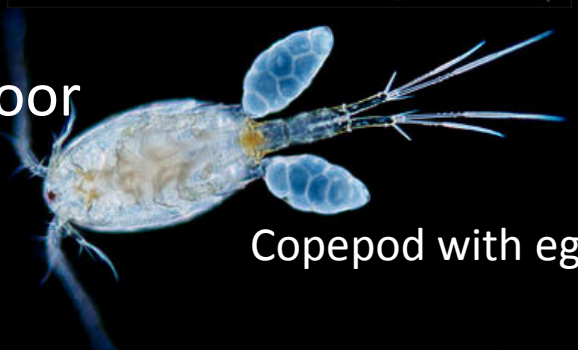


The rotifer *Brachionus*

- **Crustacean zooplankton** (>0.5 mm)
  - **Cladocerans**: found in high nutrient waters;

Daphnia

  - **Copepods**: found in more nutrient poor water



Copepod with egg sacs

Macroinvertebrates: visible to unaided eye

- **Molluscs**
  - **Bivalves** (mussels)
  - two indigenous families
  - important exotic species

Corbioculidae
1 exotic

Unionidae
42 indig,; 1exotic

Sphaeriida
27 indigenous; 5 ex.

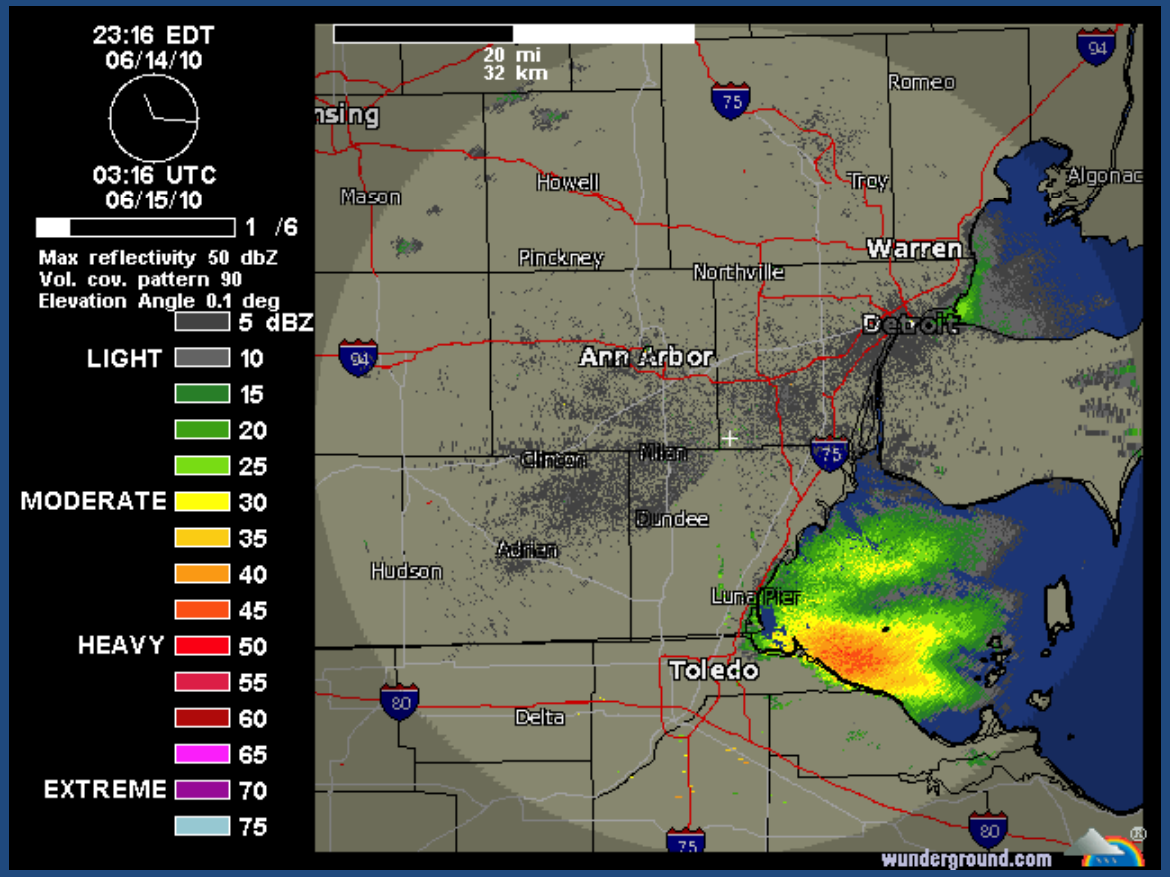
Dreisseniidae
2 exotic

  - **Gastropods** (snails)
    - numerous indigenous and introduced species

http://www.glerl.noaa.gov/seagrant/GLWL/Benthos/Mollusca/Gastropods/Gastropoda.html

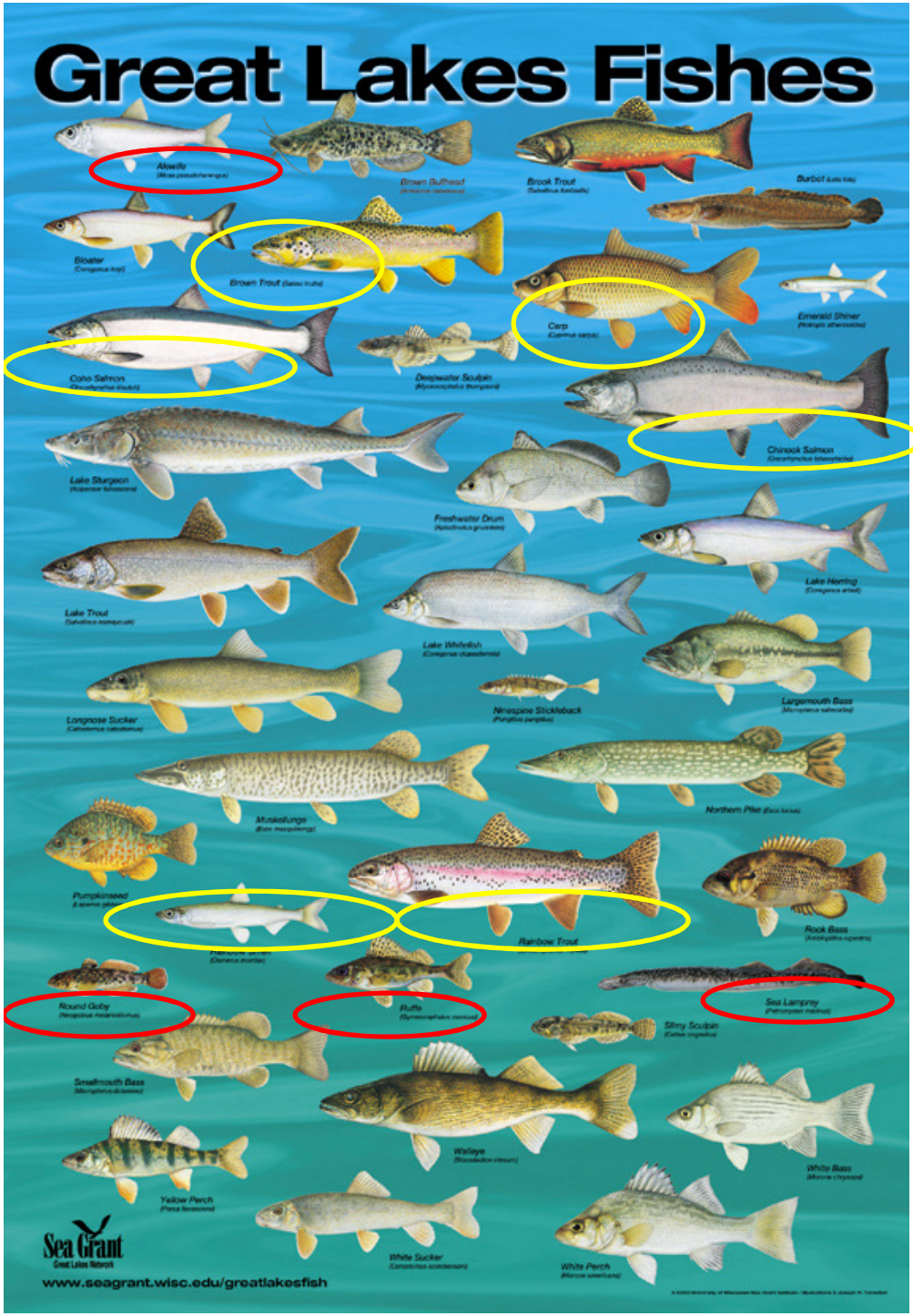
Insect larvae (macroinvertebrates)

An array of various types located the NOAA GLERL web site
http://www.glerl.noaa.gov/seagrant/GLWL/Benthos/Insecta/Insecta.html



Mayfly (Ephemeroptera)

Hordes of mayflies emerge from Lake Erie (e.g. June 15, 2010: *left*) and clouds of insects are visible on radar.



Fish migrated into the LGL-SLR system through spillways during the last ice age.

Among non-native fish in the Great Lakes, fish were introduced purposely or inadvertently.

Great Lakes Fish can be grouped as:

Carnivores:
• Lake trout, whitefish, northern pike, pickerel (walleye), bass

Planktivores
• Cisco (lake herring), alewives, smelt

Omnivores
• Sturgeon, carp

Great Lakes Birds

The Great Lakes provide abundant resources for pelagic and shore birds.
- areas to rest, and feed are present on shorelines, e.g. Pt. Pelee, Long Point (Lake Erie)


Tom Hince

Point Pelee:
one of top 50 birding hotspots in North America

"Known best for fall migrations of birds of prey, Holiday Beach is only 25 miles west of Point Pelee and offers birders another rich location to search for migrating birds. About 100,000 birds of prey are tallied at Holiday Beach each fall, but 650,000 other birds are also counted, lending credence to the fact that raptors aren't the only birds funneling through. The big attraction is the Hawk Tower, where 154,000 Blue Jays were counted migrating in one day!"
http://www.npwrc.usgs.gov/resource/birds/wildbird/5.htm

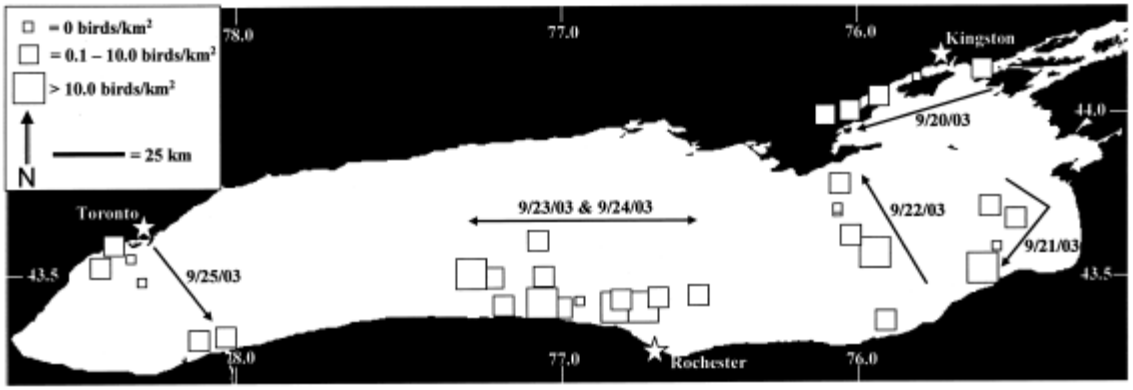
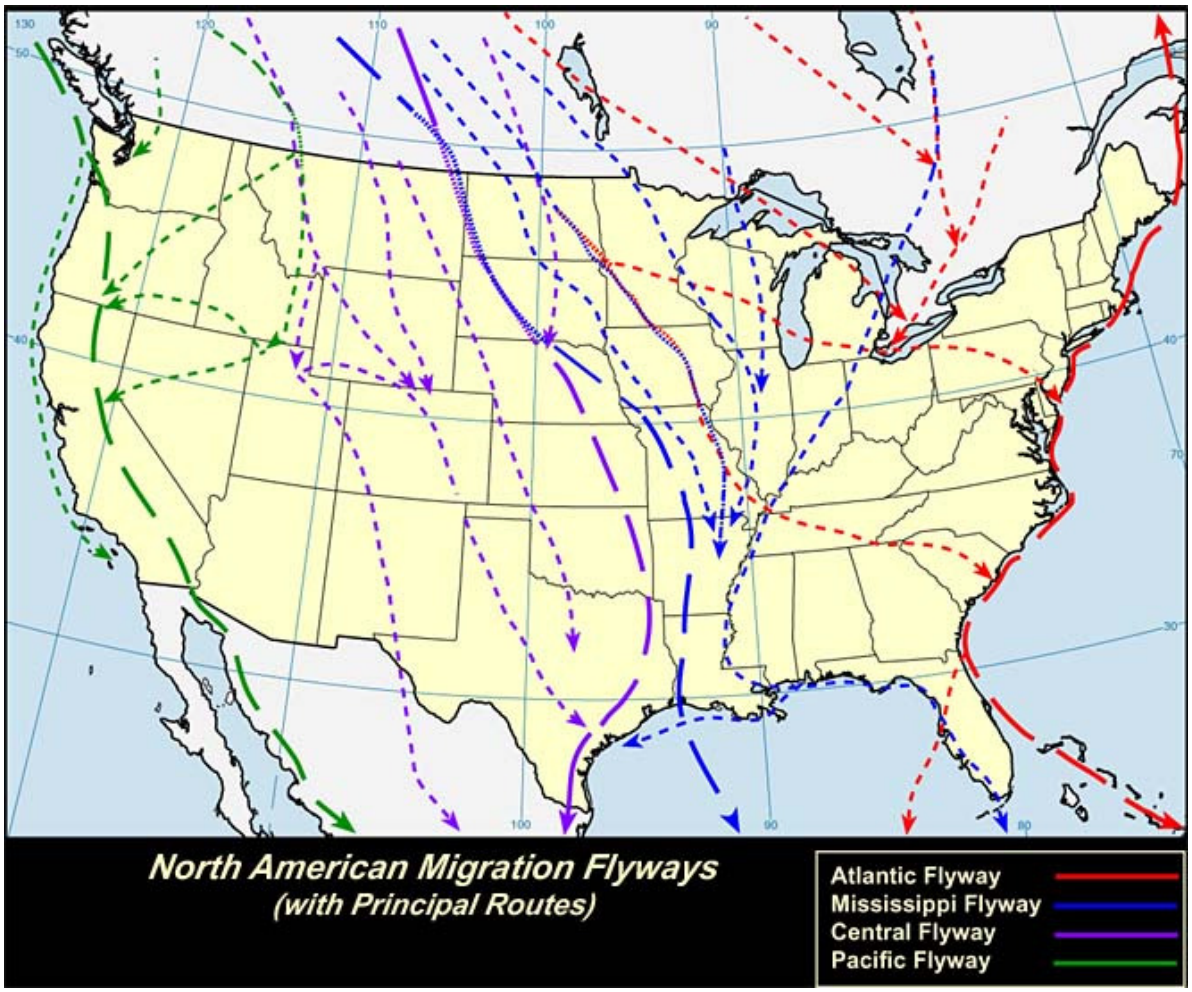


FIG. 1. The location of bird survey transects on Lake Ontario, 20–25 September 2003. The estimated local abundance of pelagic waterbirds is indicated for each point.

Water birds also occupy pelagic areas; less studied but also important.

