Manual for Scientific Educational Cruises Aboard the *D.J. Angus* and *W.G. Jackson* Vessels

Robert B. Annis Water Resources Institute
Grand Valley State University

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GRAND VALLEY STATE UNIVERSITY
ROBERT B. ANNIS WATER RESOURCES INSTITUTE
RESEARCH AND EDUCATION VESSELS

The *D.J. Angus* and *W.G. Jackson*

The Water Resources Outreach Education Program of the Robert B. Annis Grand Valley State University Water Resources Institute operates two research and education vessels: the *D.J. Angus* and the *W.G. Jackson*. The *D.J. Angus* was launched in 1986, and the *W.G. Jackson* in 1996. The vessels are designed for research and educational activities with group sizes of up to 26 participants on the *Angus* and 28 on the *Jackson*. The *Jackson* can accommodate a research crew of six overnight. The homeport of the *D.J. Angus* is Grand Haven, Michigan, and the *W.G. Jackson* is berthed in Muskegon, Michigan. Their normal operating seasons are late April to mid-October.

Availability

The *D.J. Angus* and *W.G. Jackson* are designed to serve as floating laboratories for the aquatic sciences. Grand Valley State University encourages the study of our region's water resources by making the vessels available for educational cruises as well as for research projects. Users of the vessels include colleges and universities, organizations, adult groups, and fourth through twelfth grade classes. On-board Science Instructors conduct hands-on science programs and assist visiting college faculty in conducting classes and projects.

The specifications of the *D.J. Angus* are:

Length: 45 feet (13.7 meters)
Beam: 14 feet (4.27 meters)
Draft: 4 feet (1.22 meters)
Crew: 2 (plus science support)
Engine: Cummins 6BT5.9
Generator: 20 KW Westerbeke
Electronics: VHF Marine Radio
Radar
Differential Global Positioning System
Digital & Recording Depthfinders

The specifications of the *W.G. Jackson* are:

Length: 64 feet 10 inches (19.7 meters)
Beam: 20 feet (6.1 meters)
Draft: 5 feet (1.5 meters)
Crew: 2 (plus science support)
Engine: Twin 6V92T Detroit Diesel
Generators: 30 KW and 13 KW
Electronics: 2 VHF Marine Radios
Radar
Differential GPS
Digital & Recording Depthfinders

The standard inventory of scientific equipment for the vessels includes:

Conductivity Meter and Pens	Turbidity Meter	Microscope with Video Camera
Forel-Ule Water Color Scale	Vertical Plankton Sampler	pH Meter and Pens
PONAR Grab Sampler	Alkalinity Kit	VCR, DVD, & Monitor
Van Dorn Water Samplers	Dissolved Oxygen Kit	
Secchi Disc	Turbidity Tube	

Scheduling

Persons interested in scheduling the *D.J. Angus* or *W.G. Jackson* should contact:

Roxana Taylor, taylorr@gvsu.edu
Robert B. Annis Water Resources Institute
740 W. Shoreline Drive, Muskegon, Michigan 49441
Phone: (616) 331-3749

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Introduction

Welcome to the Grand Valley State University research and education vessels, *D.J. Angus* and *W.G. Jackson*. The vessels are well equipped floating laboratory-classrooms used to study the aquatic environment of Lake Michigan and adjoining waters. Lake Michigan is the only Great Lake entirely within the United States and is the sixth largest freshwater lake in the world. Both vessels have sampled the lake and its tributaries throughout the Lake Michigan basin.

The Grand Valley State University Robert B. Annis Water Resources Institute (AWRI) operates the research and education vessels as part of its Water Resources Outreach Education Program. Aquatic science has been an integral part of the academic program at Grand Valley State University since the 1960s. The vast water resources available in western Michigan provide a natural laboratory for the study of biology, chemistry, geology, physics, and environmental science. Located at the Lake Michigan Center in Muskegon, AWRI continues its long tradition of education, outreach, and research.

This manual introduces you to the vessel logistics and provides background material on sampling and the biological, physical, and chemical parameters of water. It is written to assist in understanding the nature of the scientific cruises aboard the vessels.

The *D.J. Angus* and *W.G. Jackson* Vessels

The *D.J. Angus* and *W.G. Jackson* research and education vessels are available to schools, colleges and universities, and other groups who want a hands-on experience on a research vessel. There are usually two Instructors on-board as well as the captain and deckhand, who operate each vessel. Both vessels have sampling and analysis equipment for measuring a full cadre of biological, chemical, and physical parameters.

With her homeport in Grand Haven, the *D.J. Angus* is a steel-hulled, diesel-powered vessel that is forty-five feet long and fourteen feet wide. Built in 1985 and launched in 1986, the *D.J. Angus* has provided thousands of students, teachers, scientists and others with “hands-on” water sampling and analysis experience. The vessel is named for Donald J. Angus, a life-long supporter of GVSU, and it is supported by an endowment.

The *W.G. Jackson* was constructed in 1995-96 and joined the *D.J. Angus* on the water in 1996. The *W.G. Jackson* is almost 65 feet in length and was specially designed for research and educational purposes. The *W.G. Jackson*’s homeport is in Muskegon at the AWRI’s shoreline facility, the Lake Michigan Center. The community of Muskegon, as well as many others, contributed generously towards construction of the vessel, establishment of an endowment for vessel operations, and the shoreline facility. The *Jackson* is named after Dr. William G. Jackson of Muskegon.

Important note:
Vessels are subject to Coast Guard regulations and GVSU policies. Visiting groups must follow all instructions given by the crew.

NO WEAPONS OR BACKPACKS ALLOWED ONBOARD. ALL PERSONS/BAGGAGE/OBJECTS ARE SUBJECT TO SECURITY INSPECTION. FAILURE TO GIVE CONSENT OR REFUSE SCREENING OR INSPECTION SHALL RESULT IN DENIED ACCESS TO VESSEL. 33 CFR 104.265 (f) (2) (3)

Location of the Vessels

With two vessels operating, cruise participants need to be clear as to which vessel they have reserved and where the vessel will be docked.

W.G. Jackson

The *W.G. Jackson* is usually boarded at the GVSU Lake Michigan Center facility of the Robert B. Annis Water Resources Institute on the waterfront in downtown Muskegon (see the map in Figure 1 of this manual). There is ample parking near the *Jackson* vessel, in front of the beige, green, and white building.

In a typical cruise, the vessel leaves the dock at Muskegon Lake and makes its way across the lake to Lake Michigan. Muskegon Lake is 4,149 acres or about 6.5 square miles in size. Many of the industrial areas along the shoreline of Muskegon Lake are being re-developed and restored to pre-industrial conditions. The area once had active logging and numerous industrial operations. Homes and marinas also surround the lake. Significant heavy industrial activity along with wastewater discharge, combined sewer overflows and urban runoff in the past have led to contamination. Muskegon Lake has been designated an "Area of Concern" under the Great Lakes Water Quality Agreement. The Muskegon River watershed drains into Muskegon Lake and influences the water quality (Figure 2). Besides Muskegon and Big Rapids, the watershed has no large cities and is relatively undeveloped.

D.J. Angus

The *D.J. Angus* docking site is on Harbor Island in Grand Haven. Dedicated in 2006, the dock area has ample parking and an onshore restroom facility. The map in this manual (Figure 3) shows the location of the Harbor Island dock location. In case of construction on U.S. 31, there are alternate routes south and west of the dock site.

Weather permitting, the *D.J. Angus* makes a trip to Lake Michigan via the Grand River. Along the route to Lake Michigan, there is a former sand mining operation, a large commercial unloading dock, marinas, and a former power plant. The headwaters of the Grand River are near the city of Jackson and the river also flows through the cities of Lansing and Grand Rapids (Figure 4). Besides urban areas, land use in this watershed is largely devoted to agriculture with relatively few natural areas. The other sampling point for the *D.J. Angus* is in Spring Lake. Spring Lake is surrounded mainly by homes and has experienced elevated nutrient levels.

Figure 1: Location of W.G. Jackson, Muskegon MI

DIRECTIONS

The GVSU Lake Michigan Center, home of the *W.G. Jackson* and Annis Water Resources Institute, is located on the shoreline of Muskegon Lake in downtown Muskegon. It is adjacent to Heritage Landing.

From the south:
From northbound U.S. 31, take the U.S. 31 Business Route exit just north of the I-96 junction. U.S. 31 Business Route (Seaway Drive) should be followed until Shoreline Drive is reached (the street that angles to the left just after Southern beyond Laketon). Proceed north on Shoreline Drive to Seventh Street (second light near Heritage Landing) and turn left to the GVSU Lake Michigan Center.

From the north:
From southbound U.S. 31, take the U.S. 31 Business Route exit towards downtown Muskegon. Continue to Seventh Street (U.S. 31 Business Route becomes Webster Avenue in town) and turn right. Continue on Seventh across Shoreline Drive to the Lake Michigan Center. An alternate route is to turn right off of Business 31 on to Shoreline Drive just before downtown Muskegon.

From the east:
Travel to the end of I-96 past the US-31 junction. Do NOT go north towards Ludington at the US-31 junction. I-96 will become Business Route 31 (Seaway Drive), which should be followed until Shoreline Drive is reached (the street that angles to the left just after Southern beyond Laketon). Proceed north on Shoreline Drive to Seventh Street (second light near Heritage Landing) and turn left to the GVSU Lake Michigan Center.

Figure 2: Muskegon River Watershed

Figure 3: Location for *D.J. Angus*, Grand Haven, MI

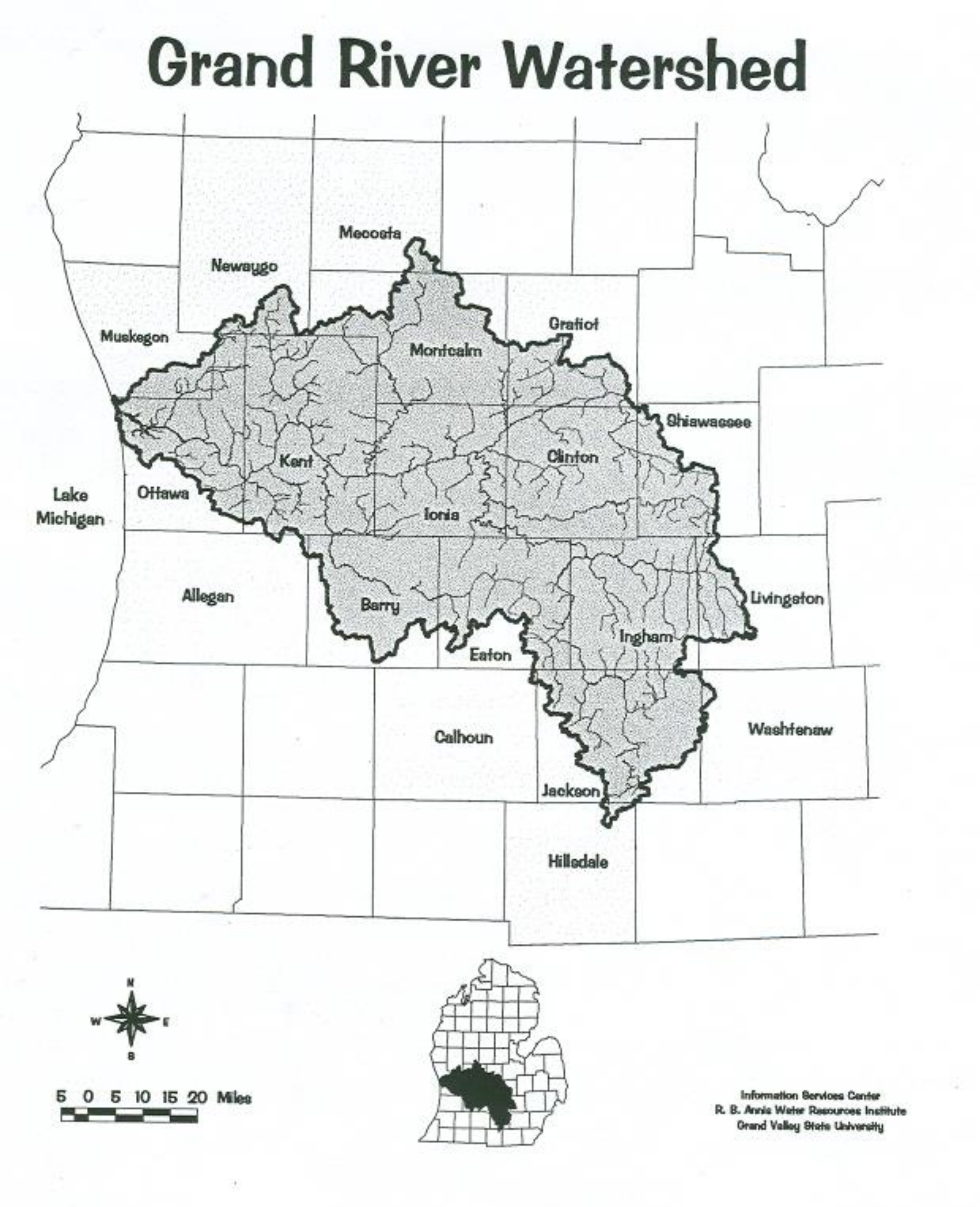
DIRECTIONS

The D.J. Angus dock is located on Harbor Island in Grand Haven, Michigan.

From the south:
From northbound U.S. 31, turn right on Harbor Island Drive before the bridge across the Grand River in Grand Haven. Continue north on Harbor Island Drive then south. Turn right (west) at Coho Drive then right (north) at the first street (North 3rd Street) When leaving, go south on North 3rd street, turn left on Coho (east), and then turn right (south) onto U.S. 31.

From the north:
From southbound U.S. 31, turn right on Coho Drive just south of the bridge across the Grand River in Grand Haven. There will be a sign for Harbor Island. Proceed to the next street, North 3rd Street, and turn right (north). When leaving, go south on North 3rd street, turn left (east) on Coho and left (north) on Harbor Island Drive. Follow Harbor Island Drive to the north then back to the south where is intersects U.S. 31 North.

Figure 4: Grand River Watershed



Planning Your Trip

1. Be certain you know in advance the time and place to meet the vessel.
See the maps on the previous pages for the location of the *D.J. Angus* in Grand Haven and the *W.G. Jackson* in Muskegon. Call AWRI at 616-331-3749 if you get lost.

2. Be prepared for any weather conditions.
The vessels will go out regardless of weather conditions with very few exceptions. For example, trips are not canceled on cold, rainy days, but trips may be cancelled if there are severe weather conditions such as lightning. If Lake Michigan is too rough, other locations will be sampled.

3. Advise participants to wear appropriate clothing.
Appropriate attire is long pants or shorts depending on the time of year. It can be colder on the lake than inland and it is usually windy as well. Your group should bring warm layers and rain jackets for cold wet days. Also, they should wear rubber-soled, closed toe shoes on-board – no open sandals or flip flops! A wet deck is very slippery. Those sensitive to the sun should wear hats, long sleeve shirts, long pants, and should bring the proper sunscreen.

You should check the weather report to determine how your group should dress. The NOAA Lake Michigan Field Station Internet Site has a live video camera view of Lake Michigan at Muskegon. See http://www.glerl.noaa.gov/data/now/lmfs/met1/ for this information. This site also lists current weather conditions. A web cam in Grand Haven for viewing weather conditions is found at http://www.grandhaventribune.com/webdna/webcam.tpl.

4. Limit the items that are brought on-board.
Limit what you bring on-board the vessels. Backpacks are not needed on the cruise and must be left onshore. Especially on the *D.J. Angus*, there is little room for storage. Leave lunches onshore since there will be no opportunity for eating on the vessels. Cell phones are used at the sole risk of the passenger, and use should be limited for full engagement on the cruise. Also, note that there is no gum chewing allowed on the vessels.

5. Determine special needs of the group.
Let AWRI (616-331-3749) know of any special needs. The *W.G. Jackson* and *D.J. Angus* have limited handicapped accessibility. For those needing medication for motion sickness, take medication at the proper time BEFORE going on-board the vessel. If there is a need for special medication or if you are allergic to insects such as bees and wasps, have any needed medication with you while on-board the vessel.

6. Be sure to go over the safety procedures provided in this manual.
All participants in the vessel experience should be aware of the safety procedures listed in this manual. Safety first is emphasized at all times. Observe the special precautions for being out on the water.

Safety Procedures Aboard the *D.J. Angus* and *W.G. Jackson*

Be sure that everyone in your group is aware of the importance of safety aboard the vessels by reviewing these procedures with them prior to their cruise. Especially in the event of an emergency, these procedures are vitally important.

1. The Captain, deckhand, and Science Instructors have all been trained in safety procedures. In the case of an emergency, the Captain is responsible for directing the response effort, which will be carried out by the crew and instructors. His orders must be followed and everyone must cooperate to the fullest.

2. Due to Coast Guard regulations, all personnel and baggage are subject to search. Student backpacks and other non-necessary items are not allowed on the vessels. Rules regarding restricted items will be enforced and trips can be terminated if there are any security issues.

3. The Captain can require individuals to wear personal flotation devices (life jackets) during the vessel trip at their discretion. Shirts and shoes must be worn at all times.

4. The yellow lines painted on the deck are there for safety reasons. You must have permission from an instructor or a crew member before crossing a yellow line. No one is permitted on the bow (front deck) or to walk around the outside of the cabin at any time unless accompanied by an instructor or crew member.

5. Access to the pilot house is restricted. You must have explicit permission from the Captain before entering the pilot house.

6. Do not touch the winch or its cable. The deckhand will operate the winch near the "hero platform" and at least one person may be assigned to help. That person must wear a life jacket. No one may stand on the "hero platform" while the vessel is underway.

7. No running, pushing, or sitting on rails is allowed. Both feet should be on the deck at all times. If the water is rough, hold on to the rail or lab bench with one hand and be extra cautious.

8. Wear safety glasses and gloves whenever chemicals are used. Do not consume food or drink in areas where chemicals are used.

9. Do not leave items unsecured or loose on the cabinet tops or on the deck.

10. Report all accidents including broken equipment to the Science Instructors. There are first aid kits on-board for minor emergencies.

11. Follow all directions from the instructors, Captain, and crew. If you don’t understand something, ask for clarification.

Using the Research and Education Vessels

I. At Dockside Before Boarding

One of the aquatic science instructors will

A. Welcome the group and introduce the Captain and crew

B. Give a Safety Lecture covering
   1. Off limits areas
   2. Personal flotation devices
   3. "Hero platform" procedures
   4. Emergency procedures and additional safety rules
   5. Importance of paying attention and following directions

The group leader will provide one copy of the participant list for the instructors and the total passenger count (adults and students) for the Captain.

II. On-board

When the group boards the vessel, the aquatic science instructors demonstrate how to wear personal floatation devices (life jackets). Under certain conditions, everyone may be asked to put on life jackets.

An aquatic science instructor will point out the various areas of the vessel including the:

A. Aft-Deck - Where sampling takes place

B. Main Cabin - Location of the science laboratory

C. Head (bathroom) - Unisex. Knock loudly before entering.

D. Pilot House - Must have permission from the Captain to enter.

E. Bow (fore deck) - Off limits.

F. Side decks (along the sides of the cabin) - Off limits while the vessel is in motion.

G. Forward Cabin (below) - Off limits, do not enter!

Note that areas D through G are off limits except with specific permission. Permission must be granted by a crewmember to cross any yellow lines.

III. Aft-Deck Orientation to Equipment

During the cruise, an aquatic science instructor will orient the participants to the equipment used on the aft (rear) deck. Most of the above equipment is for sampling. The Secchi disk is used to measure water transparency and the Forel-Ule Color Scale is used to determine the color of the water.

IV. Scientific Equipment Used in The Main Cabin

The equipment for analysis of samples is located in the main cabin. Navigation equipment is found in the Pilot House as well as the main cabin. The group will receive an orientation session on the purpose and use of this equipment.

A. pH Meter

B. Conductivity Meter

C. Turbidity Meter

D. Dissolved Oxygen Analysis

E. Microscope with Video Camera and Monitor

F. Depth Finders

G. Global Positioning System

F. Advanced Trips: Alkalinity Kit, Nitrate and Phosphate meters

V. Underway and On Station

Stations are sampled and analyzed on a cruise for the purpose of comparing different bodies of water. The instructors provide commentary on lake dynamics, river ecology, and shoreline structures/activities as the vessels travel between stations.

Examples of tasks at each station are:

A. Dissolved oxygen
B. pH
C. Turbidity/plankton density
D. Conductivity
E. Bottom sediments
F. Secchi disk and color scale
G. Temperature and Location
H. Plankton identification/food chain
I. Recorders
J. Deckhands

There is flexibility as to the number of people for each task and new assignments are made at each station so participants can experience several tasks.

VII. Summary

An important element of the *D.J. Angus* and *W.G. Jackson* experience is the summary of what participants have learned on the cruise and an interpretation of the data they collected. The stations sampled are chosen to illustrate differences in water quality.

The aquatic science instructors can facilitate the

A. review of data from each station that the recorders have gathered
B. comparison of values from the different stations
C. discussion of actual versus expected values and trends
D. identification of practical applications of physical, chemical, and biological concepts
E. question and answer session
F. summary of student learning and takeaways from the cruise

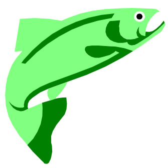
VIII. Disembarking

The groups must follow the instructions from the crew for disembarking. Take everything they brought onto the vessel, and come back again!

The AWRI website at http://www.gvsu.edu/wri has links to numerous water-related sites as well as an online instructor's manual and data. Contact Christina Catanese (Education Specialist) at catanesc@gvsu.edu for current program information.

Environmental Monitoring

Water quality is defined in terms of physical, chemical, and biological parameters with respect to a certain use. For instance, acceptable water quality for warm water fishes would not be optimal for cold water fishes, and standards for drinking water differ from those for boating and recreation. No single factor alone indicates good water quality, and water quality in a body of water can vary with the season and location. Long-term water quality measurements from well-defined locations are needed to tell if conditions are changing or remaining the same. Many of the procedures performed on the vessel help us to understand the quality of the waters being sampled.



Biological Properties of Water

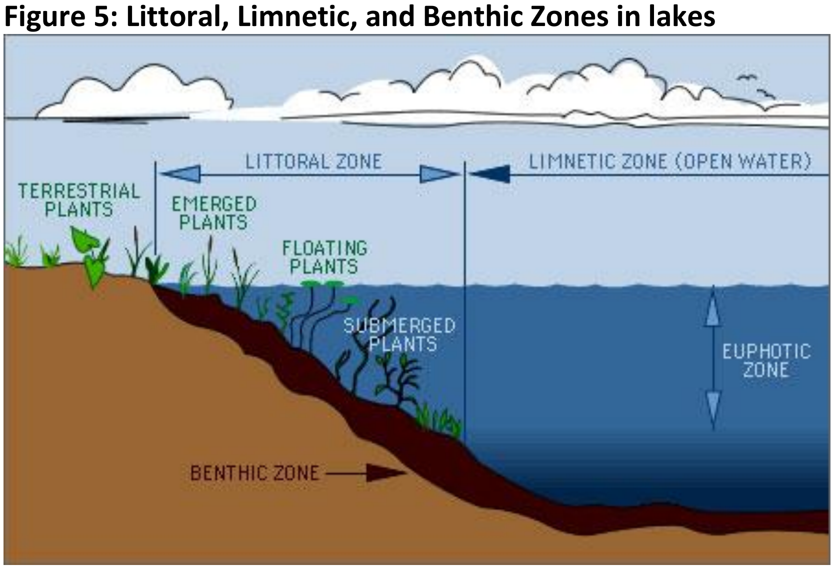
Like other ecosystems, lakes and rivers host a complex combination of plants and animals, which are interrelated through food webs. Introduction of exotic or nonindigenous species can upset the balance of existing food webs. The productivity of a body of water is dependent upon variables such as the available nutrients, light, and temperature.

Aquatic organisms are divided into groups that include:

1. Plankton – organisms that drift with the currents
   a. phytoplankton – algae, diatoms (producers)
   b. zooplankton – animals (consumers)
2. Nekton – larger size organisms that can swim freely
3. Benthos – organisms that live in or on the bottom of lakes and streams
4. Decomposers – bacteria and fungi
5. Macrophytes – aquatic plants

These organisms have a spatial distribution that is defined by regions adjacent to the shore (littoral), open waters (limnetic or pelagic), and the bottom (benthos). Recently, researchers have looked at the biological communities as a measure of water quality. These protocols are referred to as indices of biotic integrity or 'IBIs'. On the vessels, plankton nets are used to sample for plankton and a PONAR grab sampler is used to collect benthic organisms.