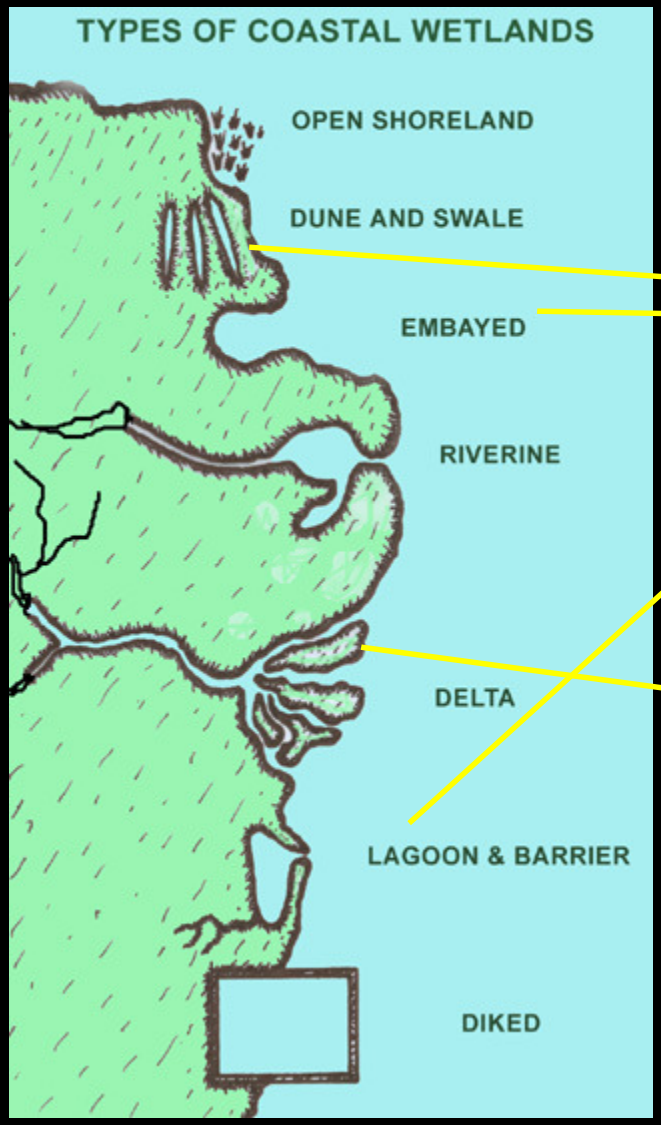
Source: Langen, T.A. Twiss, M.R., Bullerjahn, G.S. and Wilhelm, S.W. 2005. Pelagic Bird Survey on Lake Ontario Following Hurricane Isabel, September 2003: Observations and Remarks on Methodology. *J. Great Lakes Res.* 31: 219–226.

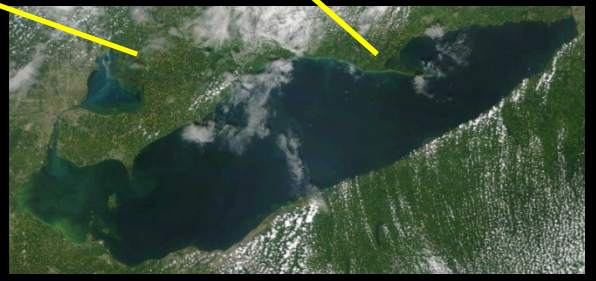
The Great Lakes are an important component of large scale bird migration pathways



Wetland ecosystems are productive in the LGL-SLR system

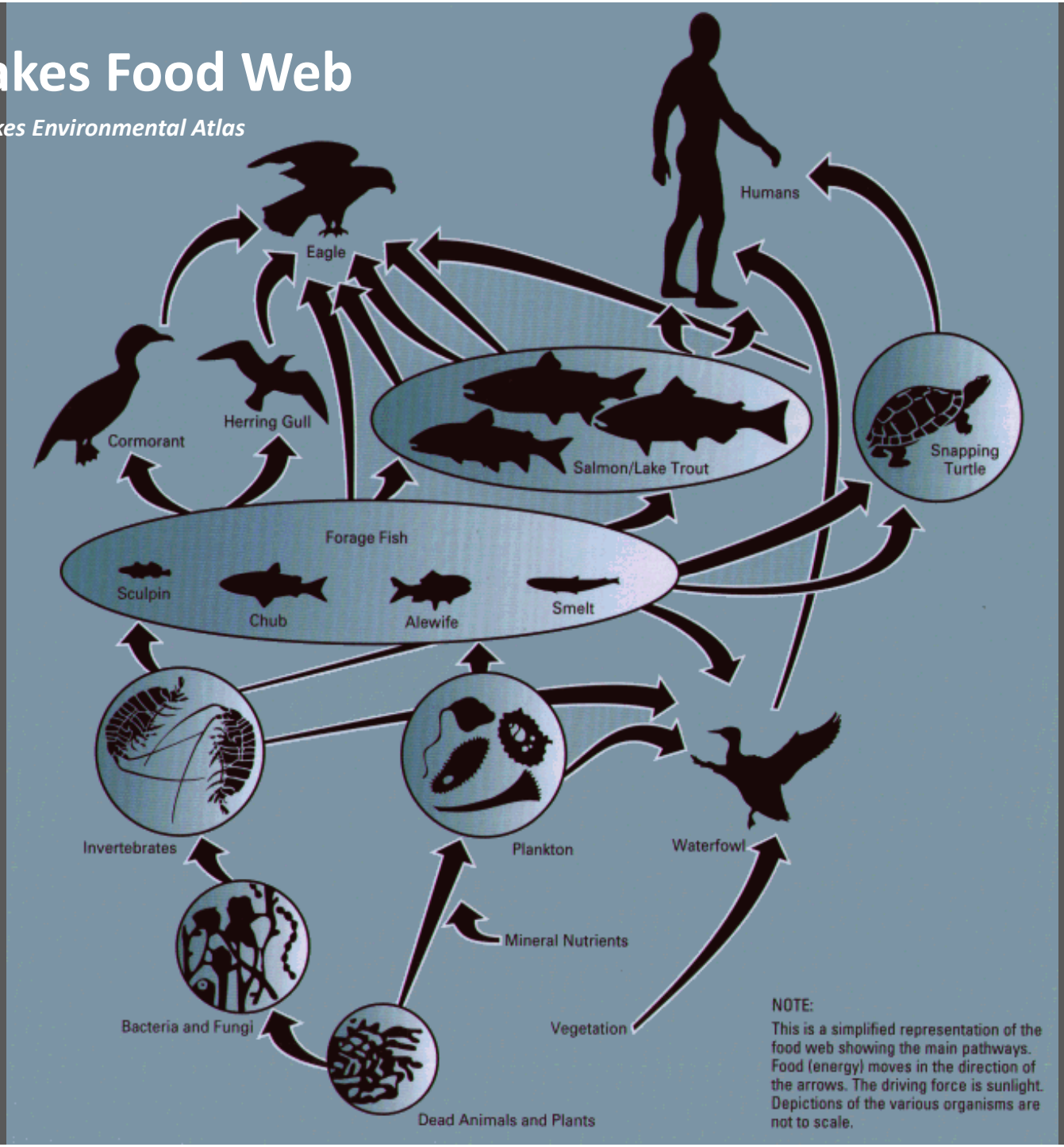
The extensive freshwater marshes of the Great Lakes coasts are unique in ecological character, size and variety. They range from small wetlands nestled in scattered bays to extensive shoreline wetlands such as those of southwestern Lake Erie, freshwater estuaries such as the Kakagon Sloughs of northern Wisconsin and the enormous freshwater delta marshes of the St. Clair River. (http://www.great-lakes.net/envt/air-land/wetlands.html)





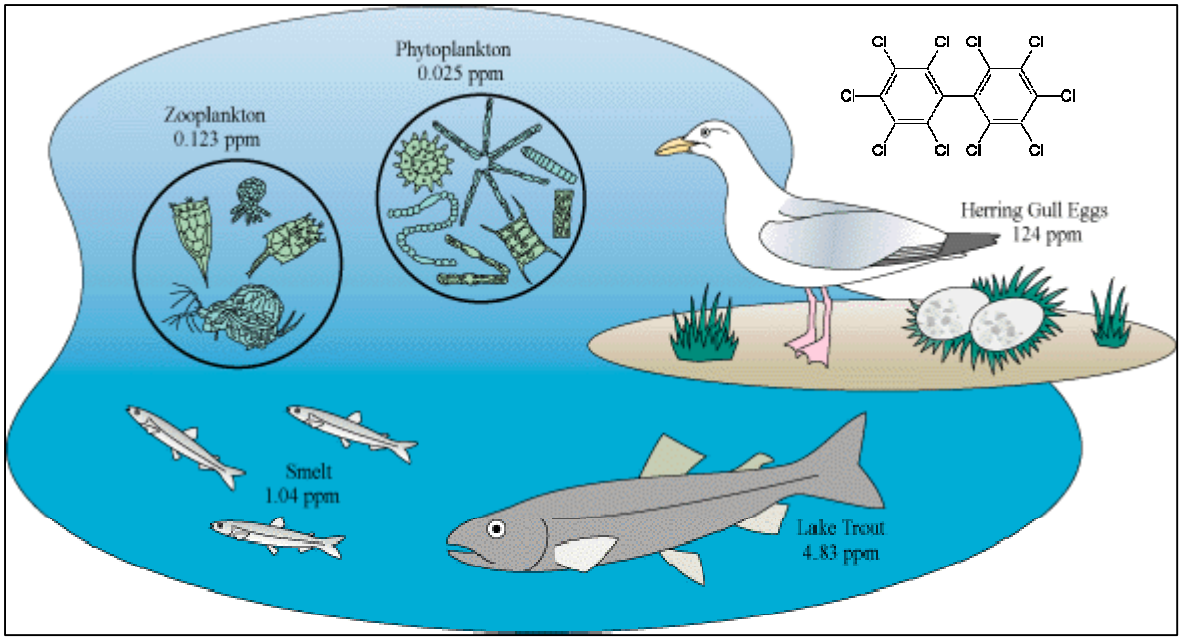
Great Lakes Food Web

Source: ***Great Lakes Environmental Atlas***



Great Lakes Food Webs and Contaminant Transfer

Source: ***Great Lakes Environmental Atlas***



Persistent Organic Chemicals such as PCBs bioaccumulate. This diagram shows the degree of concentration in each level of the Great Lakes aquatic food chain for PCBs (in parts per million, ppm). The highest levels are reached in the eggs of fish-eating birds such as herring gulls.

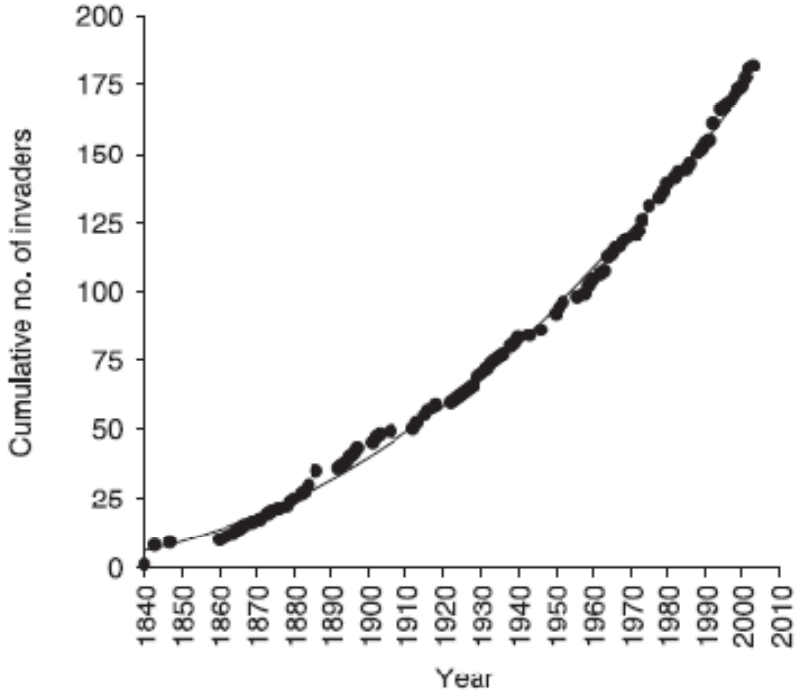
The concentration of PCB in water would be 2.5×10^{-7} ppm. Thus, the largest concentration step is the water to microbial phase (concentration factor of 10^5).

Alien and Invasive Species

Alien species (also known as introduced, non-native or exotic) are plants, animals and micro-organisms introduced into areas beyond their normal range by human actions.

Invasive species are those alien species whose introduction and spread threaten the environment, the economy or societ including human health. Invasive specie are recognized as a serious problem that threatens global biodiversity and human health worldwide. They are one of the leading causes of native species becoming rare, threatened or endangered.

Species known to have invaded the LGL-SLR ecosystem



Source: Riccardi 2009

Vector – Release from Cultivation

Medicinal Plants

- Bittersweet nightshade *(Solanum dulcamara)*
- Peppermint *(Mentha piperita)*
- Spearmint *(Mentha spicata)*

Food Plants

- Watercress *(Rorippa nasturtium aquaticum)*

Forage Crop

- Redtop *(Agrostis gigantea)*

Ornamental Plants

- White willow *(Salix alba)*
- Poison hemlock *(Conium maculatum)*
- Black alder *(Alnus glutinosa)*
- Glossy buckthorn *(Rhamnus frangula)*
- Garden loosestrife *(Lysmachia vulgaris)*
- True forget-me-not *(Myosotis peltatum)*
- Bergamot mint *(Mentha cintrata)*

True forget-me-not

Vector - Canals

Dissolved barriers between basins (Interbasin Migration)

1825 – Erie Canal

- Gov. Clinton dumps Lake Erie water into NY Harbor
- Lake Erie-bound boats carried NY Harbor water
- Foreshadowed large-scale future ballast transfers

Vector - Canal: Sea lamprey (*Petromyzon marinus*)

- Lake Ontario – 1830s
- Lake Erie – 1921

- Collapse of lake trout, whitefish, and chub populations

Vector – Canals (Solid Ballast)

- Flowering rush *(Butomis umbellatus)*
- Weeping alkali grass *(Puccinella distans)*
- Blue sedge *(Carex flacca)*
- Creeping yellow cress *(Rorippa sylvestris)*
- Purple loosestrife *(Lythrum salicaria)*
- European water horewound *(Lycopus europaeus)*
- Common reed *(Phragmites australis)*

Vector – Horticulture/Aquarium Escape

- Eurasian watermilfoil *(Myriophyllum spicatum)*
- Yellow Flag Iris *(Iris pseudacorcus)*
- Water chestnut *(Trapa natans)*

Vector – Intentional Introduction

- Common Carp (Cyprinus carpio)

- Mute Swan *(Cygnus olor)*

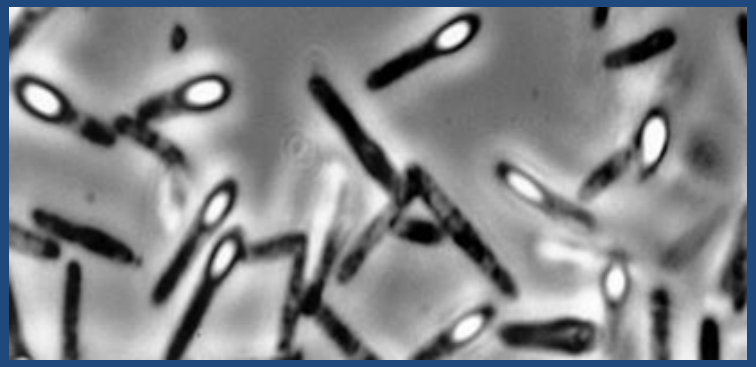
Zebra & "Quagga" mussels *(Dreissena* spp.*)*