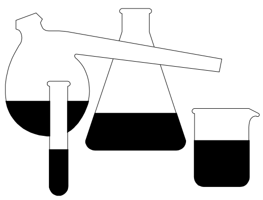
Figure 5: Littoral, Limnetic, and Benthic Zones in lakes



Source: Michigan State University Extension

Physical Properties of Water

Water is a unique chemical compound that exists naturally on earth in the gaseous (water vapor), liquid, and solid (ice) states. It has a maximum density at 3.98° C. Water boils at 100° C and freezes at 0° C. A relatively large amount of heat is needed to raise water temperature. The solid state of water is less dense than the liquid state (i.e., ice floats). Physical properties of water that are measured on the vessels include water transparency or clarity, color, turbidity, and temperature. Suspended particles in water influence water color and clarity. Particles can settle to the bottom and contribute to a build-up of sediment. Instruments and equipment used to quantify these properties include the Secchi disk, Forel-Ule Color scale, turbidity meters, turbidity tubes, and thermometers.



Chemical Properties of Water

Water chemistry is influenced by many factors (such as the geology of a region, photosynthesis and respiration, pollutant load, pressure, temperature), and can change with the time of day. Water behaves as a solvent in which a substance (solute) dissolves. It has been called the "universal solvent". The resulting solution may contain individual ions (particles with charges) or molecules. Gases, solids, and other liquids are capable of dissolving in water but some of these substances do not dissolve, e.g., they are insoluble. The solubility of a solid in water generally increases with temperature, while the solubility of a gas decreases with temperature. Concentrations of a chemical in water are generally expressed in terms of milligrams per liter (mg/L), parts per million (ppm), and percent saturation for gases. Chemical properties of water explored on the basic cruise include pH, dissolved oxygen, and conductivity. Alkalinity and nutrients (phosphorus and nitrogen) may be measured on advanced trips. Heavy metals and organic compounds require specialized laboratory equipment for their measurement and are not sampled on a standard cruise.

Evaluation of Water Quality

One of the best ways to understand water quality is to compare two areas that differ in water quality. An underlying theme of the cruises aboard the vessels is to compare and contrast Lake Michigan with another water body. Lake Michigan has a surface area of about 22,300 square miles making it the third largest Great Lake. The flushing time of the Lake (or the average amount of time that water spends in the lake) is 62 years. The average depth of Lake Michigan is 279 feet with a maximum depth of 923 feet, making it the second deepest Great Lake. In contrast, Spring Lake's surface area is about 1,300 acres with inputs of water mainly through springs, streams, and precipitation. Spring Lake is connected to the Grand River. Muskegon Lake is 4,149 acres in size, and it receives flow from the Muskegon River as well as tributaries such as Ryerson and Ruddiman Creeks.

Determining water quality is complex; many parameters go into its determination. Evaluation of water quality depends on the designated use of the water. For examples, "good" water quality for warm water fishes may not be "good" water quality for human consumption. Overall water quality can be evaluated by considering the trophic status or biological productivity. Eutrophication, or aging of lakes, progresses through various trophic states (oligotrophic → mesotrophic → eutrophic). Nutrient levels, organic matter content, dissolved oxygen levels, and water transparency give clues to the trophic state or biological productivity of a water body (Figure 6). A trophic scale has been specially designed for use on the vessels. By evaluating data from various parameters, sampling locations are rated as O (oligotrophic), M (mesotrophic), or E (eutrophic).

Oligotrophic lakes are characterized by low nutrient levels, low biomass, high oxygen concentrations, and high transparency. Oligotrophic lakes are usually deep. Eutrophic lakes are highly productive with high nutrient levels, high biomass, low oxygen concentration in the bottom waters, and low transparency. The large volume of organic matter accumulated in bottom sediments depletes oxygen as it decomposes. Mesotrophic lakes are between the other two trophic states in their characteristics. The open waters of Lake Michigan are oligotrophic and some nearshore areas are mesotrophic.

Michigan has approximately 35,000 inland lakes (includes lakes, ponds, and river impoundments) with a surface area of at least one-tenth of an acre or greater. Approximately 11,000 of these inland lakes are larger than 5 acres in surface area, and over 2,000 are more than 50 acres. Inland lakes cover approximately 1,390 square miles (889,600 acres) of the state. Michigan has the 3rd most lakes in the continental United States, behind Minnesota and Wisconsin. The average lake size is 341 acres in the southern Lower Peninsula, 1,342 acres in the northern Lower Peninsula, and 731 acres in the Upper Peninsula.

Approximately 36% of the total inland lake acreage is designated for cold water fisheries uses and the remaining 64% is designated for warm water fisheries uses. Michigan's inland lakes generally have good to excellent water quality. The majority (69%) of Michigan's public access lakes have moderate (mesotrophic) or low (oligotrophic) nutrient levels. The trophic status of Michigan's public access lakes is summarized in Table 1.

Carlson's trophic status index concept is used by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) to assess and classify 730 of Michigan's public access lakes. This classification system is based on an index derived from a combination of 3 field measurements: Secchi disk transparency, total phosphorus concentration, and chlorophyll-a concentration. The numerical value of the index increases as the degree of eutrophication increases.

Table 1: Trophic Status Summary of Michigan's Public Access Lakes

Trophic Status	Number of Lakes
Oligotrophic (low nutrients)	129 (18%)
Mesotrophic (moderate nutrients)	399 (54%)
Eutrophic (high nutrients)	174 (24%)
Hypereutrophic (excessive nutrients)	28 (4%)
Total Assessed	730

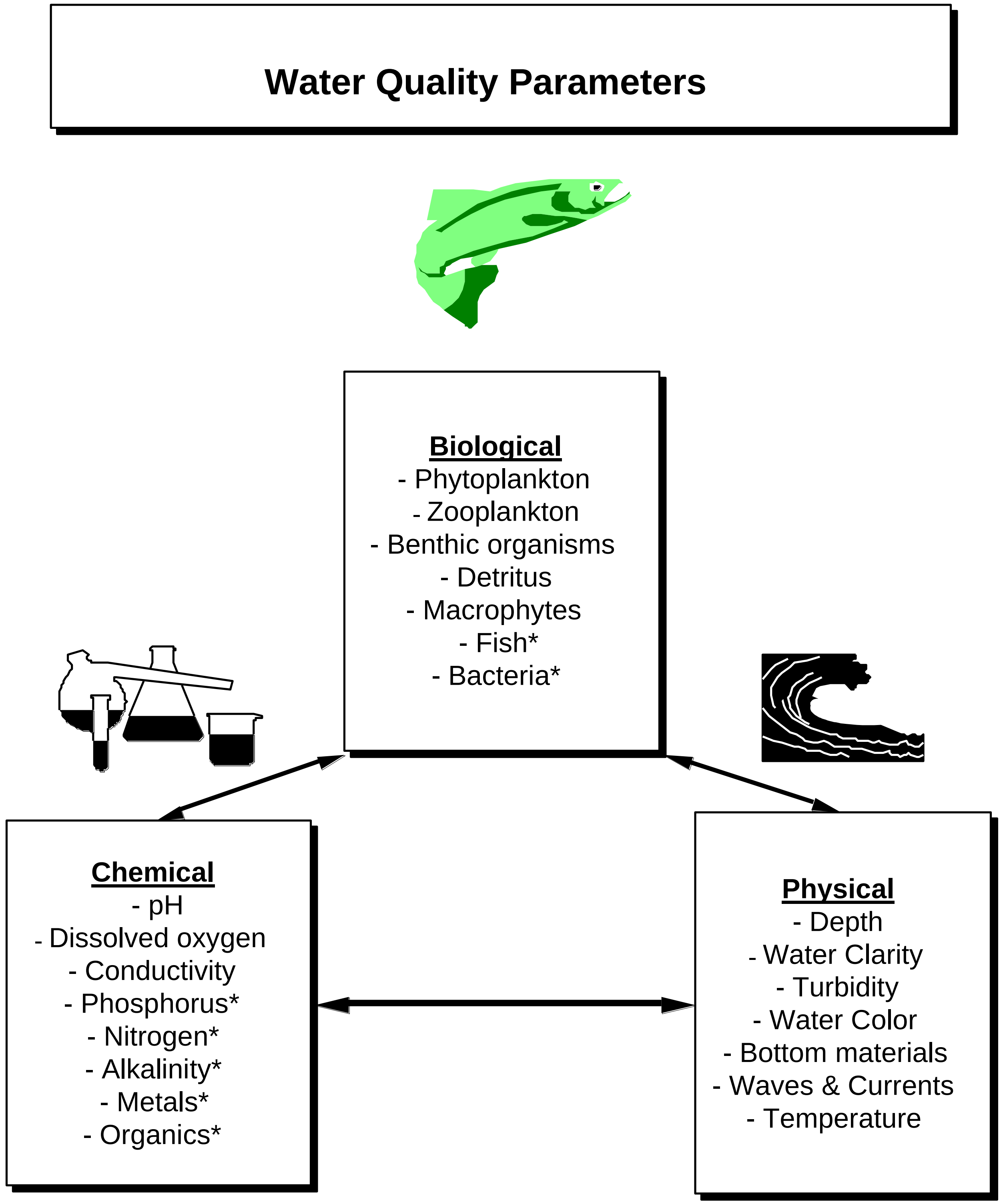
Source: Water Quality and Pollution Control in Michigan 2022, Sections 303(d), 305(b), and 314 Integrated Report

Many lakes with moderate to high nutrient levels are located in the southern Lower Peninsula where large population centers and fertile soils and extensive agriculture exist. Many lakes with low nutrient levels are located in the northern part of Michigan's Lower Peninsula where the population density is lower, soils are less fertile, and lakes tend to be larger and deeper.

Applications

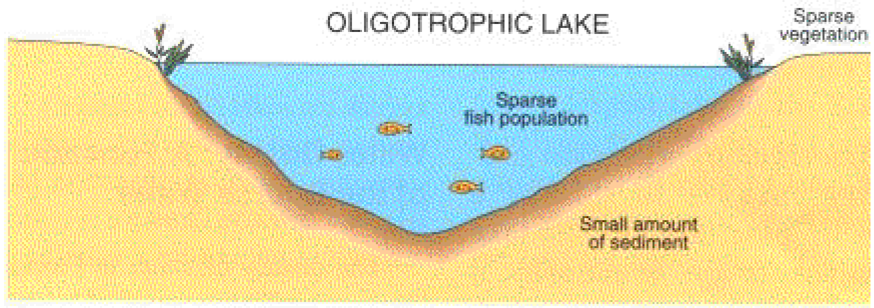
The same parameters observed and tested on vessel cruises are important for scientists and water managers to understand the health of the lakes. For example, AWRI has led long-term monitoring of Muskegon Lake since 2003. AWRI technicians collect samples at six stations to establish baseline water quality conditions. Stations were chosen to represent varying conditions across the lake. These stations are sampled 3 times per year (late spring, summer, early fall) from the *W. G. Jackson*. Fish monitoring is done at 4 other shallow-water sites using smaller vessels. Scientific papers based on data collected from the long-term monitoring study have been published in a variety of journals. These data sets have been incorporated in Master of Science theses as well. The Muskegon Lake Water Quality Dashboard provides an easy to understand visual representation of lake health.

Figure 6: Water Quality Parameters

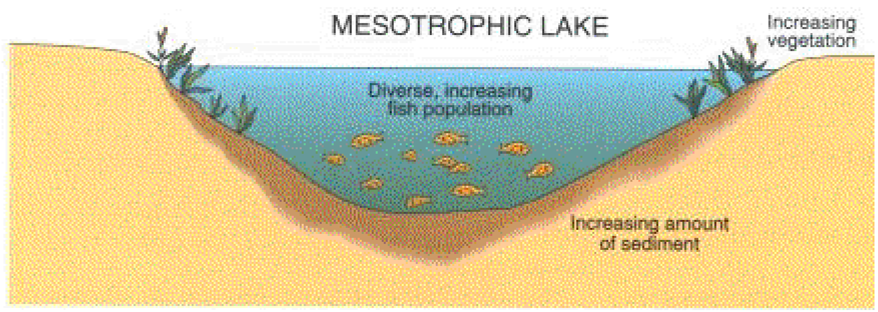


***** Not monitored on regular trips

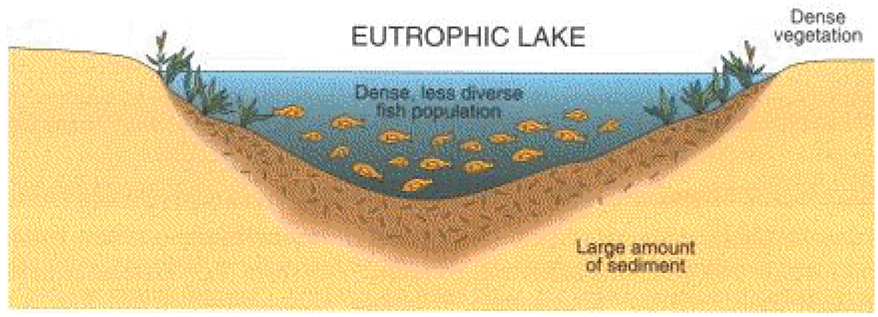
Figure 7: Trophic Status of Lakes



Oligotrophic lakes have very low levels of nutrients, very little organic material along the lake bottom, and high levels of dissolved oxygen near the bottom.



Mesotrophic lakes are moderately enriched, and the natural processes of accumulation of sediments and growth of aquatic vegetation are occurring.



Eutrophic lakes are highly enriched with nutrients, have an accumulation of organic sediments, and low levels of dissolved oxygen in water near the lake bottom. Eutrophic lakes typically have high concentrations of algae or aquatic vegetation and also differ from oligotrophic and mesotrophic lakes in the type of vegetation and animal life that can exist in the lake.

Source: *Hydrology of Central Florida Lakes -- A Primer*

Lake Michigan Food Web

The general flow of biomass in Lake Michigan is through trophic levels that include the producers: phytoplankton (algae) and aquatic plants (macrophytes), and consumers: zooplankton, forage fishes, predator fishes, and fish-eating humans and other animals. The Lake Michigan food web is composed of two distinct but overlapping parts: the pelagic food web associated with offshore open water (pelagic) and the bottom (benthic) food web. Both webs are dependent upon the phytoplankton in the surface waters.

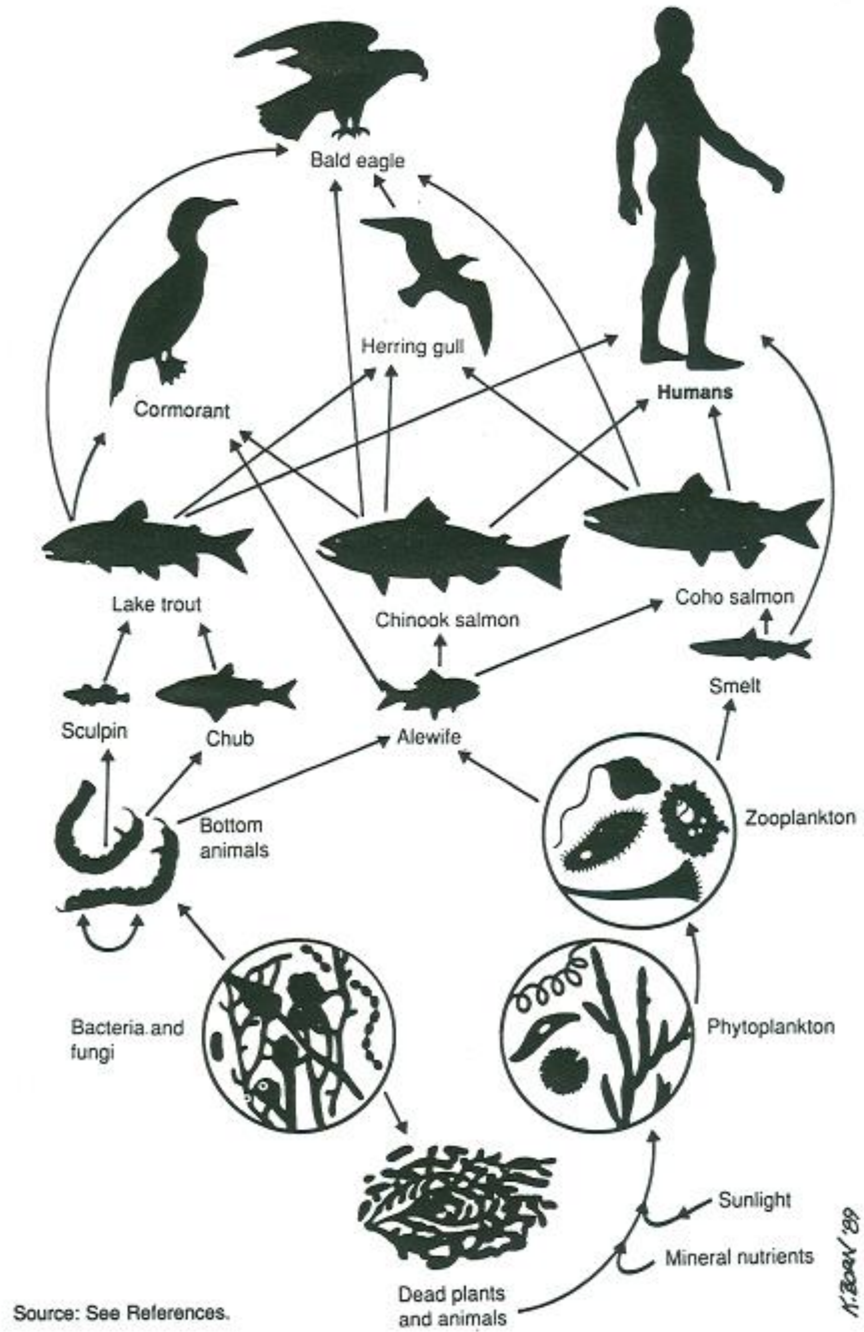
In plankton sampling on board the vessels, members of the pelagic food web, including phytoplankton and zooplankton, are collected. Samples often include zooplankton or small invertebrates such as cladocerans and copepods. Zooplankton play an important role in transferring energy between phytoplankton and fish. Changes in populations of key species at any of the trophic levels can cause a ripple effect throughout the food web. For example, two species, the opossum shrimp (*Mysis relicta*) and an amphipod or "sideswimmer" (*Diporeia* sp.), have previously been important food for foraging fish, such as alewives and rainbow smelt, but their numbers have declined, which has impacted foraging fish populations and consequently the salmon and trout fisheries.

The PONAR grab sampler collects members of the benthic food web. The benthic food web is fueled by the algae, fish, and detritus (dead and decomposing organic matter) that fall from the upper part of the water column (photic zone). Two macrobenthic animals (bloodworms and mussels) dominate the bottom samples.

The biological integrity of the fish community that is dependent on pelagic and benthic species is no longer present. Increasing levels of fishing pressure and human-induced environmental degradation have greatly altered the composition of fish species. Additionally, invasive and non-native species have substantially altered the food web of Lake Michigan. An example of these changes includes the salmon, an introduced species, and an invasive species, the alewife *(Alosa psuedoharengus)*. The arrival of the alewife into Lake Michigan resulted in a less complex, less stable food web, as alewives experienced increased levels of abundance in the Lake Michigan and consumed large amounts of zooplankton, insects, larval fish, and eggs. Coho and Chinook Salmon were stocked in the lake in the 1970s to control alewife and in an attempt to increase food web stability. Their populations grew steadily in the Great Lakes until they experienced a large decline in the early and mid-2000's. The Chinook salmon fishery of Lake Huron has since collapsed due to invasive zebra and quagga mussels disrupting the food web, declining alewife populations, and overfishing.

Besides humans, consumers of Great Lakes fish include birds such as herons, osprey, bald eagles, loons, cormorants, and mergansers. Minks and river otters also consume fish. The web comes full circle with the detritus and decomposers completing the cycle (Figure 8).

Figure 8: Lake Michigan Food Web

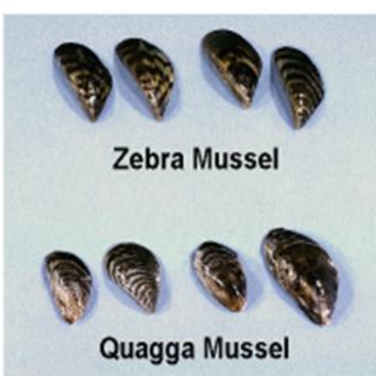


Exotic or Nonindigenous Species

Exotic or nonindigenous species are plants and animals that are found outside their native geographical range. Their impacts can be varied. Some may be beneficial to an ecosystem, but others disrupt the ecological balance of an area. When an exotic species is determined to cause ecological harm, scientists call it an *invasive species.* Harmful aquatic nuisance species (ANS) include the zebra mussel, quagga mussel, ruffe, round goby, spiny water flea, sea lamprey, Eurasian watermilfoil, common reed, and purple loosestrife. When released into habitats where there are no natural controls such as pathogens, parasites, and predators, these species can grow at an exponential rate and become established quickly.

Over one third of the 186 known aquatic nuisance species in the basin have been introduced since the opening of the St. Lawrence Seaway for shipping. Ballast water from ships is an important transporter of these species. The National Invasive Species Act of 1996 reauthorized a mandatory Great Lakes ballast program. Other means of transport for exotic species are the water used for the bait industry, food processing, exotic pet trade, and the aquarium trade. Boat transfers from one body of water to another and landscape practices are other ways of transporting aquatic nuisance species. Inland lakes as well as the Great Lakes have seen invasions of exotic species. The populations and impacts of invasive species on the food web can change over time. Some invasive species have been successfully controlled, others have been displaced, and current threats of new invasive species still remain on the horizon.

Once an enormous threat to the Great Lakes fishery, the sea lamprey populations have been greatly reduced through various control measures. Gaining entry through locks and shipping canals, the sea lamprey made its way from the Atlantic Ocean to Lake Michigan by 1936. As a parasitic fish, the sea lamprey is known for adhering its sucking disk mouth and rasping tongue to the sides of fish, including trout, whitefish, and salmon, sucking nutrition from the fish, often killing it. As the sea lamprey has no natural competition and predators in the Great Lakes, the sea lamprey disrupted the food web. The sea lamprey, though still a present threat in the Great Lakes, does offer a story of success. Scientists developed several successful control measures to decrease lamprey populations, including a chemical called lampricide which is used to target larval lamprey populations in river tributaries, mechanical and electrical barriers, and sterilization of male lampreys.

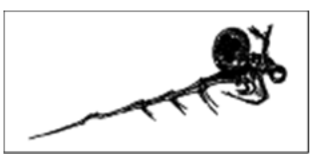


As new invasive species arrive, some prior invasive species find themselves outcompeted and displaced in the food web. Zebra mussels (*Dreissena polymorpha*) were first discovered in the Great Lakes basin in Lake Saint Clair in 1988 and Lake Michigan in 1989. They spread to all five Great Lakes and many inland lakes, and their population boomed. However, a relative of the zebra mussel, the quagga mussel (*Dreissena bugensis*) was discovered in the Great Lakes in 1990. By 2005, Quagga mussels became the dominant invasive mussel in Lake Michigan as they had several advantages over their zebra mussel cousins, including the ability to live in deeper water. Mussels attach to intake pipes, rocks, buoys, docks, piers, and many other submerged substrates including native clams. Colonies of these invasive mussels clog water intakes and use rocky substrate that is important to fish spawning. The dreissenid mussels are filter feeders that cause a decline in phytoplankton that would otherwise feed planktivorous fish. There have been reports of mussel feeding activity increasing water clarity and leading to the growth of plants attached to lake bottoms as more sunlight penetrates deeper. Dreissenid mussels have altered microbially-mediated nutrient cycling, the nearshore phosphorus cycle, patterns of contaminated sediment burial, and bioaccumulation of contaminants. Additionally, dreissenid mussels selectively reject the toxic algae *Microcystis*. In reducing populations of other algae species through their filter feeding, the dreissenid mussels have led to huge harmful algal blooms of Microcystis. On the vessel, dreissenid mussels and their shells can be found in PONAR grab samples. The free-floating larval forms of mussels, called veligers, may be found in plankton samples.

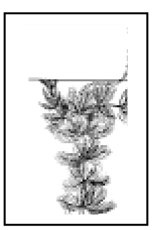
The threat of invasive species is ongoing. There are many aquatic invasive species, both plants and animals, on Michigan's Invasive Species Watch List. These plants and animals are on the list because they are considered an immediate or potential upcoming threat to Michigan ecosystems and the economy. Some invasive aquatic plants on the Watch List include: European Frogbit, Hydrilla, and Water Lettuce. Aquatic invasive animals on the Watch List include: the Red Swamp Crayfish, New Zeeland Mud Snail, and several varieties of carp (Black, Bighead, Silver, and Grass). Collectively, these four species of carp are known as Asian Carp and have worked their way up the Mississippi River and Illinois River. These carp species eat huge amounts of plankton, are fast growing, and reproduce rapidly. Electrical barriers in the Chicago Area Waterway System are a line of defense against carp invasion of Lake Michigan. According to Michigan's Invasive Species Program, Asian Carp are 10 miles from the three electric barriers in Chicago. If the Asian Carp become successfully established in the Great Lakes, they are expected thrive in areas near to the shore and in large river tributaries.