- Lake St. Clair {1988}
- Physical impact on infrastructure
- Impact beach use
- Impact navigation, recreation, angling
- Food/habitat competition
- Extirpation/extinction of native species
- $1 - 1.5 Billion since 1988: 27 states, 2 provinces *(NANSC 2007)*

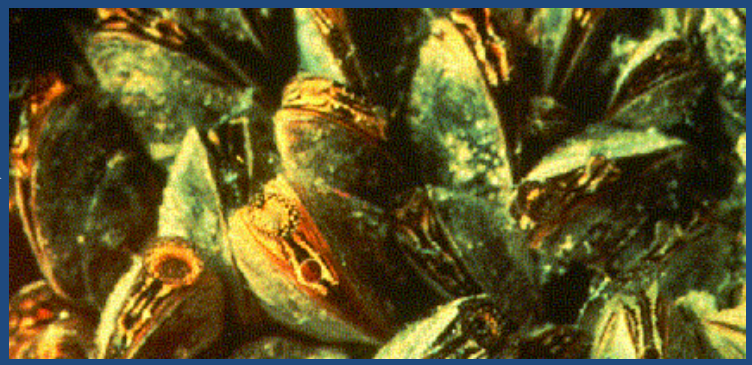
Round Goby *(Neogobius melanostomus)*

- 1990 – Ballast water – St. Clair R.
- Displace native fish (spawning habitat)
- Multiple spawnings per year
- Prey on darters, other small fish, lake trout eggs and fry
- Outcompete natives in murky, poor quality water

Synergy: Dreissenids - Round Gobies – Type E Botulism



Clostridium botulinum



Dreissenids

Round goby

Waterfowl

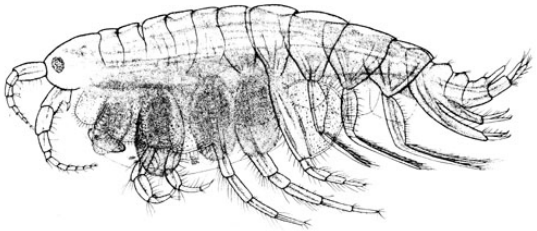
Synergy: Dreissenids - Round Gobies – Type E Botulism

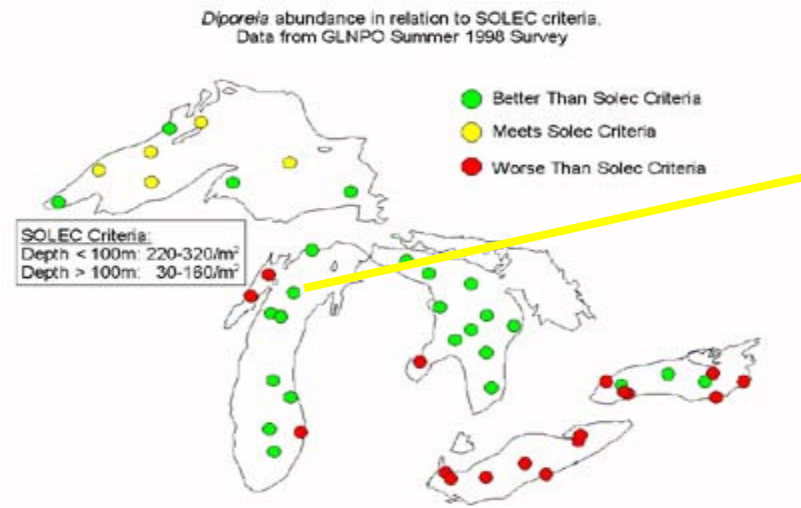
Red-breasted Merganser die-off, Lake Erie, 1999

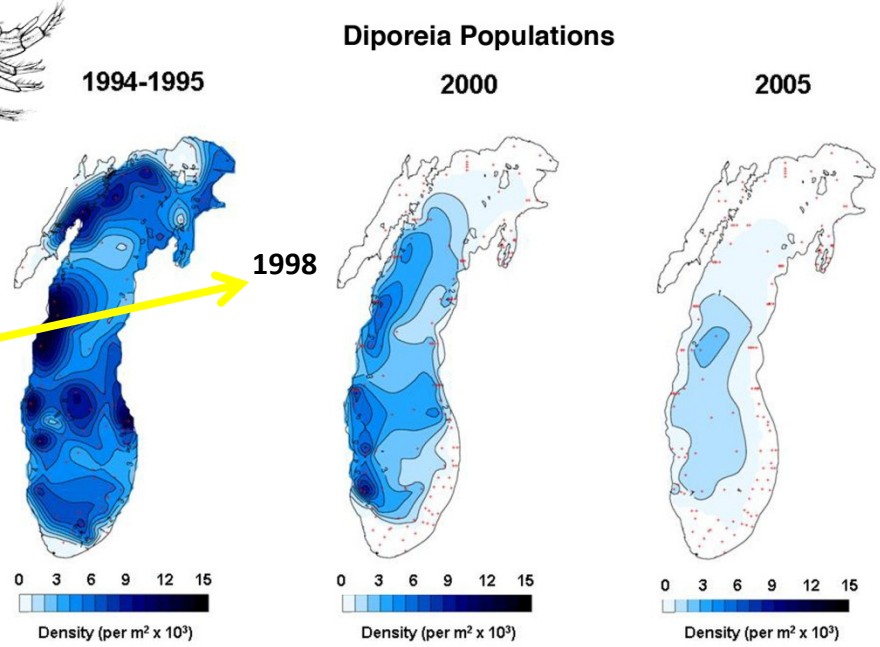
Benthic Community Health: The crustacean amphipod *Diporeia*

Populations of *Diporeia* have precipitously declined since the mid-1990s. Red crosses in the maps below denote sampling sites. Purdue Univ. researchers are searching for an explanation for their dwindling numbers, which threaten to have a major impact on fish populations throughout the Great Lakes. (Thomas Nalepa, NOAA Great Lakes Environmental Research Laboratory)

Quagga mussel impact?







Goal: *Diporeia* populations meet SOLEC Criteria for abundance.
Status: Goal is met except in Lake Erie and Lake Ontario, Green Bay and Saginaw Bay.
Trends: Significant decreases seen in *Diporeia* populations in Lake Michigan.
Issues: *Diporeia* are a key component of the Lakes' food-chain.

(SOLEC = State of Lake Ecosystem Conference)

Asian Carp and the Great Lakes

Asian carp have been found in the Illinois River, which connects the Mississippi River to Lake Michigan. To prevent the carp from entering the Great Lakes, the U.S. Army Corps of Engineers, U.S. EPA, the State of Illinois, the International Joint Commission, the Great Lakes Fishery Commission, and the U.S. Fish and Wildlife Service are working together to install and maintain a permanent electric barrier between the fish and Lake Michigan. The Chicago Sanitary and Ship Canal, where the barrier is being constructed, connects the Mississippi River to the Great Lakes via the Illinois River.

How did Asian carp get so close to the Great Lakes?

Two species of Asian carp -- the bighead and silver -- were imported by catfish farmers in the 1970s to remove algae and suspended matter out of their ponds. During large floods in the early 1990s, many of the catfish farm ponds overflowed their banks, and the Asian carp escaped released into the Mississippi River basin. The carp have made their way northward up the Mississippi, becoming the most abundant species in some areas of this river.

What effects might Asian carp have on the Great Lakes?

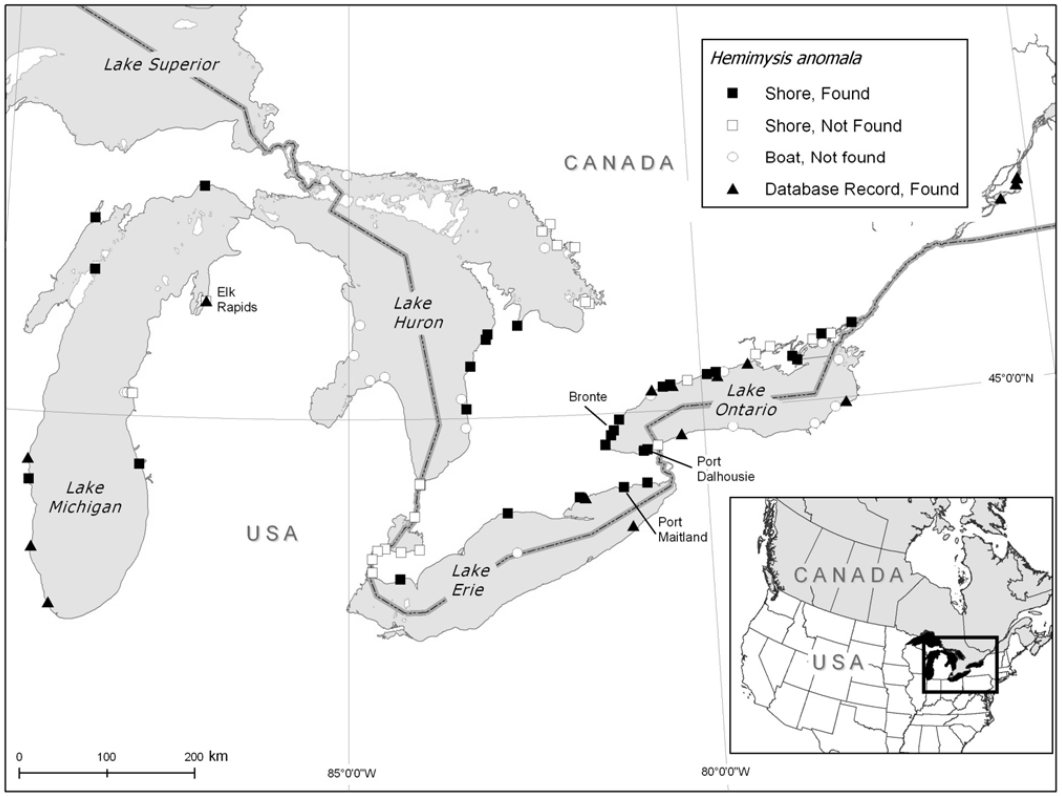
Asian Carp are a significant threat to the Great Lakes because they are large, extremely prolific, and consume vast amounts of food. They can weigh up to 100 pounds, and can grow to a length of more than four feet. They are well-suited to the climate of the Great Lakes region, which is similar to their native Asian habitats.

Researchers expect that Asian carp would disrupt the food chain that supports the native fish of the Great Lakes. Due to their large size, ravenous appetites, and rapid rate of reproduction, these fish could pose a significant risk to the ecosystem.

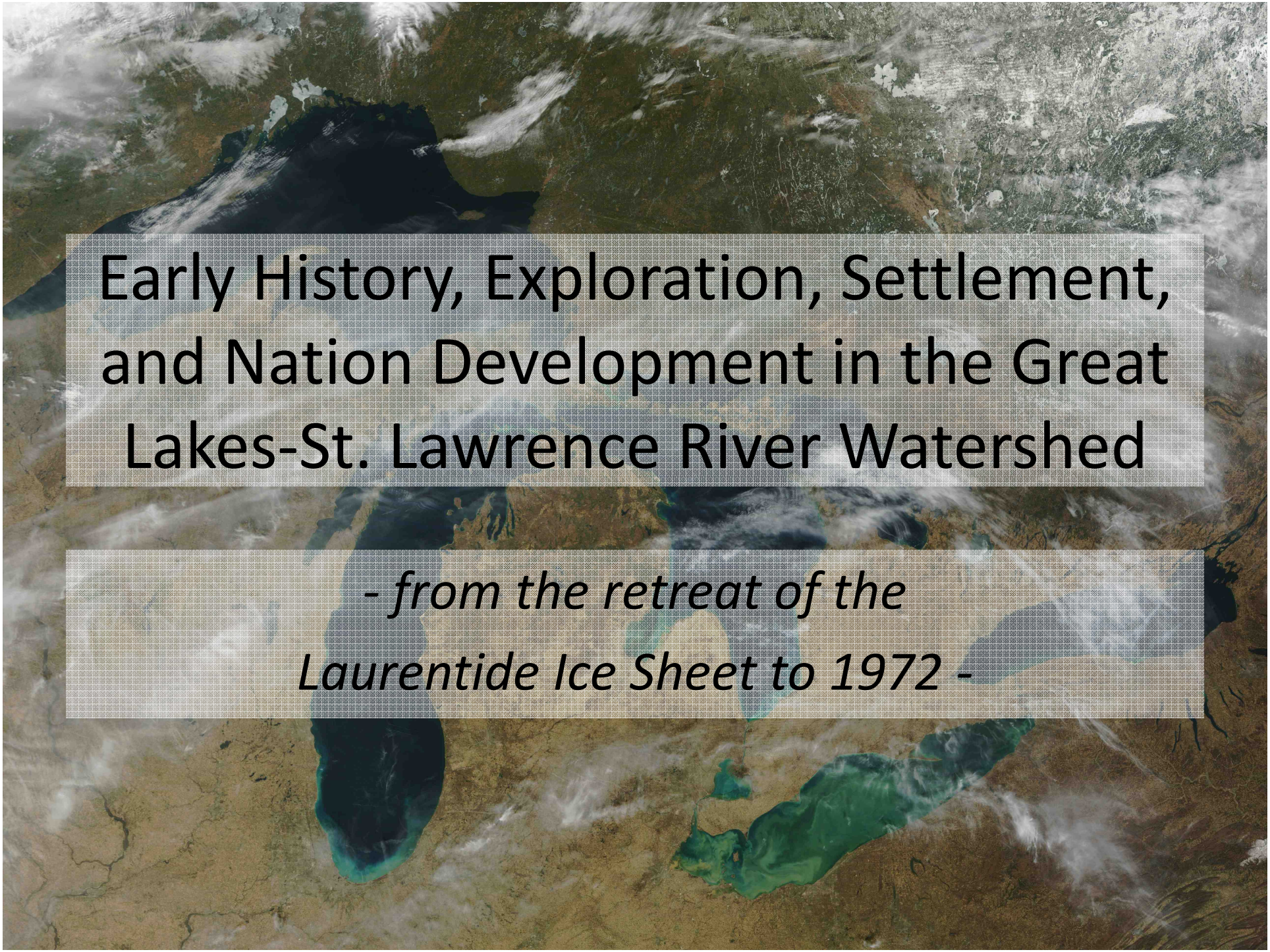
http://www.youtube.com/watch?v=PdcQ56OpxNE&feature=related
http://www.epa.gov/glnpo/invasive/asiancarp/

The Bloody Red Shrimp

Hemimysis anomala is a nearshore species of shrimp, living close to walls and rocks where it forms swarms. It is the 183rd known invasive species in the LGL-SLR ecosystem. *How will it affect food web structure and contaminant transfer pathways?*



Source: Jérôme Marty



Early History, Exploration, Settlement, and Nation Development in the Great Lakes-St. Lawrence River Watershed