Muskegon has a claim to fame with an aquatic invasive species, the "bloody-red shrimp" (*Hemimysis anomala*). It was first reported by NOAA from samples collected in Muskegon, Michigan in November of 2006 in waters connected to Lake Michigan. The bloody-red shrimp prefers habitats of rocks or shells, and it is unknown if the beds of zebra and quagga mussels in Lake Michigan will prove to be a good habitat. Scientists continue to study the distribution and impact of the bloody-red shrimp.

Data collected by citizens on exotic species can contribute to the research base for early detection of the spread of aquatic nuisance species. Participants in the cruises on the *D.J. Angus* and the *W.G. Jackson* have an opportunity to contribute to monitoring of aquatic nuisance species. Specifically, zebra mussels, quagga mussels, spiny water fleas, Eurasian watermilfoil, and purple loosestrife are species that have been observed on cruises.

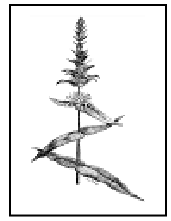


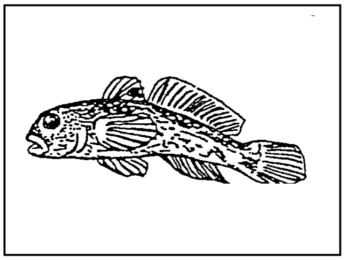
Found in plankton samples, the spiny water flea (*Bythotrephes cederstroemi*) is a predatory, shrimp-like zooplankter that grows to about 1 cm (0.4 inch) in length. It feeds on small aquatic animals that would otherwise be food for fish. It reproduces rapidly and can monopolize the food supply. The spiny water flea is protected from fish predators by its unusually long tail spine with protruding barbs. Many fish such as young alewives, lake trout, and perch can easily capture *Bythotrephes* but they have a hard time swallowing it. The spiny water flea is native to Europe and China and is thought to have been transported in ballast water to the Great Lakes in the 1980s with the first appearance in Lake Michigan in 1986.



Eurasian watermilfoil (*Myriophyllum spicatum*) was accidentally introduced to North America from Europe and reached the midwestern states between 1950 and 1980. Watermilfoil can form vast mats of vegetation at the water's surface, which crowds out native plants and interferes with recreation. The plant reproduces quickly through fragmentation and runners. Plant fragments cling to boats and can be carried unintentionally from lake to lake.

Although quite scenic, purple loosestrife (*Lythrum salicaria*) has changed the character of Michigan wetlands. A native of Europe and Asia, the plant was introduced to North America in the 1800s. The main difficulty with purple loosestrife is that it thrives and reproduces in wetlands forming dense, impenetrable stands unsuitable for wildlife food, cover, or nesting sites. Native vegetation is displaced and there is a loss of species diversity as well as food sources for wildlife in wetlands. Look for purple loosestrife along the edges of rivers and inland lakes.





The round goby *(Neogobius melanostomus)*, a common species often caught by fisherman along piers and docks in the Great Lakes, was introduced from the Black and Caspian Seas. The relatively small-sized goby has become quite abundant, feeding on bivalves (including zebra and quagga mussels), amphipod crustaceans, small fish, and fish eggs. Goby are believed to have entered the Great Lakes from discharged ballast waters where they were found in the St. Clair River in 1990. Round gobies have had both positive and negative effects on the food web in the Great Lakes. They prey on small fish and fish eggs, which has led to a decline in native fish species, but adult round goby also eats zebra and quagga mussels, creating a tropic link between the mussels and fish populations. Several fish species now consume the round goby including the burbot and small mouth bass.

Helpful sources for exotic species are https://www.michigan.gov/invasives/ and https://www.michiganseagrant.org/topics/ecosystems-and-habitats/invasive-species/

For more information about Lake Michigan, see the U.S. Environmental Protection Agency Lakewide Management Plan at https://www.epa.gov/greatlakes/lake-michigan-lamps-and-associated-reports

Sampling Gear and Instruments

On the scientific cruises, participants work as limnologists using equipment to sample and analyze water and bottom material (sediment). Limnology is the study of fresh waters including lakes, streams, and wetlands. Francois-Alphonse Forel (1841-1912) derived the term "limnology" from the Greek *limne*, meaning "marsh" or "pool." Limnologists use many of the same instruments and techniques as oceanographers, but they study inland waters instead of oceans. Participants aboard the *D.J. Angus* and *W.G. Jackson* cruises will receive a basic background in the use of limnological (usually freshwater) sampling equipment (Figure 8), and analytical instruments and procedures.

Since people are often not familiar with the specialized equipment and instruments carried on the vessel, detailed instructions on their use are given on-board before samples are taken. Some participants may want to study the more in-depth information on procedures that are included in this manual. Additionally, a video about the cruise, *Exploring the Lakes*, is available from the AWRI. There are data sheets in this manual to help organize information from the trip. When possible, water quality parameters are measured in triplicate to reflect Global Learning to Benefit the Environment (GLOBE) protocols.

The vessels carry a variety of equipment for obtaining water and bottom sediment samples, as well as biological samples. Specialized equipment for water color, clarity, and temperature measurements is found on the vessels. Each vessel has a laboratory in the main cabin with stations for water analysis including dissolved oxygen, pH, turbidity, and conductivity. A microscope with a video camera is used for examining biological samples.

In this manual, background information is provided on items such as:

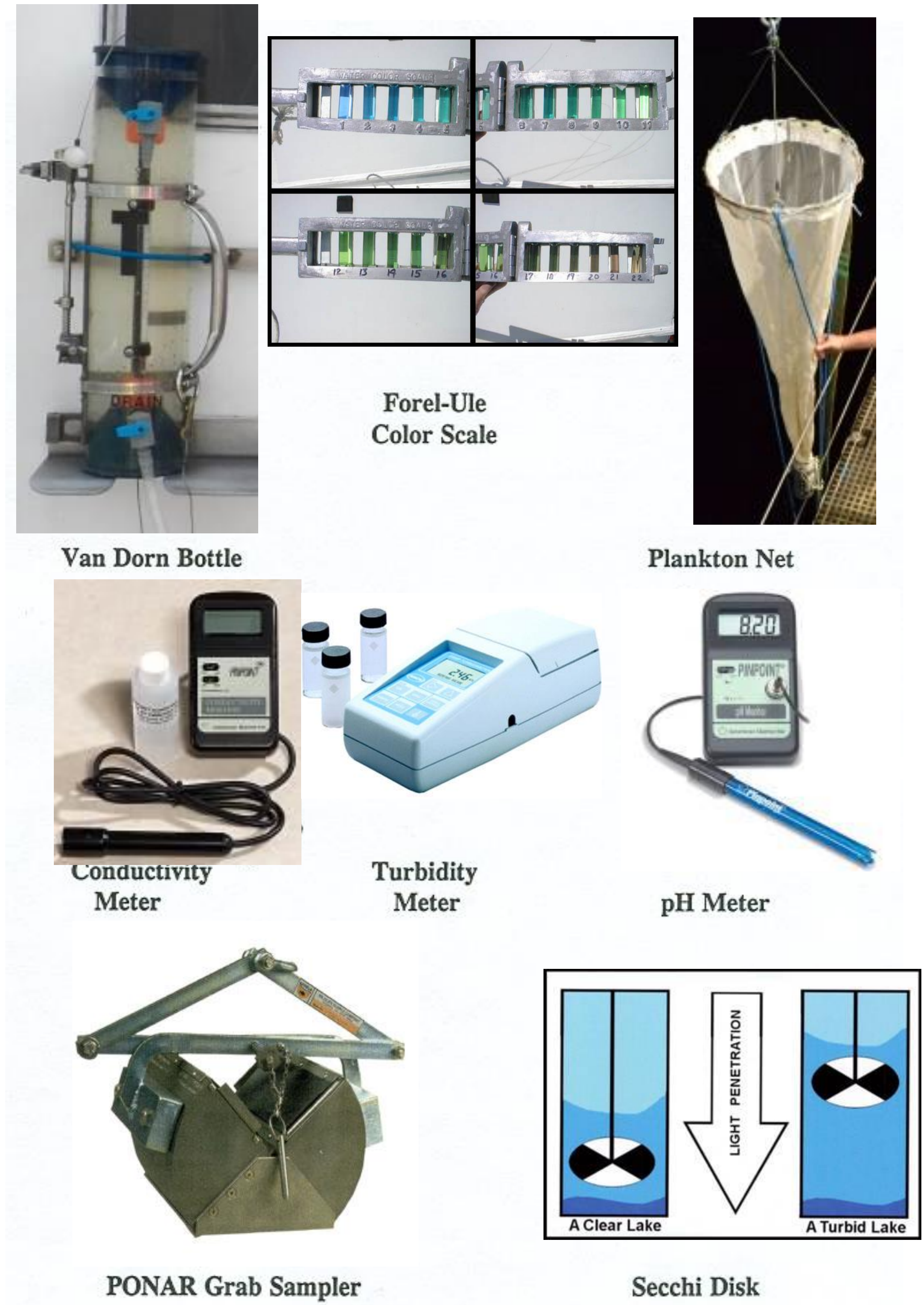
- Instruments and sampling methods used
- Parameters they measure
- Their operation
- Range of results likely to be encountered
- Significance of the data in freshwater studies
- Organisms likely to be found in samples

There is a discussion of navigation, sampling procedures, side deck activities, and use of instrumentation in the cabin area. The basic flow of the trip is:

- arrive at a sampling station,
- determine the location and depth,
- take water samples which are analyzed in the laboratory,
- measure water temperature,
- determine water clarity and color using equipment at the side deck,
- take sediment samples to be viewed on the deck,
- and perform a plankton tow followed by microscopic viewing in the laboratory.

Many activities are happening at once, and participants will maximize their experience if they have been briefed on the activities prior to the trip. There is a wrap-up session at the end of the trip where the Science Instructors review and interpret the sampling results.

Figure 9: Sampling Equipment



Sample Location and Navigation

Why is the exact location of the sampling site important?

Water quality data are not useful if the sampling location is unknown, incorrect, or mismatched. It is important to know the location of the site where samples of water or bottom sediment samples are taken for analysis. The location provides information that makes it possible for other samples to be taken at the same place at a later time, to make comparisons, and for others to find the site.

It is possible to return to the general area of a sampling station in a lake by using dead reckoning. This is done by keeping track of how fast the boat moves, the time it is moving a given speed, and the direction or directions traveled. If the wind is blowing, the waves are large, a current is present or any combination of these factors, the accuracy of knowing where the vessel is located is reduced. Returning to a given point on the lake by using this method can be only approximate.

What is latitude and longitude?

Navigational charts use latitude and longitude coordinates to mark positions. Latitude and longitude are indicated by degrees, minutes, and seconds. Each degree has 60 minutes (‘); each minute has 60 seconds (“). Latitude is measured in degrees north or south relative to the equator. The equator is 0° latitude and the poles are 90° N and 90° S latitudes. Longitude is measured in degrees east and west of the Prime Meridian which is an imaginary line running from the North Pole to the South Pole through Greenwich, England.

The Vessel Data Sheets have blank spaces for latitude and longitude for each sampling station. Typical readings for *Jackson* trips in the Muskegon area are 43° 12’ to 43° 23’ N latitude and 86° 15’ to 86° 24’ W longitude. Sampling stations for the *D.J. Angus* trips in the Grand Haven area are generally between 43°02’ to 43°06’ N latitude and 86°10’ to 86°18’ W longitude.

What is a Global Positioning System?

Location coordinates are pinpointed through use of the Global Positioning System (GPS). This is a satellite navigation and positioning system that can be accessed by a relatively inexpensive GPS receiver that can be used anywhere in the world. Developed by the U.S. Department of Defense, the first satellites for the system were deployed in 1978.

GPS consists of 24 satellites orbiting the earth, five ground stations, and GPS receivers. Ground stations monitor satellites in "known" positions and triangulation is used to determine position. The distances between the GPS receiver and a satellite are determined by a timing-signal process where the signal’s travel time multiplied by the speed of light equals distance. Each satellite continuously transmits a unique high frequency radio timing signal sequence or a binary code. Signal travel time is determined by the difference between the GPS receiver’s internal signal generation and the arrival of the satellite’s signal.

Four satellite ranges are used to calculate a three-dimensional position with accuracy of 25 to 100 meters (82 to 328 feet). Differential GPS (DGPS) employs a base station that increases the accuracy to 1 to 5 meters (3 to 16 feet). Global positioning units measure in degrees, minutes, and fractions or decimals of minutes for latitude and longitude. These units also measure altitude.