- from the retreat of the Laurentide Ice Sheet to 1972 -

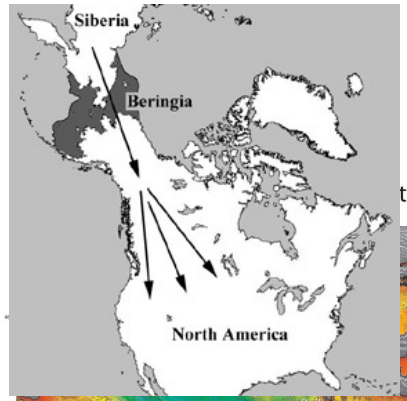
Outline: Early History, Exploration, Settlement, and Nation Development in the Great Lakes-St. Lawrence River Watershed

- Pre-historical settlement
- Exploration by Europeans
- Settlement by Europeans (French, English)
- Conflict in the LGL-SLR watershed
  - French and Indian Wars/Seven Years War and the Fall of Quebec (1756-1763)
  - Revolutionary War/War of Independence (1775-1783)
  - War of 1812
  - Border disputes and issues
- Treaties:
  - Rush-Bagot Treaty (1817)
  - Boundary Waters Treaty (1909)
  - Great Lakes Water Quality Agreement (1972)

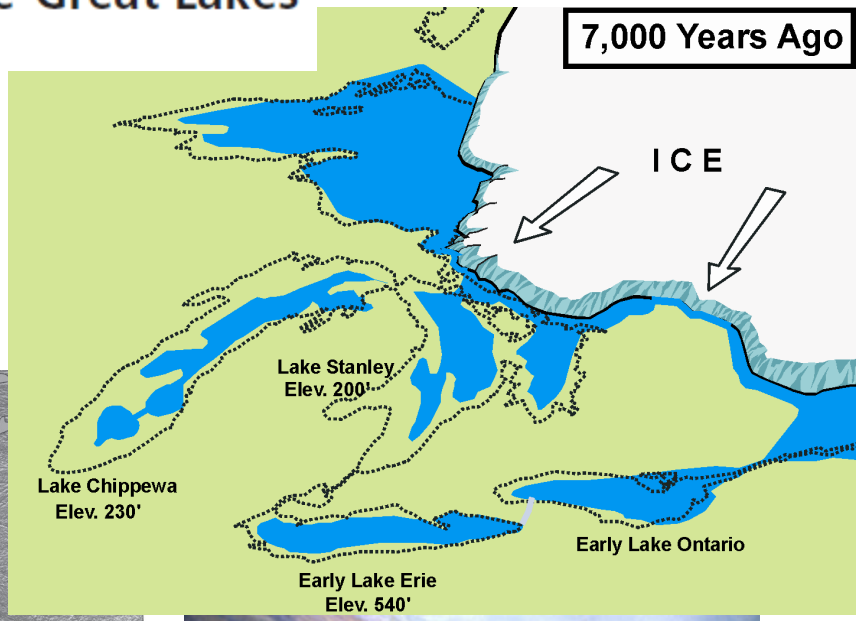
Evidence for early hunters beneath the Great Lakes

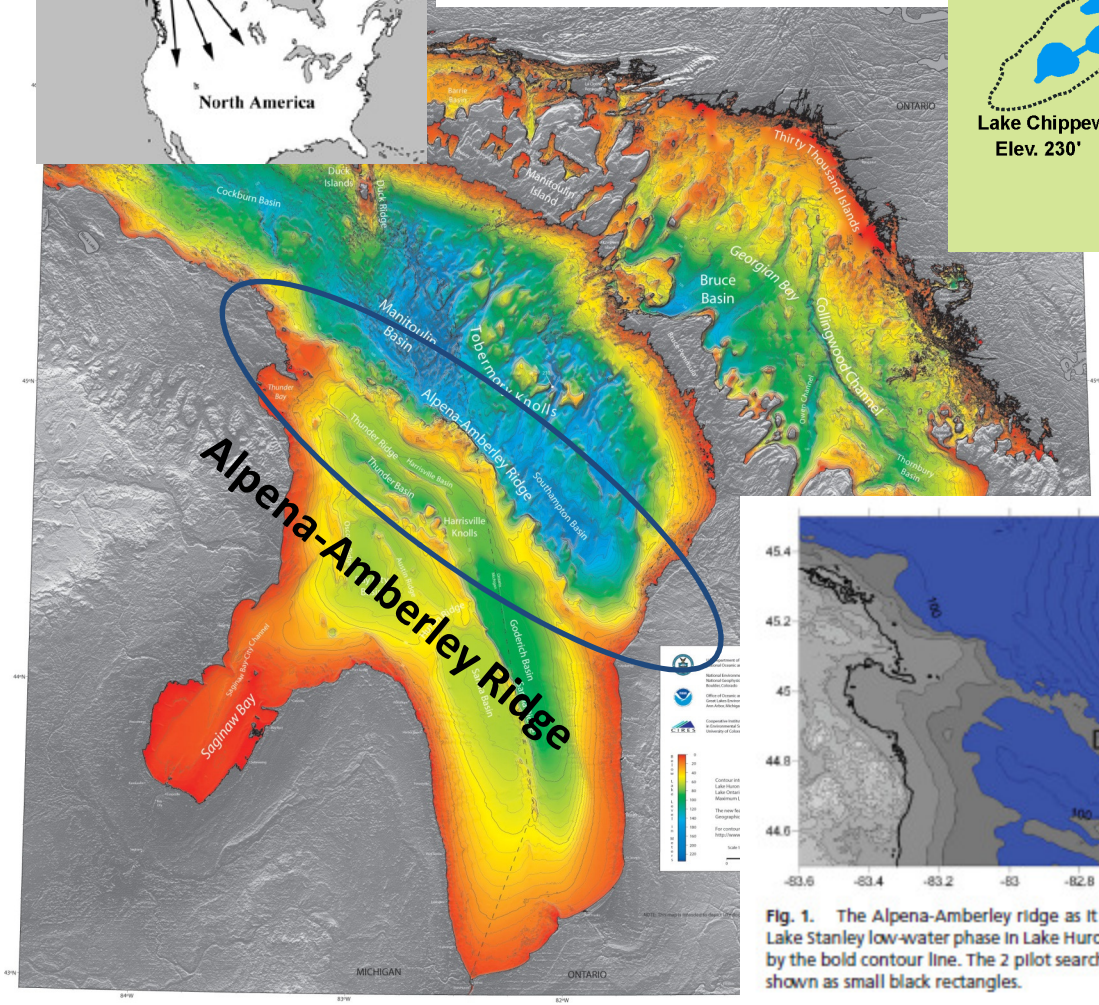
John M. O'Shea[a,1] and Guy A. Meadows[b]

www.pnas.org/cgi/doi/10.1073/pnas.0902785106



The Beringia land bridge last existed 28 to 10 kya





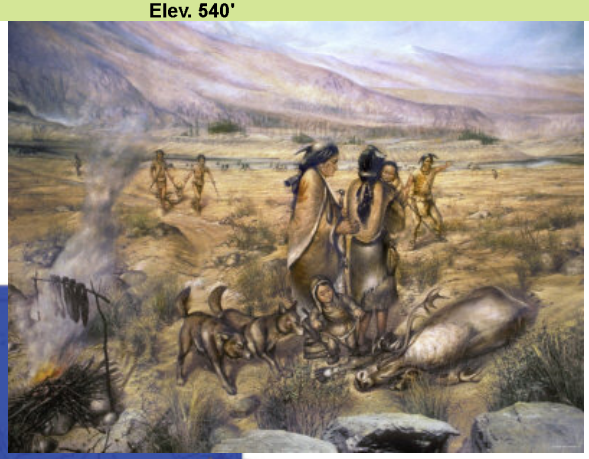


Fig. 1. The Alpena-Amberley ridge as it would have appeared during the Lake Stanley low-water phase in Lake Huron. The modern lakeshore is shown by the bold contour line. The 2 pilot search areas described in this report are shown as small black rectangles.

This pro-glacial region was more dry and colder than today.

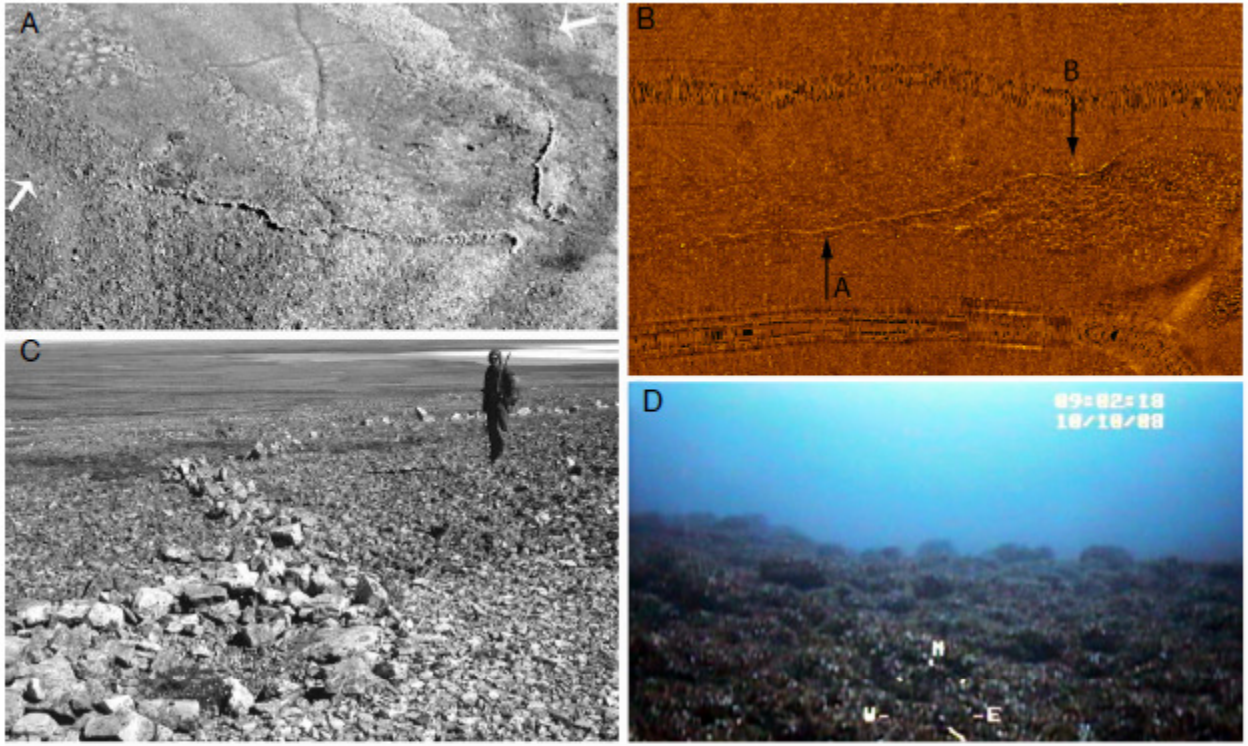


Fig. 2. Caribou channeling structure. (*A*) Caribou drive lanes photographed on Victoria Island in northern Canada. The structure at the bottom is approximately 300 m long. White arrows in the photograph indicate stone cairns leading into the channeling feature. (*B*) Acoustic image of a potential caribou drive lane beneath Lake Huron. The linear structure is designated by *A*, and a potential hunting blind (see Fig. 3*A*) is at *B*. The total length of the structure is 350 m. (*C*) A view of a Victoria Island caribou drive structure at ground level. (*D*) A similar, ground-level view of the Lake Huron structure. [Victoria Island photos reproduced from ref. 24 (Copyright 2005, Board of Regents of the University of Wisconsin System. Reproduced with permission of the University of Wisconsin Press).]

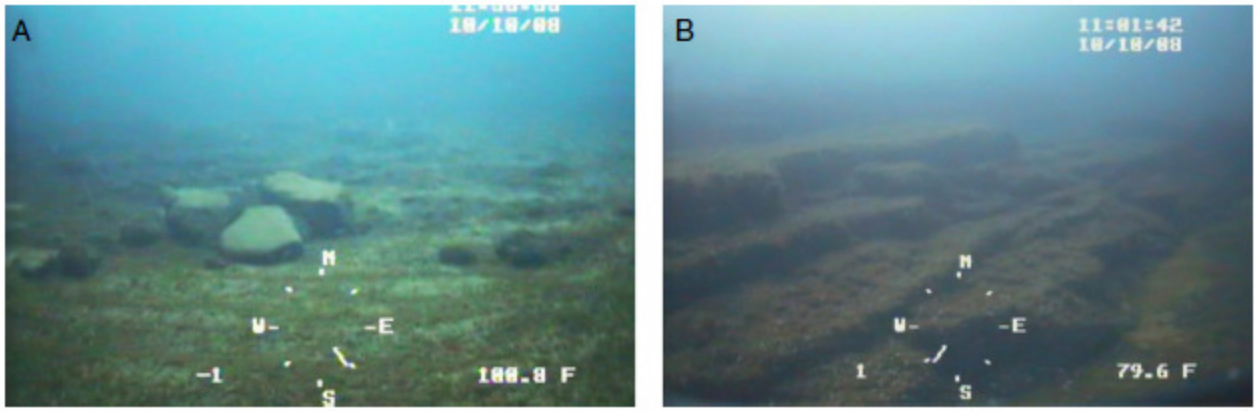


Fig. 3. Images captured from ROV video examination of the lake bottom. (*A*) View of a potential stone hunting blind (see Fig. 2*B*) that is approximately 3.5 m across. (*B*) Bedrock outcrop showing massive limestone blocks and thinner bedded layers, which may include chert deposits. Exposure is approximately 250 m long. The direction of view and camera depth (in feet) is recorded in the foreground of each image.

- The discovery of archaeological sites on the Alpena-Amberley ridge demonstrate the existence of a series of features that are consistent in form, construction, and placement with known caribou hunting structures.

- Artifacts and other debris are very scarce in the area of hunting structures and blinds. This makes good sense in terms of hunting, but makes the job of confirming the cultural (man-made) origin of structures more difficult. This problem is compounded by the tendency for hunters to maximize the use of existing terrain and features.

- Zebra mussels and *Cladophora* cover smaller features.

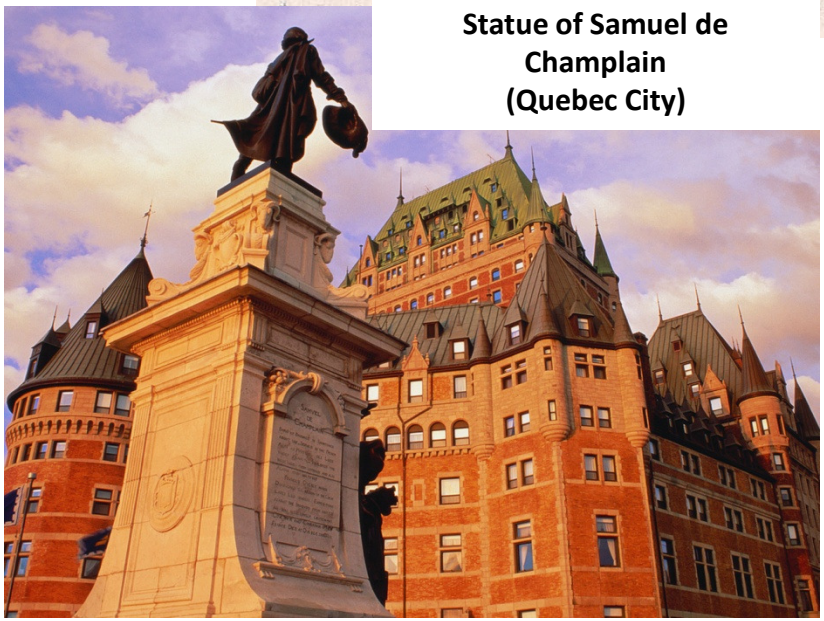
The Great Lakes were discovered first by a European by ***Samuel de Champlain*** (in 1613), 5 years after he founded Quebec City.