What is RADAR?

One important piece of information that the GPS does not provide is the presence of other boats or the shore that could present danger to the boat and its occupants. The vessels are equipped with RADAR, which uses radio waves to provide information about objects on or above the surface of the water near the vessel. RADAR is an acronym taken from the phrase <u>RA</u>dio <u>D</u>irection <u>A</u>nd <u>R</u>ange.

Very high frequency radio waves can be reflected in the same way light is reflected from a mirror. RADAR sends out a short pulse of radio waves in a very narrow beam from an antenna located above the pilot house. The narrow beam rotates in a horizontal plane several times per minute. The radio signal will travel out into space unless it hits an object. If some of the radio waves hit an object, they will be reflected from the object back to the RADAR set where they are received, amplified, and then used to create a picture on the face of a cathode ray tube (CRT).

The picture is a view looking down from above. It shows the location of the vessel you are on in the center of the screen. Objects from which the RADAR signal is reflected appear as bright spots on the CRT. Since it takes time for the RADAR signal to leave the antenna, travel to an object, and then reflect back to the antenna, a simple relationship between time and distance is established. This is shown on the CRT with the bright spots representing other boats or the shore at a distance from the center of the screen corresponding to the actual distance between the boat you are on and objects in its vicinity.

The person using the RADAR set can select various ranges or distances by pushing the range switches. Selection of a range will cause bright concentric circles to show up around the center of the CRT screen. The concentric circles are called Range Markers. Comparison between the bright spot representing an object and the concentric circles makes it possible to determine the distance between the vessel and the object. The angle between the direction the vessel is headed and the surrounding objects can also be seen on the screen. Consequently, the name RADAR represents what the instrument can do. It uses radio waves (RA), to find the direction (D) between the vessel and an object, and the distance or range (R) to that object.

Whenever the vessel is used, the RADAR is turned on and a range is selected to give the Captain a good view of objects in the vicinity of the vessel. By watching the picture on the CRT screen, the Captain can note the presence of other boats, piers, and the shoreline. He can select other ranges to look for objects close to or far from the vessel. He can navigate by comparing the location of the vessel within the banks of the river or along the shoreline. The RADAR, combined with the GPS and depth finder, allows the Captain to know where obstacles on the surface are located, where the vessel is located, and how deep the water is below the vessel keel.

What other kinds of vessels navigate the lakes?

The ports on Lake Michigan are visited or are home for a variety of commercial and government vessels. The largest ships are freighters that are designed to carry bulk cargoes such as coal, iron-ore, stone, and grain. Ocean bulk freighters are about 500 to 730 feet in length and have one main cabin area. Lake bulk freighters or straight-deck bulk carriers are 600 to 800 feet in length with cabin areas at the bow and stern. Self-unloader freighters are the largest vessels ranging up to 1,000 feet long. Other vessels include Coast Guard cutters with distinctive bows that can cut ice, dredges that are barges with cranes, harbor tugs, and fish tugs.

Vessel fleets can be identified by the flag flown at the stern of the ship, port of registry painted across the stern, the hull colors, and smoke stack markings. For instance, the stack insignia of the U.S. Army Corps of Engineers has a silver castle on a red field bounded by narrow silver bands on a black stack. Ninth District Coast Guard boats have orange and black stacks with the Coast Guard insignia. Algoma Central Marine freighters have black, red, and white striped stacks with a bear logo; Inland Lakes Transportation vessels have black, red and white striped stacks with an "I"; and Oglebay Norton freighters have yellow with a red logo on their stacks. There are over 800 ships from 60 countries that visit the Great Lakes.

How does the weather affect navigation?

Especially on Lake Michigan, there are often small craft warnings when small vessels should stay off the "Big Lake". The greater the wind velocity, the higher the waves. Wave height is directly related to the amount of energy possessed by the wave, which depends on the wind speed, length of time the wind blows over water, and the fetch or distance over deep water that the wind blows. Wavelength is the distance between successive waves. If the steepness of a wave reaches a ratio of the wavelength divided by 7 (L/7), the wave becomes unstable resulting in whitecaps.

Wind speed and direction can be determined by use of an anemometer. The anemometer is an apparatus with four cups on a rotating axis that turn in response to the wind. A cable leads to a recorder that measures the wind speed. A wind vane indicates the direction of the wind. The arrow on a wine vane points into the wind and shows the direction from which the wind is blowing. For instance, northwest winds (onshore breeze) often bring in storms across Lake Michigan and east winds (offshore breeze) can move near-shore water to offshore locations.

Sky observations are clues to weather. The three basic types of clouds are cirrus, cumulus, and stratus. Cirrus clouds are wispy high clouds composed of ice crystals. Towering, billowing, or puffy cumulus clouds are found in both fair weather and approaching thunderstorms. Stratus clouds are low layers of thick, gray clouds typical of overcast days. They are often associated with rainy weather that lasts all day.

Both vessels have on-board weather stations. There is also a weather station at the AWRI Muskegon shoreline facility. The sensor channels at the weather stations gather information about wind direction, wind speed, barometric pressure, relative humidity, temperature, and rainfall. Interesting comparisons can be made between conditions onshore and out in the lake. Real-time weather information for the Muskegon area can be found at https://www.glerl.noaa.gov/metdata/mkg/

Water Depth

How is the depth of the water determined?

There are at least two reasons why it is important to know the depth of the water below the surface: to prevent running the vessel aground and to be able to relate scientific findings to the depth of the water from which samples are taken. Many water quality parameters such as temperature and dissolved oxygen vary with depth as well as with the time of day. The depth of light penetration, which is influenced by turbidity, has an effect on the productivity of plants and algae in an aquatic ecosystem. Various depths in a lake or river host different assemblages of benthic (bottom-dwelling) organisms. Plankton and fish move from one depth to another based on changing environmental conditions.

A simple and old fashion method for finding the depth of water is to lower a weight attached to a rope over the side of the vessel. When the weight touches the bottom, the rope becomes slack. The rope is then pulled back on-board and the length of the rope needed to touch the bottom is determined. This is a slow method and is not very useful if the vessel is moving very fast. If the water is very deep, it is difficult to retrieve the rope unless a mechanical winch is used.

A faster and continuous method for determining the depth of a body of water is to use sound waves. Sound travels at a very fast speed in water, about 1500 meters per second in fresh water, so there is little delay in measuring the depth of water. For example, if the water is 50 meters (about 150 feet) deep, sound waves will take approximately 0.07 seconds to leave and return to the vessel.

What is SONAR?

The technique for determining the depth of water is called SONAR. This is an acronym for <u>So</u>und <u>N</u>avigation <u>A</u>nd <u>R</u>ange. The use of sound in water to determine the direction and distance to underwater features was developed during World War II when it became a basic method for detecting the presence of submarines when they were submerged. SONAR is still used for that purpose, but on-board the *D. J. Angus* and the *W.G. Jackson* to determine the depth of water.

The principle is very simple. On-board the vessel is a sending unit that produces a short burst of sound in the water directed toward the bottom. The sending unit then becomes a receiving unit that detects the presence of the sound reflected from the bottom. Within the sending/receiving unit is a means of measuring the time between the pulse sent out and the reflected echo from the bottom. Since the speed of sound in water is known, the simple equation "$d/2 = vt$" is used to find the depth "d". The letter "v" represents the speed of sound in water and the letter "t" is the total time for the sound to leave and return to the vessel.

The depth "d" is divided by 2 in the equation because the time "t" is the total time from the vessel to the bottom and then from the bottom back to the vessel. This calculation is done automatically by the depth finder.

What are the types of depth finders?

The depth to the bottom can be given as a numerical value or as the position of a line on a screen or a strip of paper. The depth finders show not only a digital read out of depth but also has a line depicting the bottom. The color of this line indicates the bottom characteristics: bright red is a hard bottom and blue is a soft bottom. At high gain settings, this unit could be used as a fish finder.

Water Sampling

How is water sampled on the vessels?

Two kinds of sampling bottles are used on the vessel: Van Dorn water sampling bottles and, less frequently, Kemmerer water samplers. The idea behind these samplers is to collect water at a known depth. The Van Dorn bottles are used for sampling at various depths and the Kemmerer water sampler is used for surface water samples.

What are Van Dorn Water Sampling Bottles?

The Van Dorn bottles provide a means of obtaining water samples at selected depths below the surface. It consists of an open-ended clear plastic cylinder that can be attached to the hydrographic wire (the steel wire wound on the winch) and lowered to any desired depth. A deckhand operates the winch. The bottles also provide a platform to which thermometers can be attached to record the temperature of the water at the location of each Van Dorn bottle.

Each end of the cylinder is fitted with a rubber cover. The open Van Dorn bottle is attached to the line with the covers pulled out and twisted back and around to the side. The bottle is lowered to a pre-selected depth and left there until the thermometers attached inside equilibrate with the water at that depth.

Two Van Dorn bottles are attached to the same line and lowered to two different pre-selected depths. A metal weight called a "messenger" is attached below the upper bottle. The water sample is taken by dropping a "messenger" down the wire. When the weight hits the catch on the upper Van Dorn bottle, the catch releases the rubber end covers. The two ends snap around and seal the water inside. The other "messenger" then travels down the winch line to the lower Van Dorn bottle causing it to be sealed.

When it is time to lower the Van Dorn bottles into the water (this is called making a "cast"), a decision is made about the depth to which to send the bottles. This decision is based upon the depth of the water at the station and the number of samples needed. Normally only two water samples (surface and bottom) are taken. If a third water sample is required, the Kemmerer bottle may be used to obtain the surface sample. One Van Dorn bottle could then be used to obtain a mid-depth sample for some trips. In shallow areas, typically only one water sample is taken.

When both bottles have been tripped, they are retrieved and returned to their storage rack. Water samples from each bottle can then be taken for analysis and the temperature read from the attached thermometers. You may be able to see organisms in the water samples through the clear walls of the Van Dorn bottles.

What is a Kemmerer Water Sampler?

The Kemmerer Water Sampler is a device that makes it possible to obtain a sample of water from a pond, river or lake with little effort. The sampler is essentially a metal tube with stoppers on each end that can be held open when the sampler is lowered by a line to a desired depth. These same stoppers can then be triggered to close the ends of the tube when a metal cylinder called a messenger is dropped down the line holding the Kemmerer sampler. After the stoppers close the ends of the tube, the sampler is retrieved with the desired sample of water being uncontaminated by other water. This maintains the integrity of the sample.

Since only one sample of water can be obtained at a time, the process of obtaining several samples at various depths at the same sampling station is slow. The Kemmerer sampler is generally used in shallow water where only one or two sampling depths are needed. The Van Dorn bottles are used when several samples are needed from various depths at the same time. The Van Dorn bottles also allow greater depths to be explored than with the Kemmerer sampler.

Water Temperature

How is water temperature measured on the vessels?

Usually water temperature is measured on the vessels using thermometers that are mounted on the sampling bottles. The thermometers on the sampling bottles must be read immediately after the bottles are retrieved. Temperature is recorded in degrees Celsius (°C). The Celsius scale (once called the centigrade scale) uses the freezing (°O) and boiling (°100) points of water as the basis of the scale. The conversion from degrees Fahrenheit to degrees Celsius is found in Table 2. A bathythermograph is sometimes used on advanced trips to record a continuous temperature profile of the water column (see Appendix B). Another device for obtaining temperature profiles is a "fish finder" data logger that is attached to the line on the PONAR sampler.

On the day of a cruise, one can get an indication of the surface water temperature on Lake Michigan by querying the Michigan Sea Grant Coast Watch site. This site can be found at http://www.coastwatch.msu.edu/michigan/m41.html. An example of the surface temperature data is found in Figure 9, which is based on information from the Coast Watch Internet Site.

What is the significance of temperature data?

Several interesting studies can be made from the data obtained from the temperature readings. Most prominent is the identification of temperature patterns at various depths and the relationship to the seasons of the year (Figure 10). Stratification refers to distinct layers of water that do not mix with each other due to density differences.
The temperature readings also give an indication of whether conditions are favorable for cold-water fishes. The rates of metabolism of animals, as well as rates of photosynthesis and decomposition, are temperature sensitive. The migration of fish and their spawning behavior are associated with temperature changes. Temperature and dissolved oxygen are related in that warmer water holds less oxygen than cooler water.

How does the lake temperature vary throughout the year?

In most inland lakes in the temperate zone, the temperature of the lake is essentially uniform from top to bottom two times per year, spring and late fall. When this occurs, wave action on the surface will mix oxygen in the air with the water and the oxygen-rich water is driven down to lower depths. The bottom oxygen-poor water will be brought to the surface where it can be replenished with oxygen. Since this occurs twice per year in spring and fall, these lakes are said to be dimictic; “di” meaning two and “mictic” meaning “to mix”. Turnover is not uniform in a lake and strong winds can cause upwellings where nutrient rich deep water moves towards the surface.

At other times of the year, the water temperature of a large body of water like Lake Michigan can be understood by looking at how the density of water is related to temperature. Water freezes at 0°C (32°F) but it has its greatest density at 43.98°C (39.2°F). Less dense water will float on top of dense water, that is, water colder or warmer than about 4°C will float.

During winter, temperate zone lakes generally achieve a relatively uniform temperature from surface to bottom with slightly colder water near the surface. Once covered with ice, the water just beneath the ice is slightly above the freezing point, and increases to no more than 4°C (the temperature of maximum density) towards the bottom of the lake. It is because of the direct relationship between water temperature and density that ice floats on the surface of a lake. The ice layer provides protection from mixing of water by wind, inhibits diffusion of oxygen, and if the ice is covered with snow, then the transmission of light into the water below. The fact that the density of water is greatest at 3.98° C and not zero prevents lakes from freezing from the bottom up to the surface.

The relationship between water temperature and density also plays a determining role in lake conditions during the summer. Remember that above about 4° C, the water density decreases and this warmer, lighter water floats on colder, heavier water. Hence, as heat from the sun increases during the summer, the upper waters of the lake become warmer and lighter than deeper waters. The energy of the wind is inadequate to mix the upper water with the colder, more dense, deeper water. This situation leads to a summer stratification period with the warmer water separated from the deeper, much colder, bottom water (Figure 10).

In the summer, lakes show thermal stratification, which means that there are distinct layers defined by temperature. When stratification occurs, the different layers are given names to identify their location. Warm water is found in the top layer (epilimnion) followed by a deeper layer where there is a drastic temperature drop of about 1ºC per meter. This is the thermocline; the major thermocline located between the epilimnion and the hypolimnion is called the metalimnion. Colder, heavier water is found in the bottom layer (hypolimnion). Figure 11 illustrates temperature profiles.

One very important consequence of summer stratification of a lake is that circulation due to wind action is largely confined to the upper water mass known as the epilimnion. Because the lower water mass is isolated from the atmosphere and receives little, if any, sunlight, dissolved oxygen is not replenished in this water mass. The dissolved oxygen may diminish to such a level that it limits aquatic life. However, oxygen will be replenished at the end of summer when water temperatures become more uniform and the wind circulates all of the water in the lake basin.

Table 2: Celsius to Fahrenheit Temperature Conversion

°C	°F	°C	°F	°C	°F
1	33.8	11	51.8	21	69.8
2	35.6	12	53.6	22	71.6
3	37.4	13	55.4	23	73.4
4	39.2	14	57.2	24	75.2
5	41.0	15	59.0	25	77.0
6	42.8	16	60.8	26	78.8
7	44.6	17	62.6	27	80.6
8	46.4	18	64.4	28	82.4
9	48.2	19	66.2	29	84.2
10	50.0	20	68.0	30	86.0

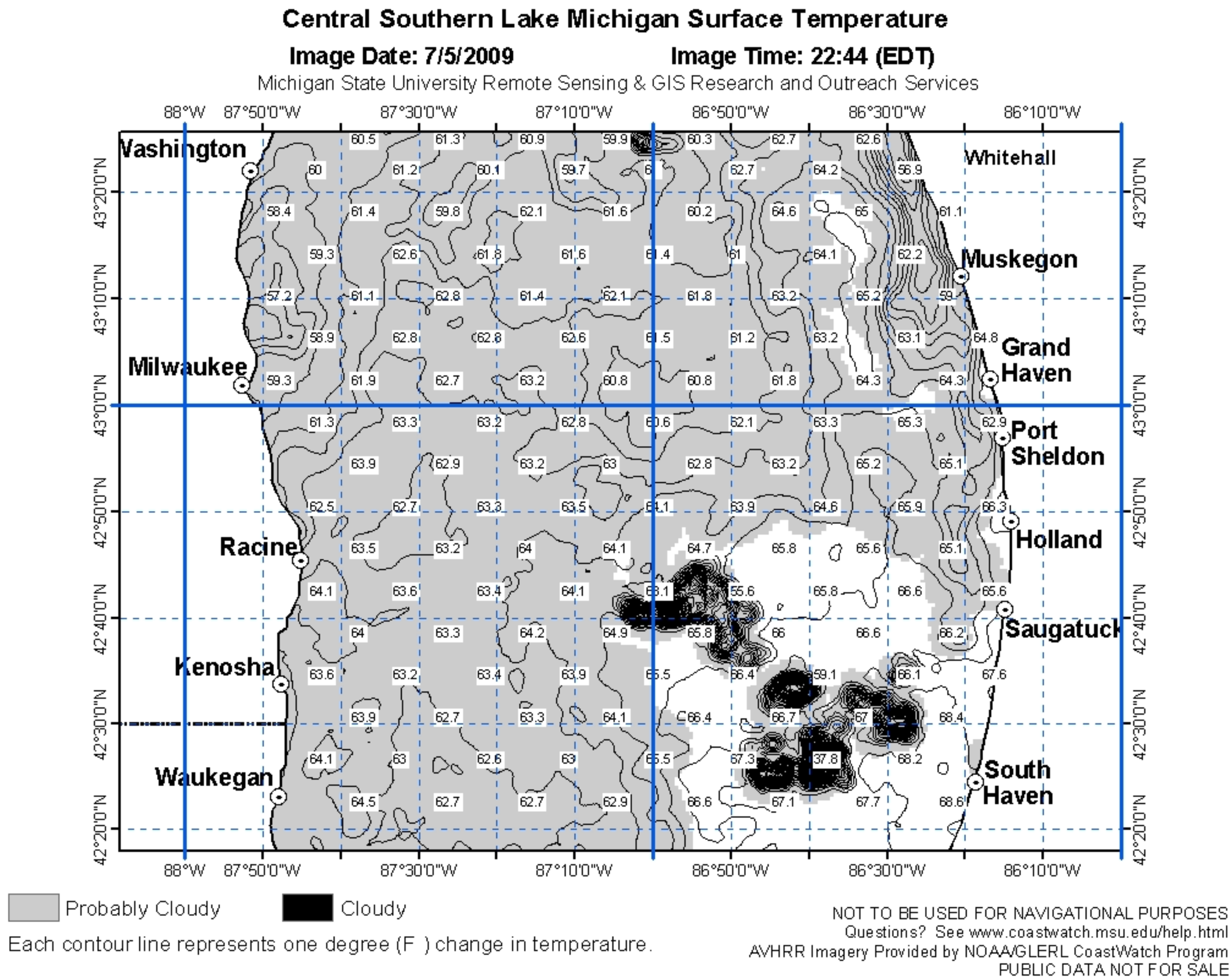
Some lakes in the temperate zone may not be dimictic because they are either very large, like Lake Michigan, or very shallow, like Spring Lake. Lake Michigan experiences summer stratification similar to what is described above, but early in the summer the stratification begins near shore and works its way toward the middle of the lake as the summer progresses. The outer most end of this stratification is called a thermal bar. The thermal bar can be found where the surface temperature of the lake is at 3.98° C (this water mass is continuously sinking and acts like a barrier between the nearshore and offshore waters); surface water farther offshore will be colder, and closer to shore will be warmer. Eventually, the stratification process that began around all of the shoreline will meet in the middle of the lake and the lake will be stratified completely (as described above).

The difference between Lake Michigan and smaller lakes in the temperate zone lies in the fact that, since satellite imagery has been available, it has never completely frozen across (over 90% has frozen, but this is rare). Instead of the system starting fall turn over and eventually freezing to stop the turnover process, it continues to turn over all winter long right into spring turnover. Therefore, the system really only turns over once per year; it just lasts from fall to spring!

Instead of referring to Lake Michigan as a dimictic lake, we say that it is warm monomictic. This certainly does not suggest that the system is warm. We just divide monomictic into two categories, cold and warm. If the system only mixes once per year during the summer because it is frozen most of the year (like in the sub-arctic zone), then we call it cold monomictic. If the system never freezes completely, then we call it warm monomictic.

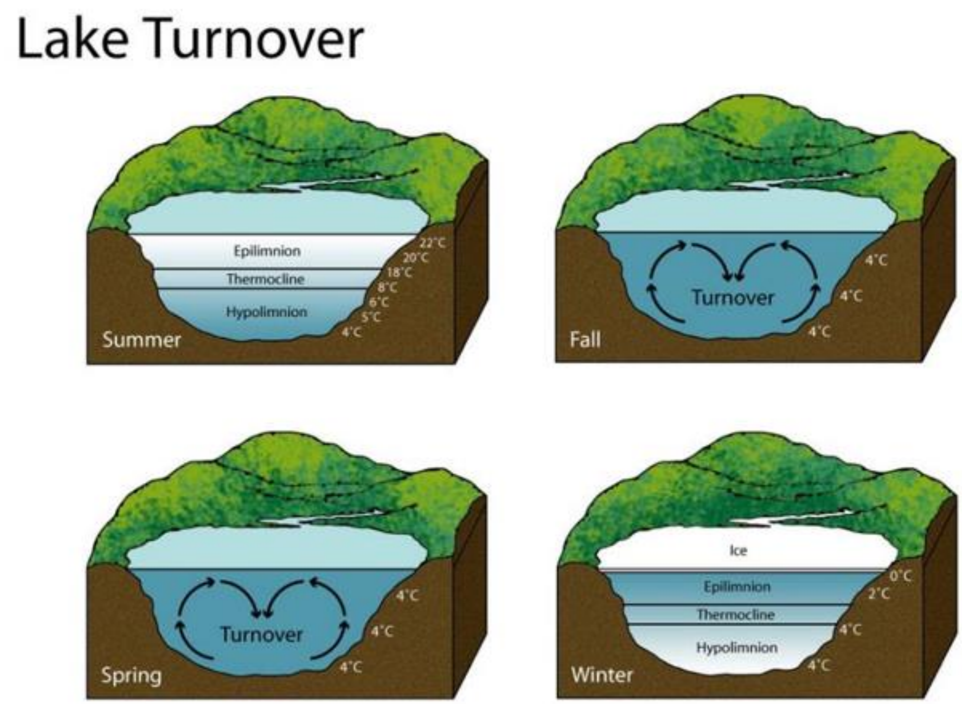
A lake like Spring Lake is a different story. Spring Lake's shallow system freezes over completely so we may think that it is dimictic. However, because it is shallow and a riverine system, the stratification breaks down several times throughout the summer. Every time this happens, the lake turns over. Since it mixes many times per year, we call it polymictic.