Ville de Montréal. Gestion de documents et archives

1613 Map

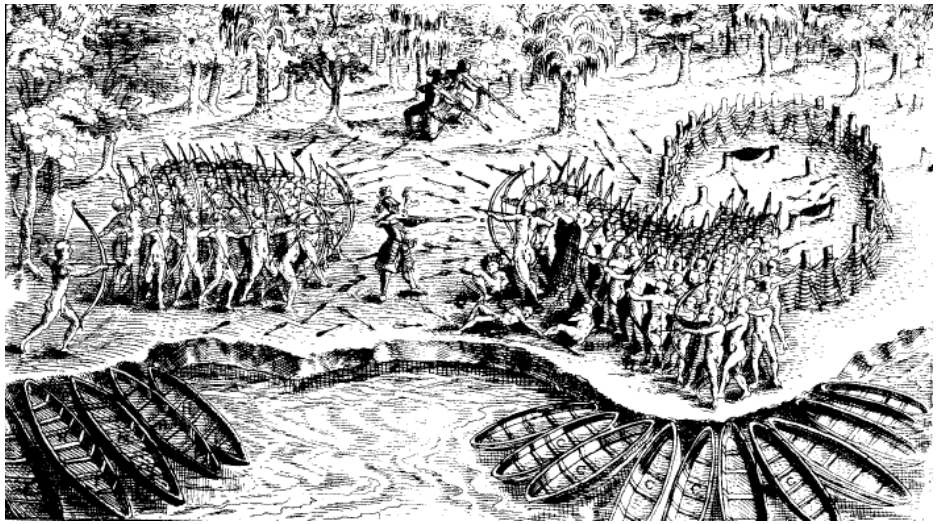
PART OF CHAMPLAIN'S 1613 MAP.[1]

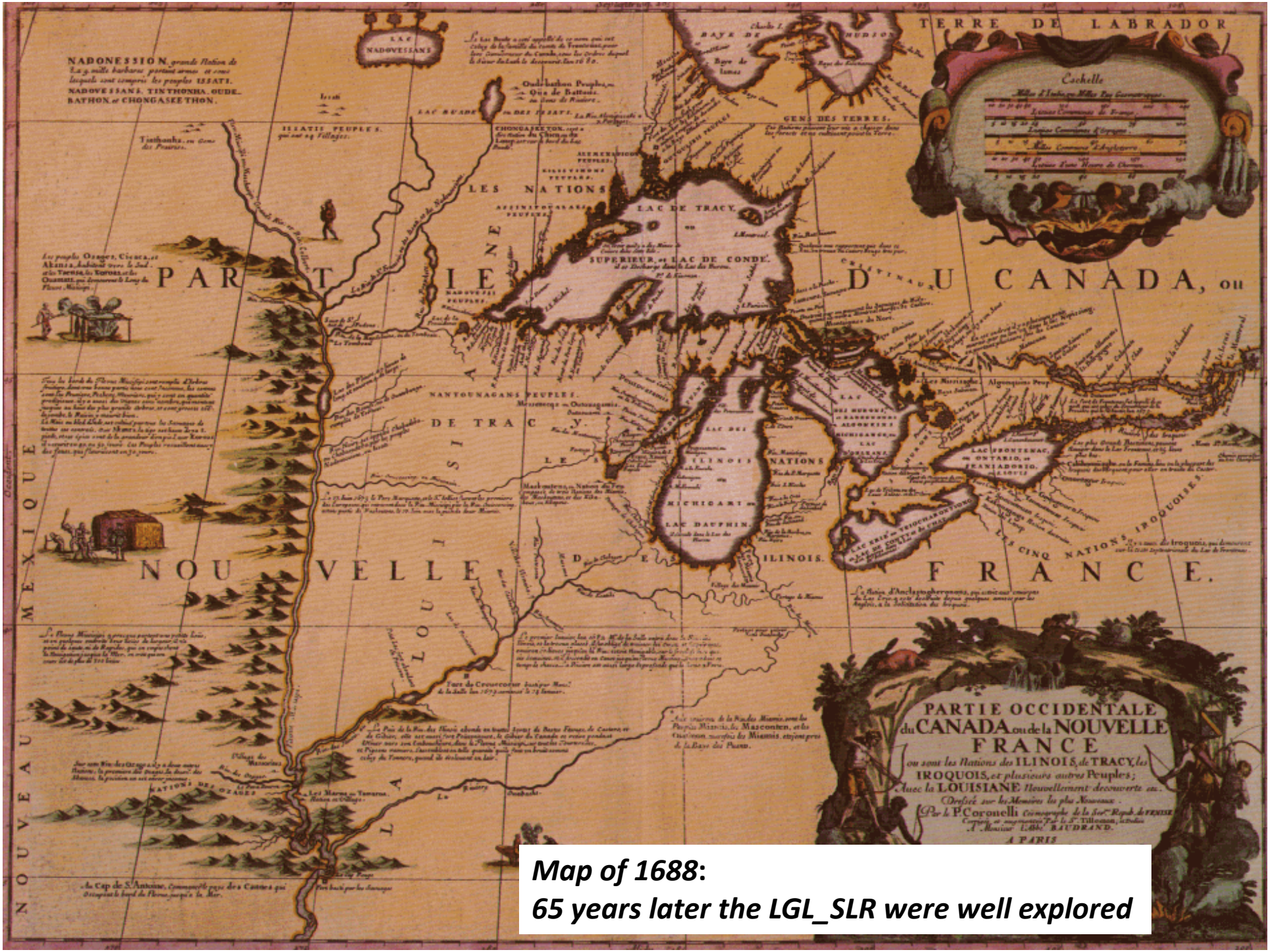
Lake Ontario (*lac St. Louis*)



Statue of Samuel de Champlain (Quebec City)

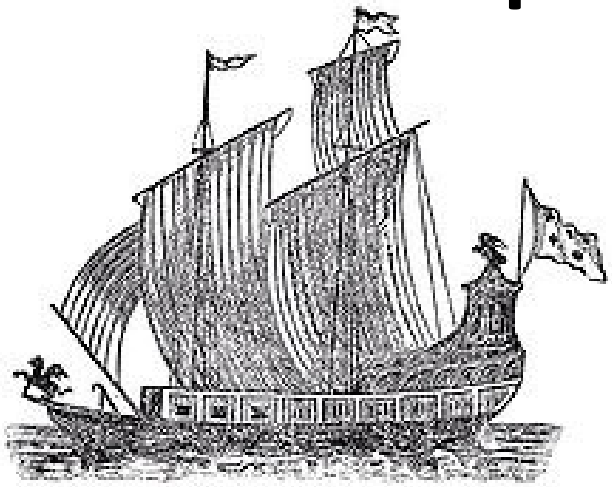
Champlain with Huron Indians using gunpowder against Iroquois





***Map of 1688*:**
65 years later the LGL_SLR were well explored

Exploration



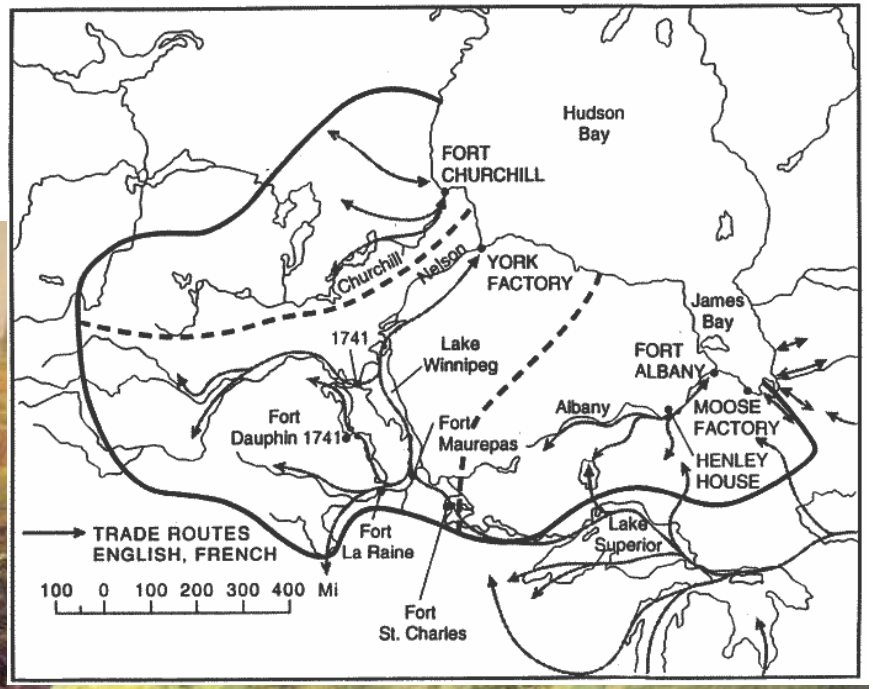
(left) The brigantine *Le Griffon*, which was built at Cayuga Creek, near the southern end of the Niagara River, and became the first sailing ship to travel the upper Great Lakes on August 7, 1679. (*right*) The modern Class 1 ice-breaker named after the *Griffon*.

Fur Trade: 1670 to 1870

The Hudson's Bay Company (British, est. 1670): operations from Hudson Bay to LGL-SLR watershed.

The *Compagnie d'Occident* (French, est. 1718): operations from St. Lawrence River and in the region of the eastern Great Lakes.

Also English trade through Albany and New York, and French trade down the Mississippi.



The Seven Years War/French and Indian Wars (1756-1763)

- **France loses possessions in northeastern North America with the Fall of Quebec (1759)**
- **Access to the interior of North America now controlled by England**

(*left*) British troops lay siege to Quebec City and force a battle on the Plains of Abraham. (*right*) Both French (Montcalm) and British generals (Wolfe) are killed.

The British hampered colonial expansion into the interior by the Proclamation of 1763.
The Thirteen Colonies revolt (1775) and win independence from Britain (1783).
The Great Lakes were controlled by Britain; the St. Lawrence River and Lake Champlain were areas of conflict.

American immigrants into Canada, known as **United Empire Loyalists**, were the result of the American Revolution. At the time Canada was the British Province of Quebec. It became a refuge for those wishing to remain loyal to the British Crown. When Britain had taken control of New France following the French and Indian/Seven Years War, they had at first imposed British rule on the colony (1763), and then subsequently changed to incorporate French civil law and giving civil rights to Catholics (1774). When Loyalists came north to Canada, the colony was still under French law. Having just lost their lands and rights in the American Revolution they could not bear to settle within and around the existing settled areas of Quebec and be ruled under French law. As a result several Loyalist Officers travelled to London to petition the King, not only for separate land, but also requesting British Governance and Civil Law.

Three main areas were chosen for settlement, the north shore of the St. Lawrence River, near Kingston, ON; the Bay of Quinte (Lake Ontario); and the Niagara Peninsula.

The immigrants included those who fought on the British side during the Revolution (including several thousand Iroquois natives), those fleeing minority and religious persecution in the states, free blacks and escaped slaves, and later, simply those in search of new land to settle. ***In total, some 80,000 to 100,000 Loyalists fled the newly created United States, about half of them to Canada. Some 7,500 settled in what is present day Ontario.***

The British Crown was very generous with these new immigrants, granting them land, and supplying them with three years of clothing, tools and provisions. The land settlements were based on service to the Crown as follows:

To Loyalists who fought for the Crown:

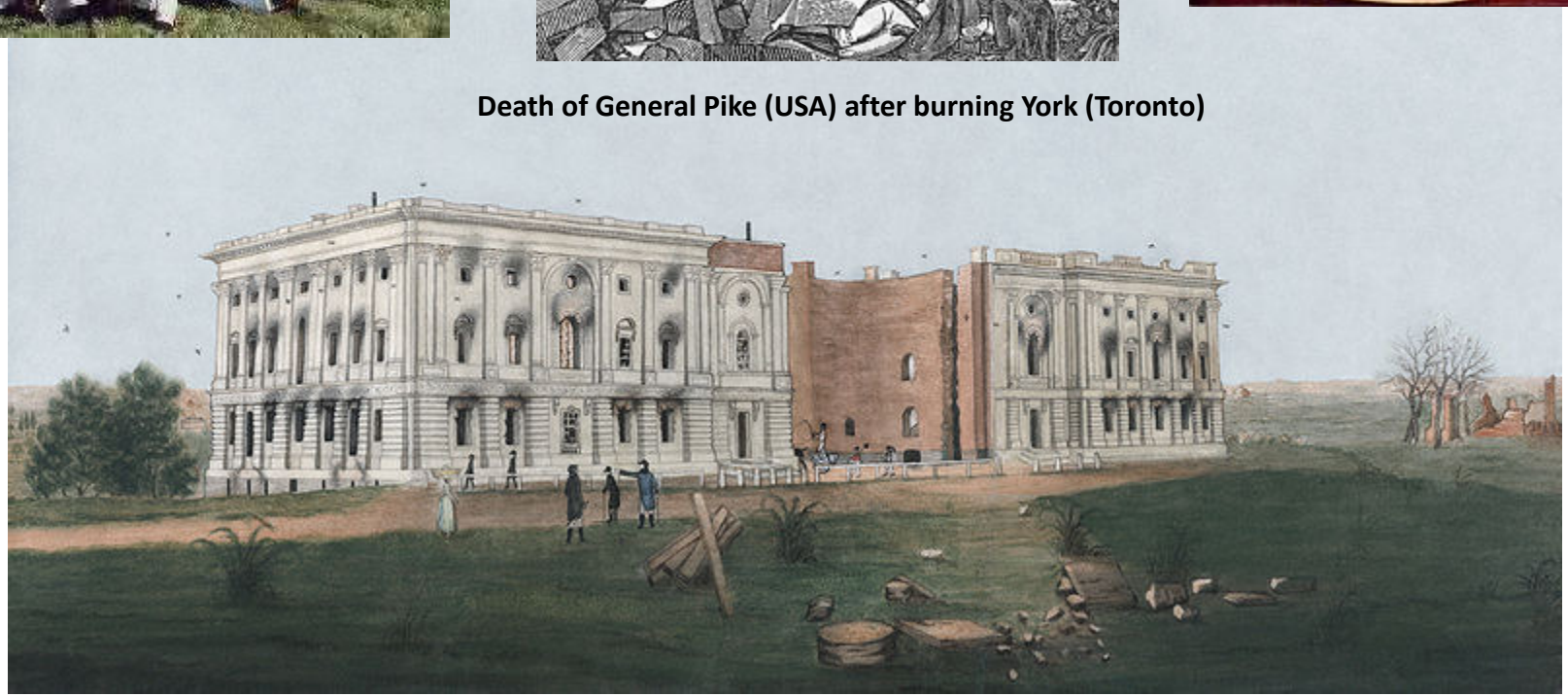
- To every field officer - 1,000 acres
- To every captain - 700 acres
- To every subaltern, staff, or warrant officer - 500 acres
- To every non-commissioned officer - 200 acres
- To every private - 100 acres
- For each member of their families - 50 acres

To non-combatant Loyalists:

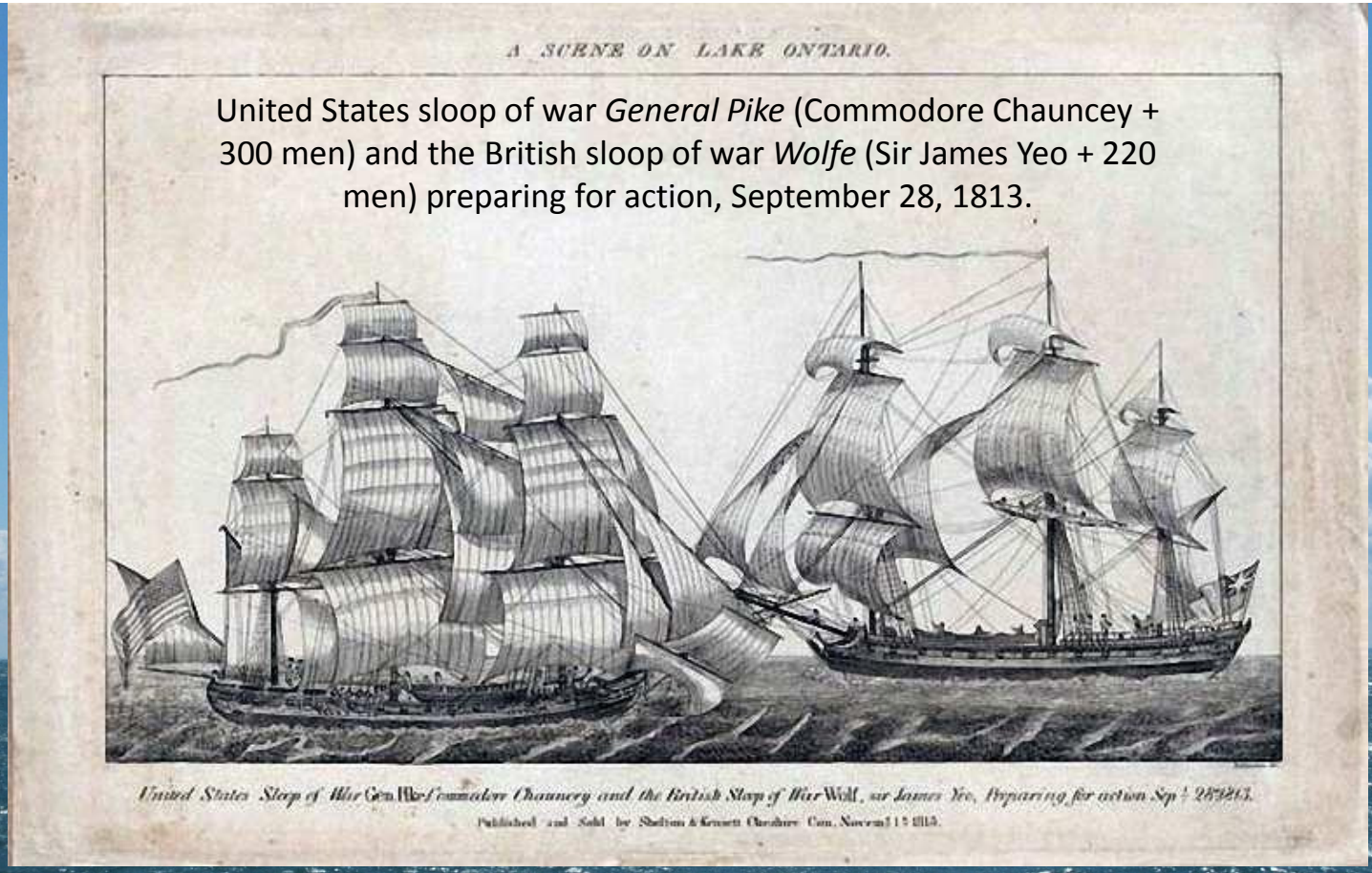
- Every master of a family - 100 acres
- Every person in the family – 50 acres
- Every single man – 50 acres

USA versus Britain: Round 2
The War of 1812-1814

Death of General Pike (USA) after burning York (Toronto)



The US Capitol building after the sack of Washington ,D.C. by the British



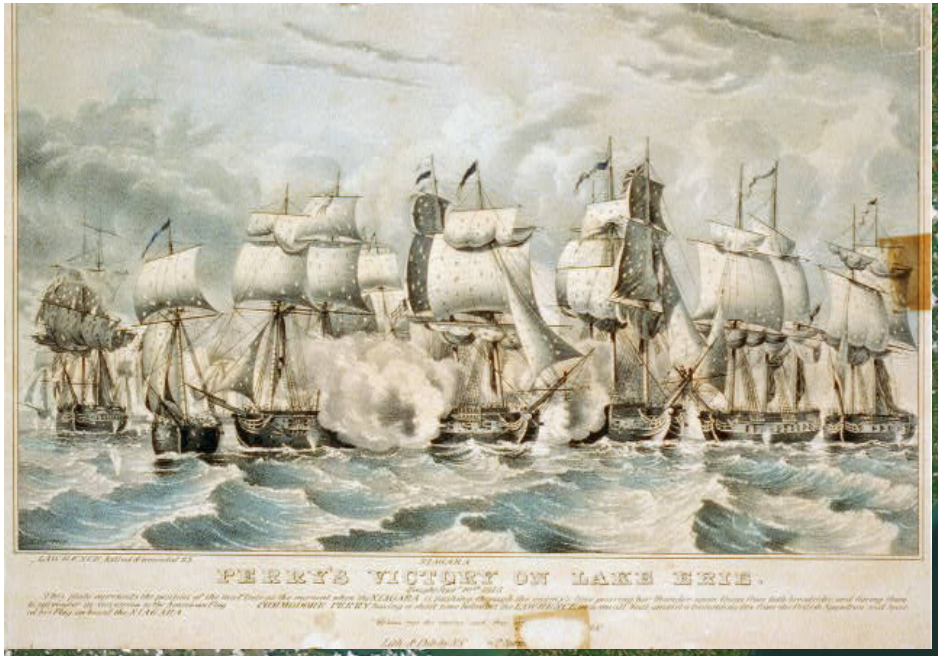
Battles on Lake Ontario, War of 1812

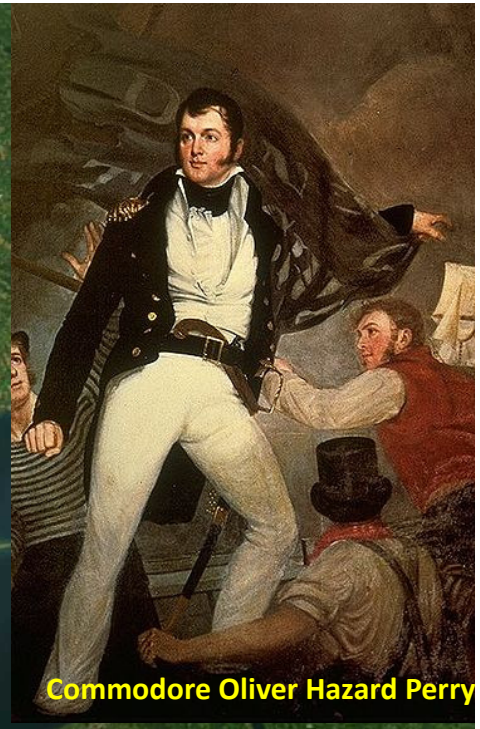
US and British forts around Lake Ontario

Sackets Harbor, NY

By 1814, the British had in place on Lake Ontario the ship-of-the-line H.M.S. *St. Lawrence* (115 guns, 700 men)

The Americans were kept in port.





Commodore Oliver Hazard Perry

Battle of Lake Erie
September 10, 1813

British 6 ships versus USA 9 ships
USA: captured all 6 British ships

"Don't give up the ship."

The Rush-Bagot Treaty (1817)

"The naval force to be maintained by each Government on the Great Lakes should be limited, on Lake Ontario, to one vessel not exceeding 100 tons burden and armed with one 18-pound cannon; on the upper Lakes, to two vessels of the same burden and armament; and on Lake Champlain, to one similar vessel. All other armed vessels on the Lakes were to be forthwith dismantled, and no other vessels of war were to be there built and armed. This stipulation was to remain in effect till six months after either party should have given notice to the other of a desire to terminate it."

Issues:

Canadian Rebellion: During the years 1838-41 the rebellion in Canada led the British Government to increase somewhat its naval force on the Lakes.

US Civil War: Parties of Confederates, using Canada as their base, had captured Federal steamers on Lake Erie, and had raided a town in Vermont. Mr. Seward, the American Secretary of State, gave notice that "owing to recent hostile and piratical proceedings on the lakes" it would be necessary to increase "the observing force" maintained there. In February 1865 Seward gave the requisite six months' notice to terminate the Agreement.

War on Terror - 2006: Live fire exercises by Coast Guard boat and cutter crews in the U.S. waters of the Great Lakes attracted attention in the U.S. and Canada.

U.S. machine-gun fire suspended on Great Lakes

Last Updated: Monday, October 16, 2006 | 4:54 PM ET (Canadian Broadcasting Corporation: http://www.cbc.ca/canada/ottawa/story/2006/10/16/coast-guard-guns.html?ref=rss

The U.S. Coast Guard has suspended its machine-gun exercises on the Great Lakes until nearby American residents have their say, Canadian Foreign Affairs Minister Peter MacKay said Monday. MacKay was responding to questions about controversial coast guard plans to set up 34 live-fire zones in the Great Lakes so its crews can practice shooting machine guns mounted on their boats. The guns can shoot up to 600 rounds per minute. The agency has already conducted some live-fire exercises and began holding public hearings Monday in order to ask American residents near the lakes what they think are the best proposed locations for the ranges. NDP Leader Jack Layton asked MacKay in question period Monday what the Canadian government was doing to ensure the security of people who live, work and play on the Great Lakes while the U.S. fires live ammunition there. MacKay said no coast guard machine-gun exercises will take place until the public hearings are over on Nov. 13. "Canada has made its views known to the United States, and clearly we will follow these consultations in the United States to make those views further known to see that we get a proper resolution," he added. ***MacKay noted that the previous Liberal government confirmed the firing ranges are permitted under a Canada-U.S. treaty signed in 1817.*** Lt. Ryan Barone, a spokesperson for the U.S. Coast Guard, said the firing ranges are allowed under a 2004 "understanding" reached between the two countries in response to concerns about terrorism and border control.

Canadians want a say

Politicians representing Canadian cities bordering the Great Lakes have complained that they cannot participate in the public hearings, even though they are near some of the proposed firing ranges. One site is within 40 kilometres of Kingston, Ont. The city's mayor, Harvey Rosen, said Kingston residents should be consulted. Coast guard officials have said guns will only be fired in American waters. But Bob Runciman, Conservative MPP for Leeds-Grenville in Eastern Ontario, said he is concerned the exercises will impact the Canadian side of the lake. "It interferes with boating channels, recreational boating channels. It could have an impact on tourism, fishing, [and] commercial boat traffic," Runciman said. ***"These are waters we share."*** Sarnia, Ont., Mayor Mike Bradley said he is also concerned the bullets will harm the freshwater plants and animals in the lakes.

'They effectively have now made the Great Lakes a military zone.'

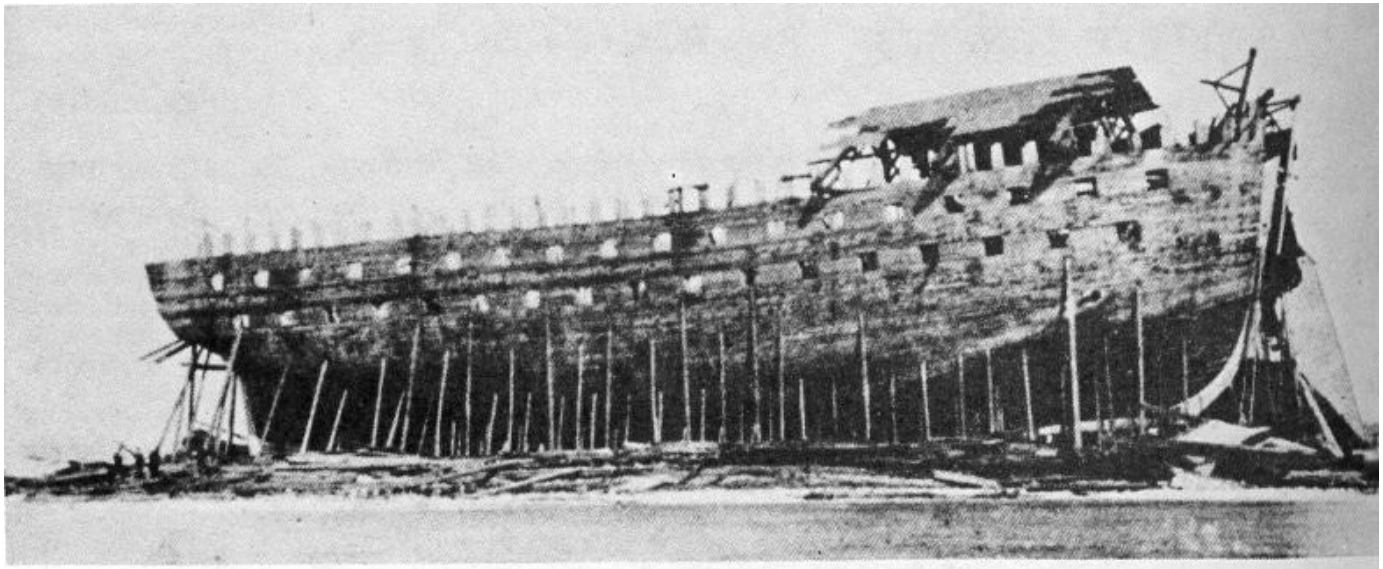
Sarnia, Ontario Mayor Mike Bradley

"We're talking about lead and copper bullets polluting the waters of the Great Lakes at a time when we're making major strides in cleaning up the Great Lakes." However, a U.S. study said the bullets would not harm the freshwater ecosystems. Prior to the start of the coast guard exercises in January, guns have not been fired on the Great Lakes since the war of 1812, said Bradley. He said the new firing ranges are a huge backward step. "They effectively have now made the Great Lakes a military zone," he said, adding that the Canada-U.S. border used to be the longest undefended border in the world, and that claim to fame is now a myth. U.S. Coast Guard officials said Canadians will have plenty of notice before the firing ranges begin operating.

Onboard a Canadian warship HMCS *Charlottetown* in the Detroit River (Ambassador Bridge in background)

Result of the Rush-Bagot Treaty:

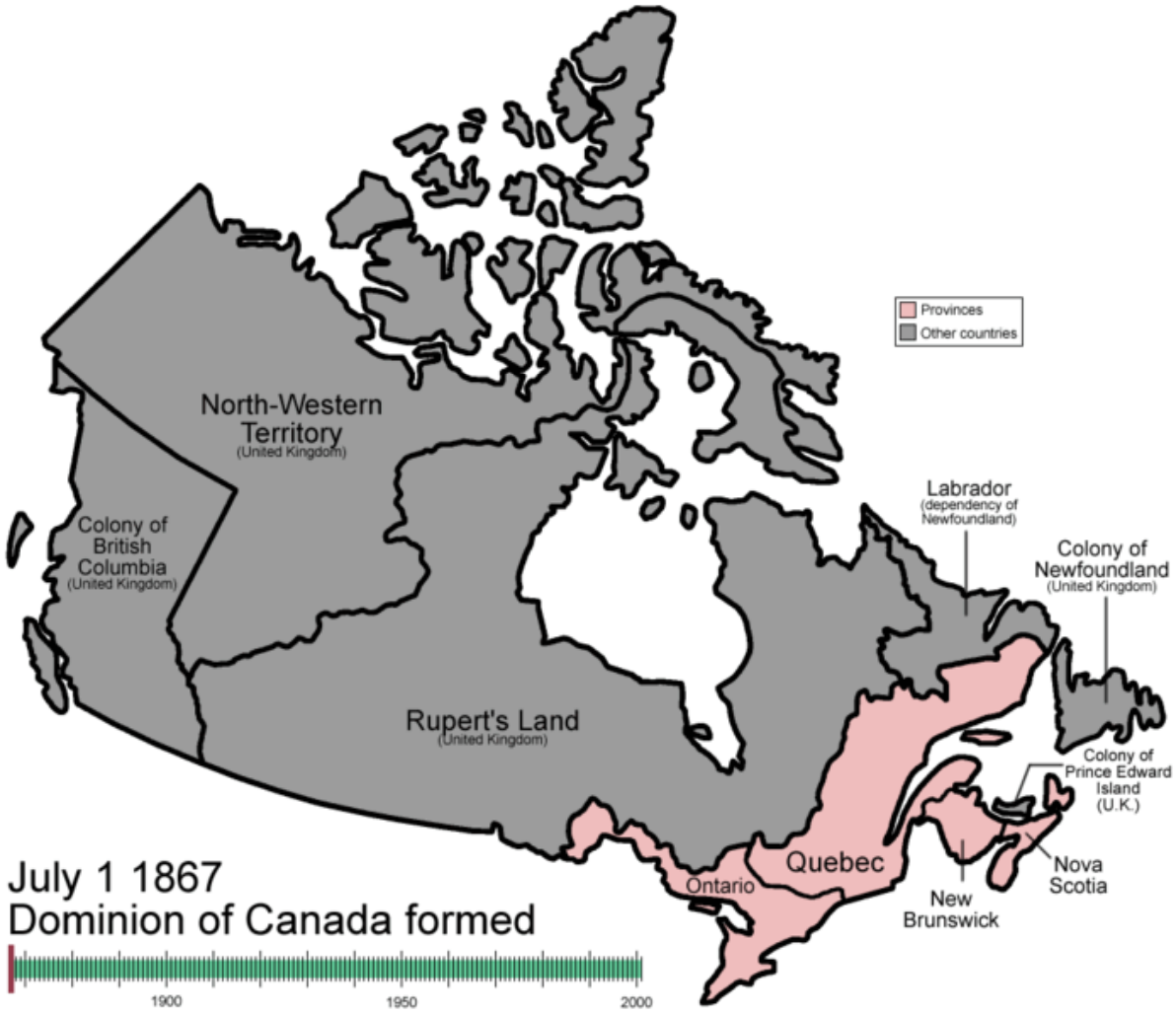
• an expensive arms race was averted; ships of the line were scrapped



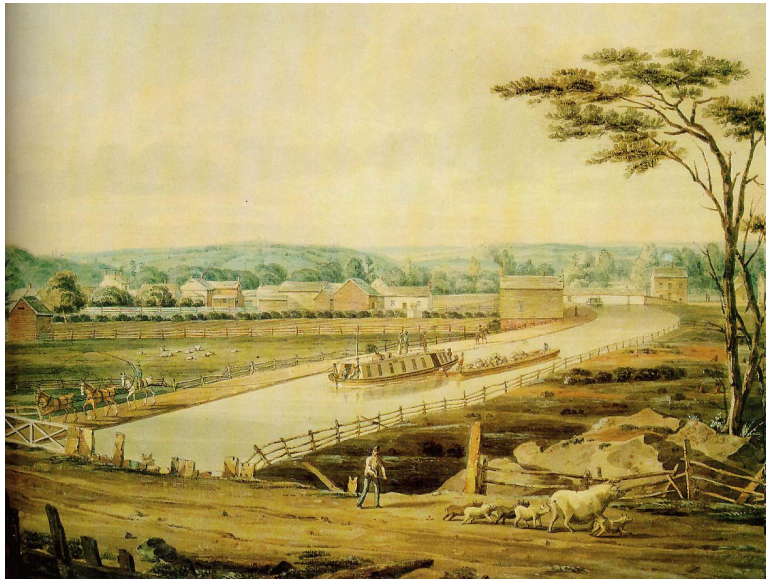
Photograph from the Jefferson County, New York, Historical Socie

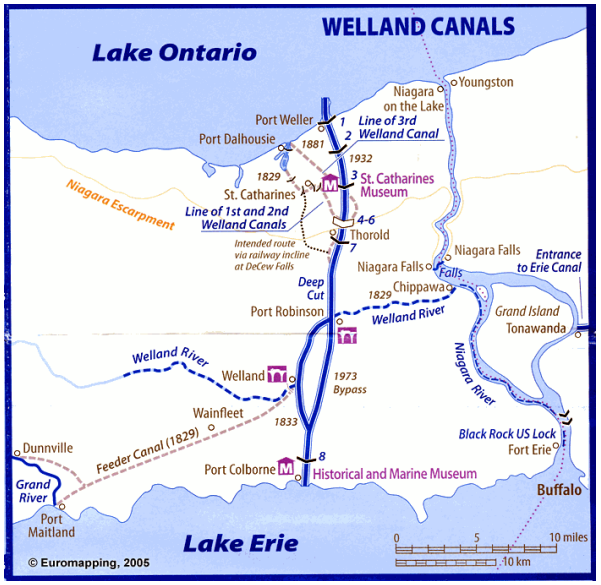
Ship-of-the-Line *New Orleans* on the stocks at Sacketts' Harbor, Lake Ontario, New York, in 1883. Note that a portio of the shiphouse remains.

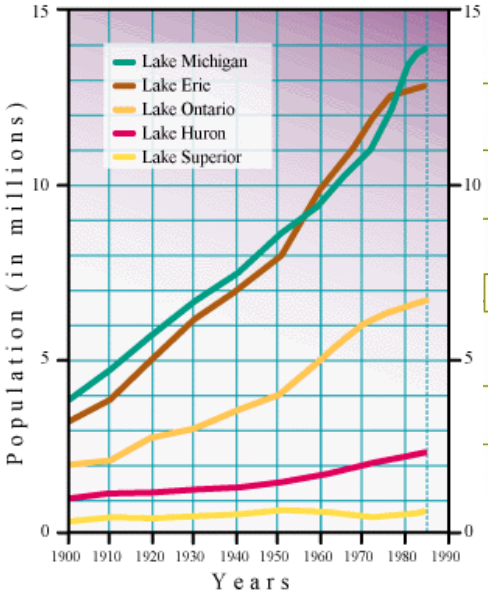
…Fifty years later, the Dominion of Canada is founded.
During the peace following the War of 1812, settlement in the Great Lakes accelerated.

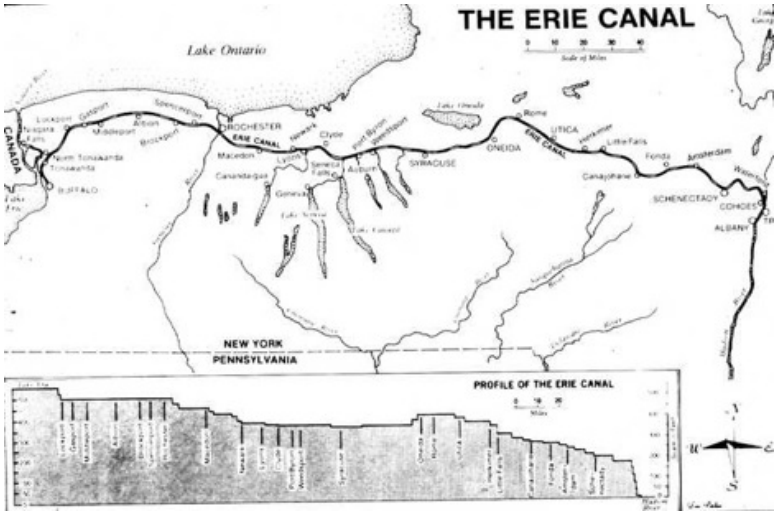


Agricultural expanded as forest were cleared and swamps drained. The Erie Canal (NY; 1825) and the early Welland Canal (ON; 1829) increased trade traffic and further stimulated industrial and agricultural development









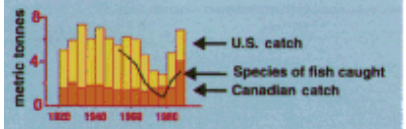
The Great Black Swamp

LAND USE, FISHERIES & EROSION

Land Use

- Intensive General Farming
- Low-Intensity Farming/Pasture
- Coniferous Forest
- Mixed-wood Forest
- Deciduous Forest
- Urban Areas

Commercial Fisheries



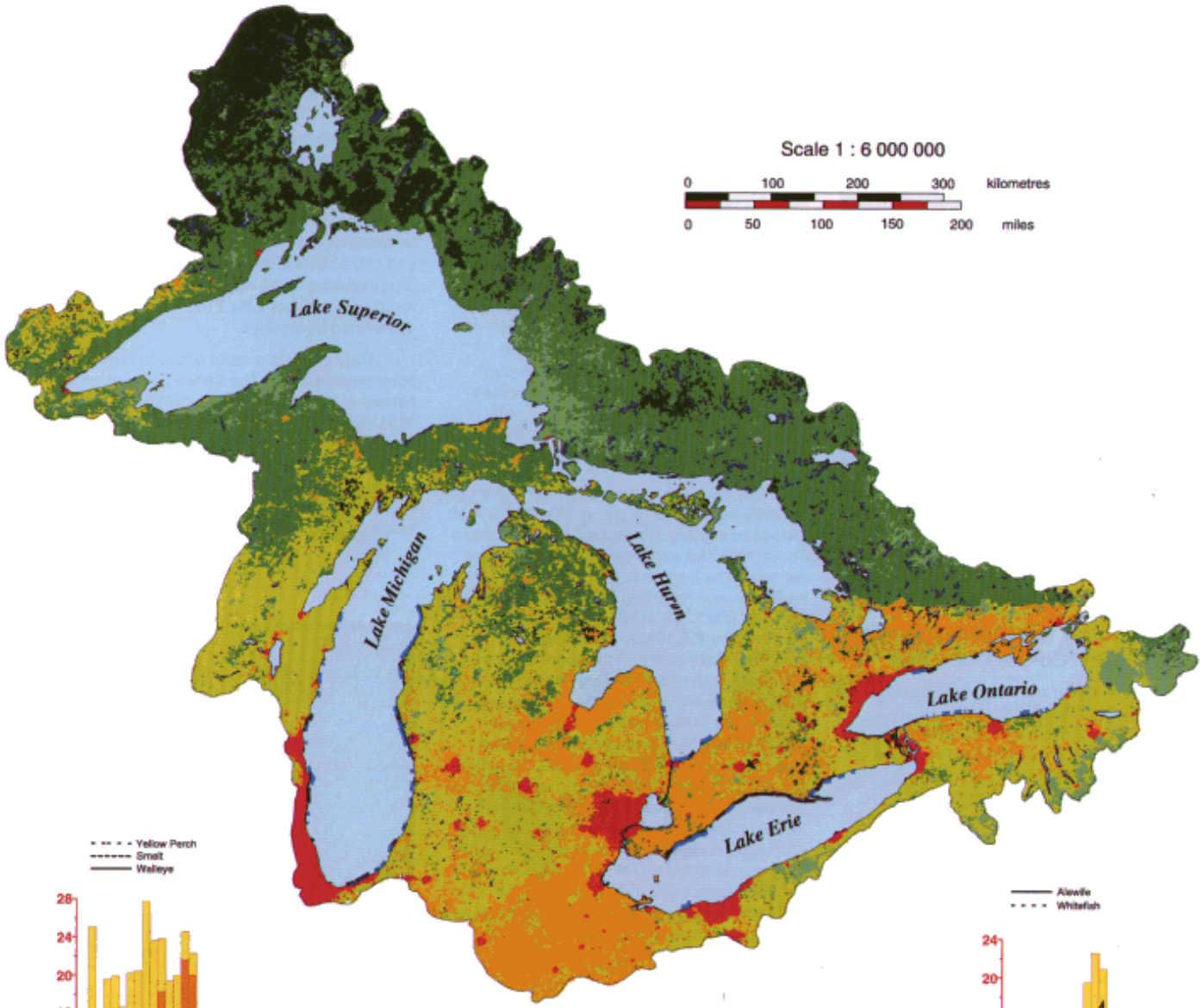
NOTE:

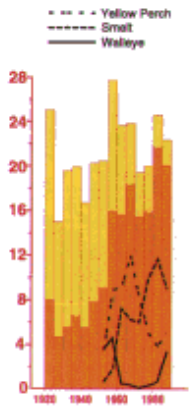
1. Each bar represents the average catch over a five-year period.
2. The species shown for each lake are those which have been consistently important since 1950. They are not necessarily those which yielded the largest catch in any five-year period.

Tonnes	Tons
4 000	4 400
8 000	8 825
12 000	13 225
16 000	17 625
20 000	22 050
24 000	26 450
28 000	30 875

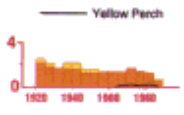
Shoreline Erosion

- Minimal
- Moderate
- Severe

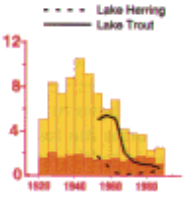




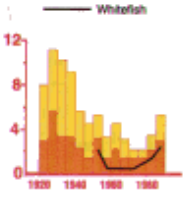
Lake Erie



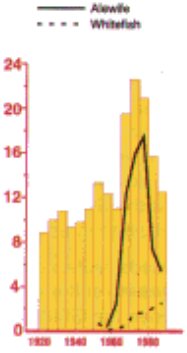
Lake Ontario



Lake Superior



Lake Huron



Lake Michigan

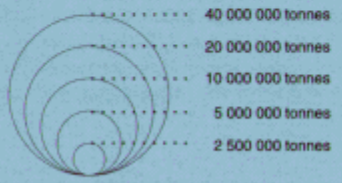
WATERBORNE COMMERCE

Cargo Volume By Port In Tonnes, 1990

Ports under 2 500 000 tonnes

- 100 000 - 500 000 tonnes
- 500 000 - 2 500 000 tonnes

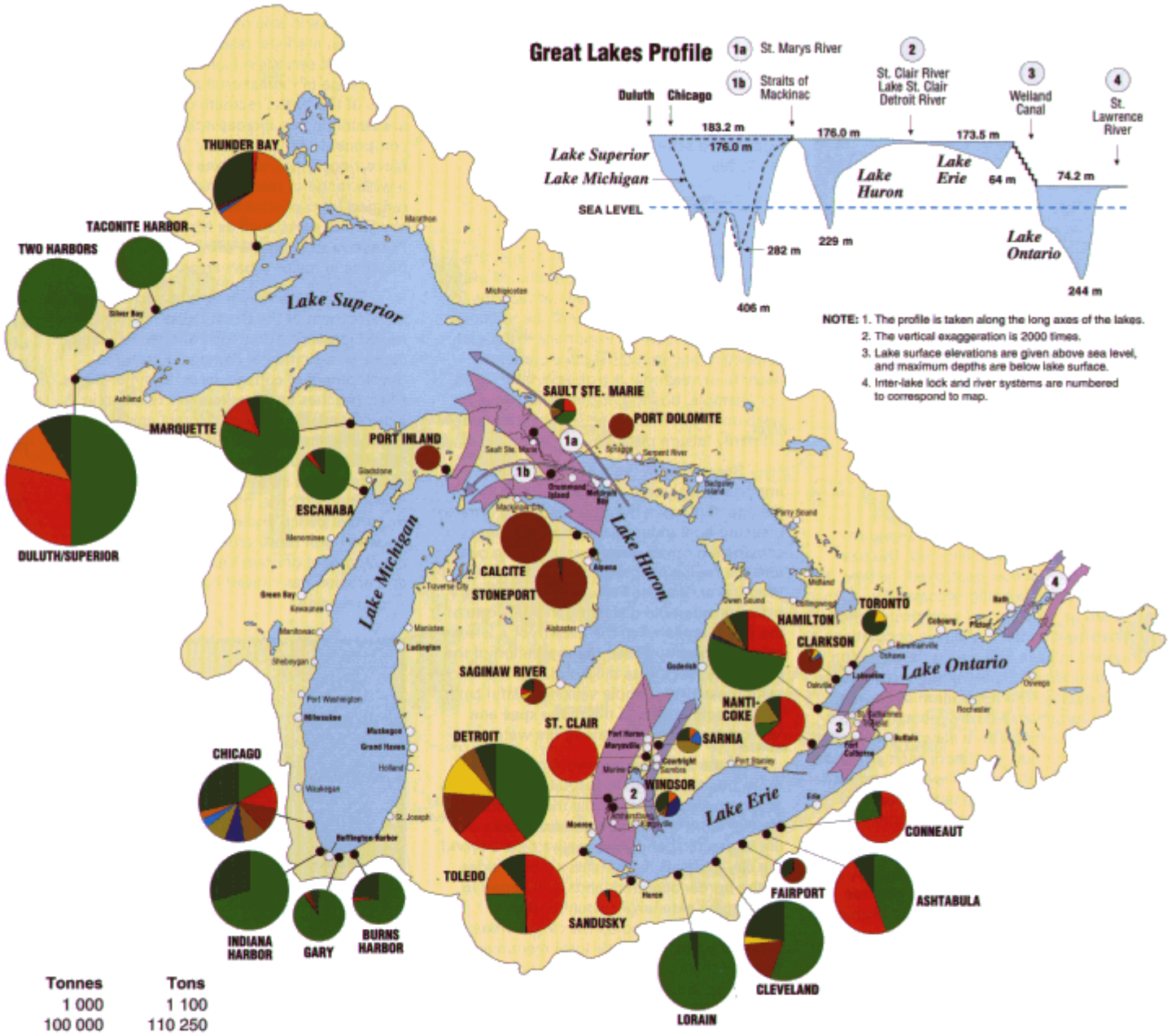
- **Ports over 2 500 000 tonnes**



Commodity Types

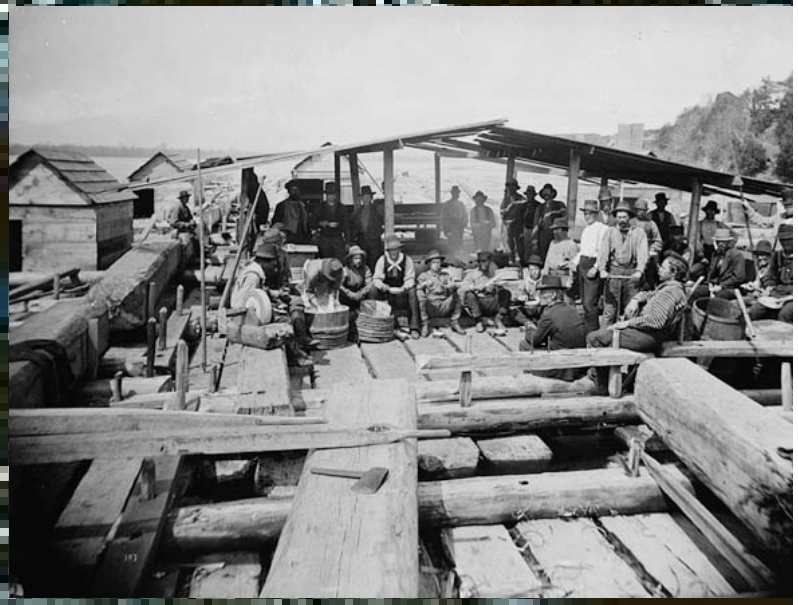
- Coal
- Grains/Soybeans
- Iron Ore
- Cement
- Chemicals
- Coke
- Electrical Products
- Limestone
- Metals and Metal Products
- Petroleum Products
- Other

Inter-Lake Commodity Flow In Tonnes, 1990



Tonnes	Tons
1 000	1 100
100 000	110 250
500 000	551 270
2 500 000	2 756 340
5 000 000	5 512 680
10 000 000	11 025 360
20 000 000	22 050 720
30 000 000	33 076 070

Development in the Great Lakes (and elsewhere) prompted **conservationist movements in the 1890s** on both sides of the border.
e.g., soil erosion from clear-cut forests was a basin-wide impact affecting land and water (fisheries)



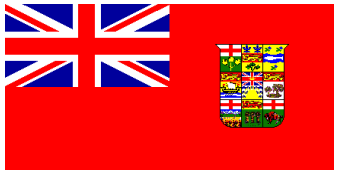
The Boundary Waters Treaty: 1909; A Model for Cooperation

While conflicts arise when countries share water, the Boundary Waters Treaty helps Canada and the United States find their common interests. (www.ijc.org)

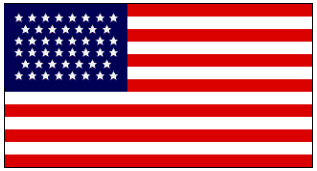
Origins of the Boundary Waters Treaty:

• Water diversion conflicts; importance of water pollution and its impact on human health; desire to facilitate commerce and industrial development

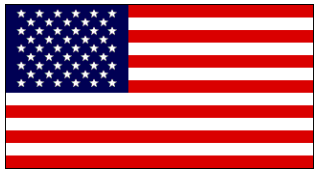
• *IMPORTANT Sections regarding Great Lakes Water Protection (lines refer to handout*



1909

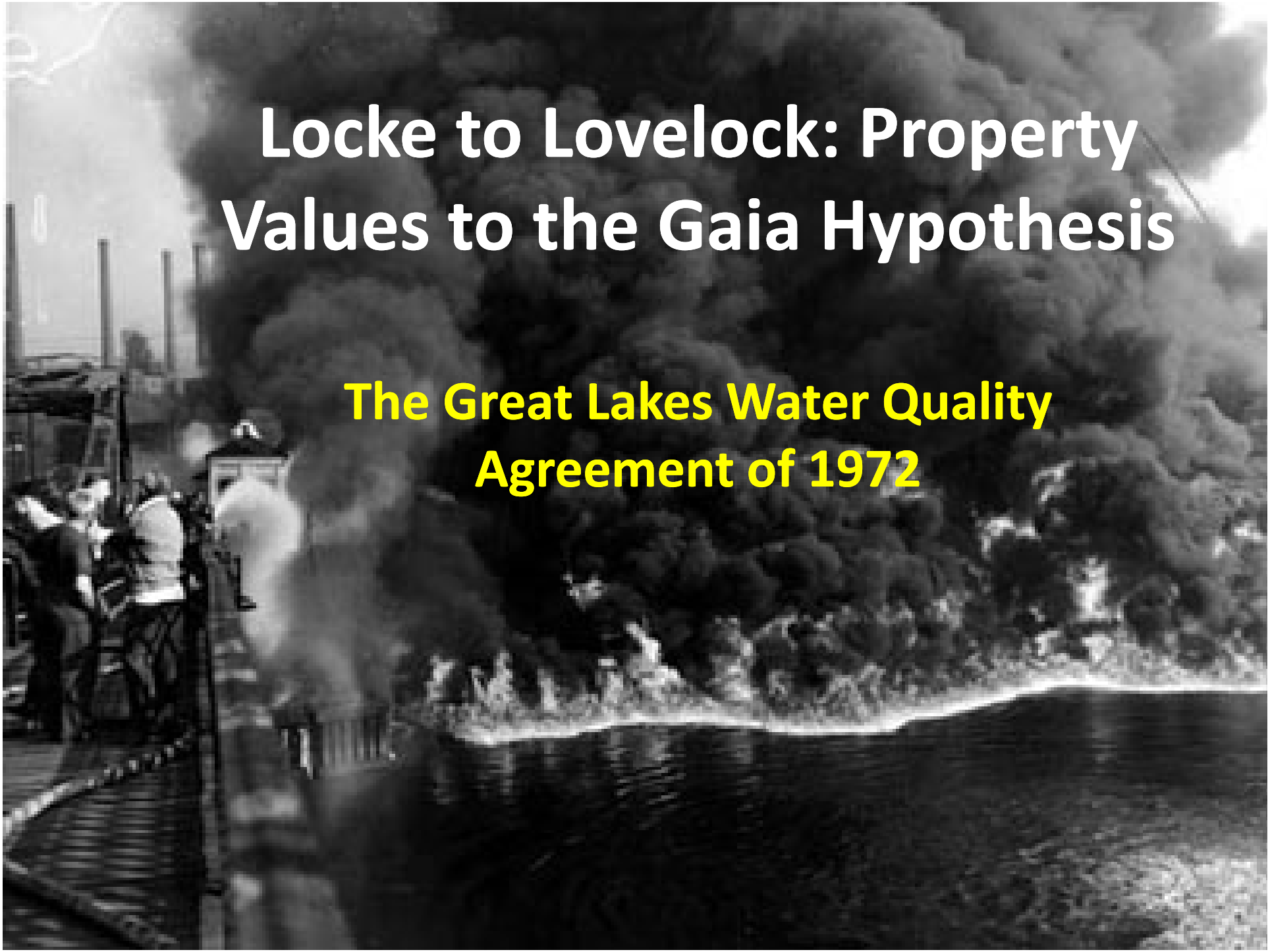


present



Yellow areas show boundary waters;
it includes the entire LGL-SLR system.

1909-2009
BOUNDARY WATERS TREATY
TRAITÉ DES EAUX LIMITROPHES



Locke to Lovelock: Property Values to the Gaia Hypothesis

The Great Lakes Water Quality Agreement of 1972

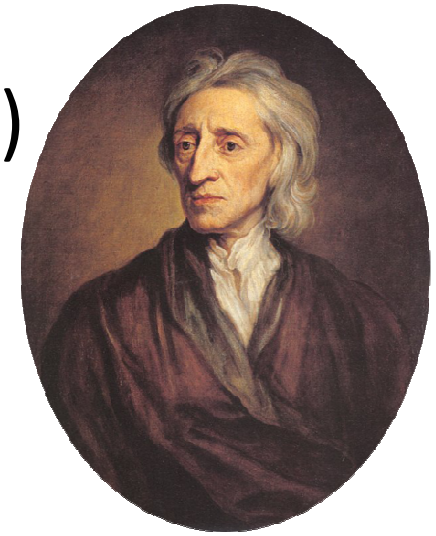
The Cuyahoga River Fire of 1969

GREAT LAKES
BREWING CO.

Burning River

A Handcrafted Pale Ale
Cleveland, Ohio

John Locke (1632-1704)



- Philosopher
- *Of Property,* an essay in *Second Treatise on Government*
- How do humans interact with Nature?
- How can we own anything?
- If we obtain value from Nature then Nature is valuable.


PARTIE OCCIDENTALE du CANADA ou de la NOUVELLE FRANCE
ou sont les Nations des ILINOIS, de TRACY, les IROQUOIS, et plusieurs autres Peuples; Avec la LOUISIANE Nouvellement decouverte &c.
Dressé sur les Memoires les plus Nouveaux.
Par le P. Coronelli Cosmographe de la Sere Republ de VENISE
Corrigé, et augmenté Par le Sr Tillemont, Ingenieur
A Monsieur L'Abbé BAUDRAND.
A PARIS
Aux Privilege du Roy.
1688.
TERRE DE LABRADOR
Echelle
NOUVELLE FRANCE
LES NATIONS
LAC DE TRACY.
SUPERIEUR, et LAC DE CONDE'.
LAC DES ILLINOIS
LAC DAUPHIN.
LAC FRONTENAC, ou ONTARIO, ou SKANIADORIO.
LAC ERIE ou TEIOCHAGORONTONG.
LOUISIANE
NOUVEAU MEXIQUE
LES CINQ NATIONS IROQUOISES.
NADONESSION, grande Nation de 24 grandes villes barbares portant armes et ainsi laquelle sont comprises les peuples ISSATI. NADOUESSANS. TINTHONHA. OUDE-BATHON. et CHONGASEE THON.
ISSATIS PEUPLES, qui sont 24 Villages.
NANTOUNAGANS PEUPLES.
ILINOIS.
NATIONS DES OZARES
Au Cap de S. Antoine, Commencement des Cannes qui occupent le bord du Fleuve jusques à la Mer.

James Lovelock (b. 1919)

Gaia Hypothesis:

- A controversial ecological hypothesis or theory proposing that the biosphere and the physical components of the Earth (atmosphere, cryosphere, hydrosphere and lithosphere) are closely integrated to form a complex interacting system that maintains the climatic and biogeochemical conditions on Earth in a preferred homeorhesis. Originally proposed by James Lovelock as the *earth feedback hypothesis*, it was named the *Gaia Hypothesis* after the Greek primordial goddess of the Earth, at the suggestion of William Golding, Nobel prizewinner in literature and friend and neighbor of Lovelock. The hypothesis is frequently described as viewing the Earth as a single organism. Source: Wikipedia.org

evidence?

How the Gaia Hypothesis applies to Great Lakes Water Protection

a. Leave the lakes alone – life will proliferate in them.
b. The lakes are only 10k years old – of course there will be invasive species (see [a.])
c. Allow natural processes to occur – the lakes will adjust
    i. Define “natural”. Does this include humans?
    ii. Can we “help” Nature?

Great Lakes Water Quality Agreement (1972)

- The ***GLWQA*** *established common water quality objectives to be achieved in both countries and three processes that would be carried out binationally.*

President Richard M. Nixon and Prime Minister Pierre E. Trudeau sign the GLWQA in 1972

Great Lakes Water Quality Agreement of 1972

1. The first is ***control of pollution***, which each country agreed to accomplish under its own laws. The chief objective was reduction of phosphorus levels to no more than 1 ppm (mg/L) in discharges from large sewage treatment plants into Lakes Erie and Ontario together with new limits on industry. Other objectives included elimination of oil, visible solid wastes and other nuisance conditions.*

2. The second process was ***research*** on Great Lakes problems to be carried out separately in each country as well as cooperatively. Both countries established new Great Lakes research programs. Major cooperative research was carried out on pollution problems of the upper Great Lakes and on pollution from land use and other sources.

3. The third process was ***surveillance and monitoring*** to identify problems and to measure progress in solving problems. Initially, water chemistry was emphasized and levels of pollutants were reported. Now, the surveillance plan is designed to assess the health of the Great Lakes ecosystem and increasingly depends on monitoring effects of pollution on living organisms.

**sensu* Cuyahoga River Fire

Source: *Great Lakes Environmental Atlas* (pp. 40-42)

Great Lakes-St. Lawrence River Treaties

1. Rush-Bagot Treaty 1817

"let's be friends"

2. Boundary Waters Treaty 1909

"good fences make good neighbors"

3. Great Lakes Water Quality Agreement 1972

"let's work together to clean up the neighborhood"