Figure 10: Lake Michigan Surface Temperatures



Source: http://www.coastwatch.msu.edu/michigan/m4.html

Figure 11: Temperature Cycles in a Lake



Source: National Geographic

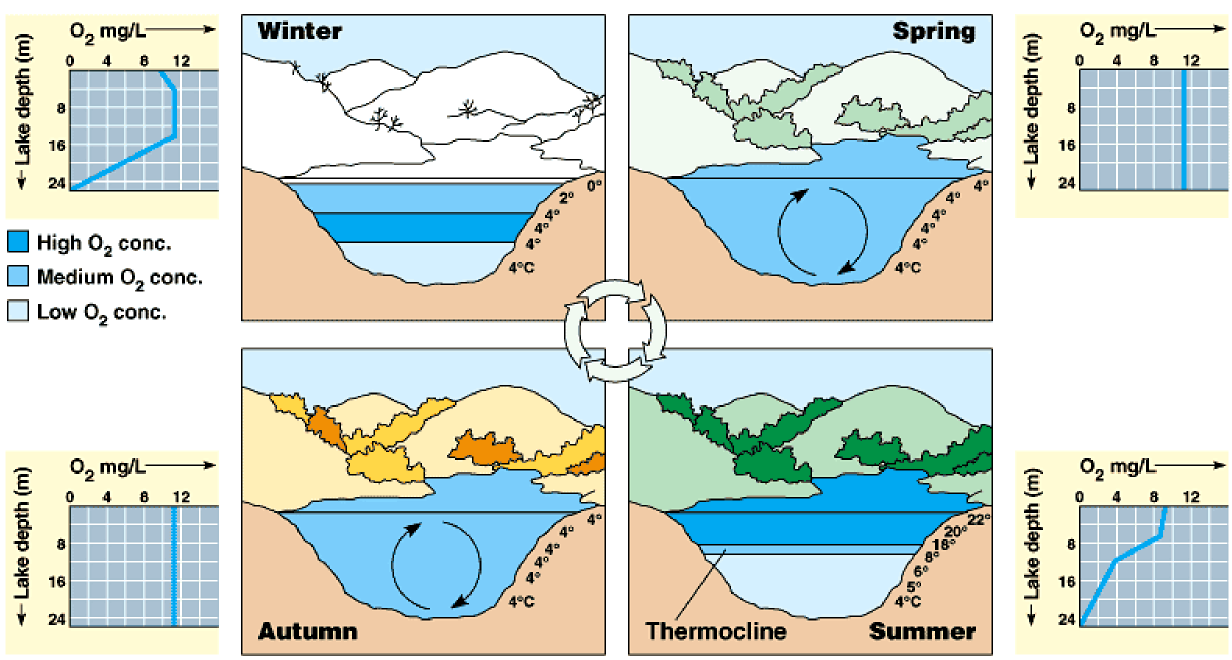
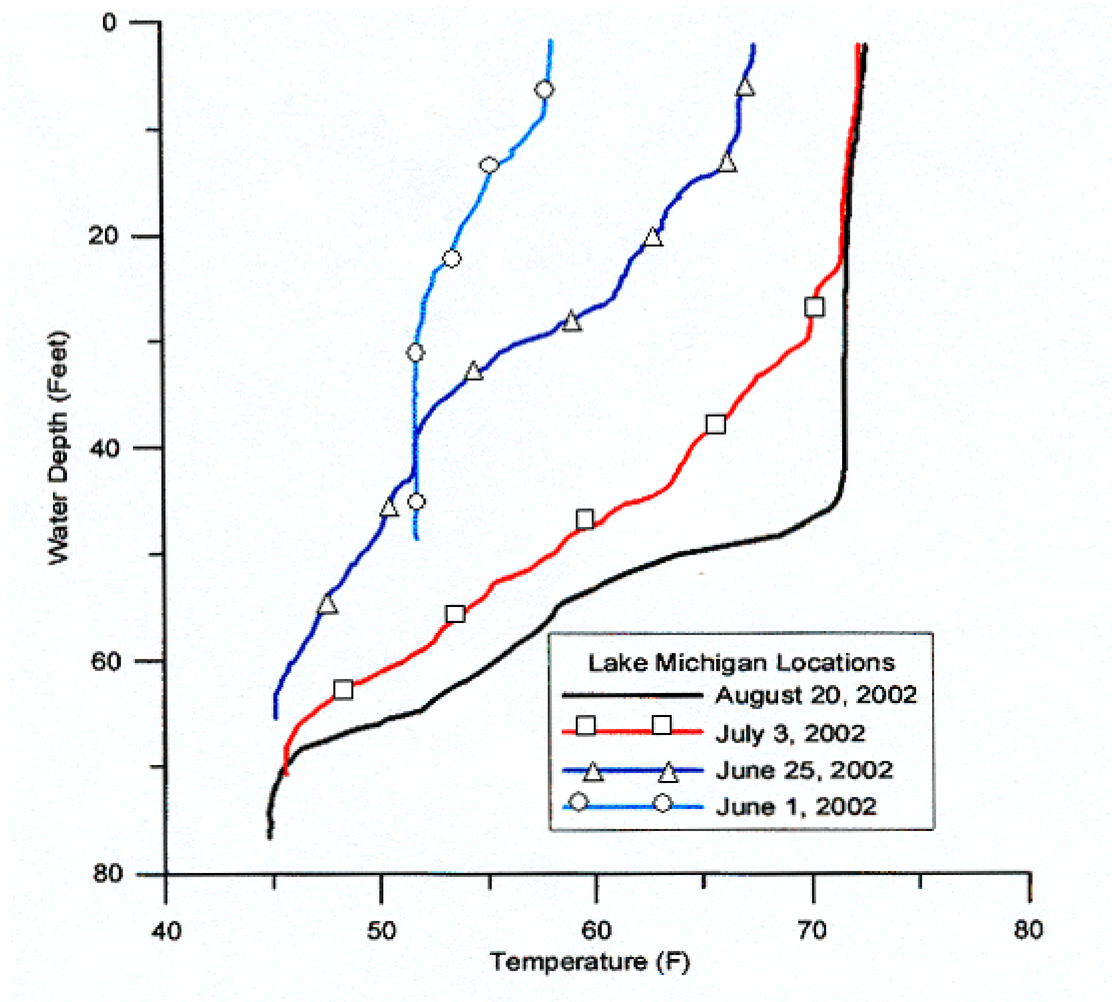


Figure 12: Temperature Profiles



Water Transparency

What is water transparency?

The transparency of water relates to the depth that light will penetrate water. The transmission of light into a body of water is extremely important since the sun is the primary source of energy for all biological phenomena. Light is necessary for photosynthesis, a process that produces oxygen and food for consumers. It is common practice for biologists to consider the depth of the euphotic zone (the upper layers of a body of water into which sufficient light penetrates to permit growth of green plants) to be 2.7 times (roughly 3 times) the limit of visibility. As light penetrates water, it becomes attenuated and altered in its spectral composition. The change that occurs is from predominantly yellow light at the surface to blue-green at depth in clear water or yellow-green in waters having a high concentration of dissolved organic material.

What is a Secchi Disk?

The Secchi disk is a very simple device about 20 cm in diameter made of metal or plastic. It is based on the work of Father Pietro Angelo Secchi of Rome, Italy who devised a method for studying the transparency of the waters of the Mediterranean Sea in 1865. Secchi was a science advisor to the Pope and head of the Roman Observatory.

The Secchi disk provides a means for determining the limit of visibility that is based on contrast. The upper surface of the Secchi disk is divided into four quadrants that are alternately black or white. An eyebolt is located at the center of the disk on the upper side so that a line can be tied to the disk. This makes it possible to lower the disk into the water from a boat or dock. A weight is attached to the underside of the disk so that the equipment will sink below the surface. This line is marked every 0.5 meter making it possible to determine the depth at which the Secchi disk disappears from sight as it is lowered into the water.

The Secchi readings are a semi-quantitative measure of water transparency since a variety of factors such as the time of day, sky and water surface conditions, and differences between observers will give varying depths for the same location. It is possible that each person will have a different opinion of the depth at which the disk disappears from sight. That is why it is important that Secchi disk records contain information about the conditions under which the readings were taken.

Standard conditions for Secchi disk measurements include a clear sky, sun directly overhead, and minimal waves or ripples. These measurements must be taken on the shaded and protected side of the vessel. Any deviations from these conditions should be clearly stated in the data. It is interesting to note that visibility in water is roughly twice the Secchi depth since the light must travel twice through a column of water equal in length to the Secchi depth from the surface to the disk and then back up again after being reflected from the disk.

What is the significance of Secchi Disk readings?

Secchi disks are standard tools for inland lake monitoring along with measurements of chlorophyll *a* and phosphorus. Volunteer groups throughout the state and country take Secchi disk readings to indicate the current status of their lake and to compare with data from previous years. The Secchi disk provides a measure of the amount of suspended inorganic and organic matter in the water.

Transparency readings in oligotrophic or low nutrient lakes are often greater than 15 feet (5 meters) whereas eutrophic or nutrient rich lakes have readings less than 7.5 feet (2.5 meters). Water clarity is related to amounts of suspended particles (turbidity) as well as amounts of phytoplankton and zooplankton.

Instructions for use of a Secchi Disk

1. A Science Instructor will take selected members of the group to the shaded side of the vessel to perform the Secchi disk readings. If working from a dock, provide some kind of sunshade.

2. Make certain that the line on the Secchi Disk is free of tangles.

3. Hook or tie the free end of the line or line holder to the railing to prevent losing the Secchi disk overboard.

4. Lower the disk into the water. While lowering it, count the number of half-meter marks on the rope as they go below the surface. Lower the disk until it disappears. A team of two or three people working together on this makes it easier. One person handles the line and counts the half-meter marks while the others concentrate on the disappearance and reappearance of the disk.

5. Lower the disk an additional half meter, then slowly lift it until it reappears. As the disk is retrieved, count the number of half-meter marks on the rope as they emerge from the water.

6. Average the two depths, the depth at which the Secchi disk disappeared and the depth at which it reappeared. Record this value as the Secchi depth. The Secchi depth is also known as the Secchi transparency.

Water Color

What influences the color of the water?

The description of the color of a body of water varies from one person to the next. Many variables affect our perception of its color. Among them are sky conditions, time of day, surface conditions, suspended materials, and the direction from which the water is viewed.

Sky conditions include the presence or lack of clouds. Water viewed on a clear sunny day will appear blue unless there is a sufficient quantity of suspended or dissolved material in the water to affect its color. When the same water is observed on a cloudy day it will look gray. If there is a large amount of water vapor or dust in the air, the color of the water will be affected because both the quantity and quality of the light will be changed.

The altitude of the sun will change during the day. When the sun is seen near the horizon at sunrise or sunset, the color of the water will appear very dark. Later in the day, the water will appear blue or bluish green in the absence of suspended material.

A flat water surface viewed with reflected light can appear to be without color while the same water will take on a color if the surface is covered by waves. If the waves are large and foam from white caps is present, the apparent color of the water can be affected by light passing through the waves.

Water viewed in the direction of the sun will be seen in reflected light while the same water viewed from directly above will take on the color of the light scattered from under the surface. Even turbid water will look like clear water when looked at in a direction toward the sun. The same water viewed from directly overhead will show a color dependent upon the nature of the material creating the turbidity.

What is the Forel-Ule Color Scale?

Since there are many variables that affect the apparent color of the body of water including the perception of the person making the observation, it is necessary to establish a standard method for determining color. One such technique uses a series of colors obtained by using standardized chemical procedures for producing colored water. Each of these colored samples is contained in a sealed glass tube. The colors range from blue to a range of greens and yellow-browns, and are composed of various solutions of potassium chromate, cobaltous sulfate, and cupric sulfate. These colors form the Forel-Ule color scale. Each color is given a number. Number 1 is a pale blue and number 22 is brown.

The glass tubes are mounted in a metal frame to protect them from damage. Each frame of vials has a loop that should be placed over the wrist so that it will not drop overboard. A determination of water color is made by lowering the Secchi disk from the shady side of the vessel into the water to a depth of one meter. The observer then compares the color of the standard samples in the tubes to the color of the water as seen against the white portion of the Secchi disk.

The apparent color of the water as determined by the above technique is very subjective. Two observers viewing the same water can disagree within one or two numbers. However, if the same technique is used each time color is to be determined, usable data can be obtained.

NOTE: The Forel-Ule colors are contained in glass vials that are subject to being easily broken. Care should be taken when they are used to guard against breakage. This is why it is important that the loops should be placed over the wrist to prevent dropping the equipment overboard.

What is the significance of the color of the water?

The color of a body of water can give an indication of its quality and composition. Color can be associated with material dissolved or suspended within it. The altitude of the sun, water vapor in the air, clouds, and dust also relate to water color. Deep blue may indicate low amounts of organic matter or plankton. Green shades are associated with phytoplankton and high biological productivity. Colloidal calcium carbonate scatters green and blue light, and it is linked to the “whiting” of portions of Lake Michigan. Brown is indicative of mineral matter, organic matter, or large populations of diatoms. Open sea water color is blue to blue-green, inshore water and inland lakes are often yellow-green, and water in rivers and harbors tends to be brown or brown-green.

The water in Muskegon Lake is coffee colored because of the breakdown of natural organic matter in the wetlands. This matter includes tannins, lignins, and humic acids that are a result of decay of plants and wood.

The dissolved and suspended material in the water flowing from a river into Lake Michigan provides an excellent contrast where the effect of these materials on the color of water is easily seen. The interface between the river and lake waters can be very sharp if the wind and resulting waves are not present. The color of the river is almost coffee-like while the lake is a clear blue-green. The Grand River contains organic matter in addition to suspended clay minerals. Turbidity measurements can help differentiate between dissolved and suspended materials that color the water.

Instructions for use of the Forel-Ule color scale

1. Obtain the Forel-Ule color scale and place the loop around your wrist.

1. On the shady side of the vessel, a second person should lower the Secchi disk to a depth of one meter.

2. The observer then compares the Forel-Ule color scale to the color of water as seen against the white portion of the Secchi disk. Record the Forel-Ule color number that is the closest match.

3. Repeat the observations by having two other people determine the color match.

Turbidity

What is Turbidity?

Turbidity, or cloudiness, in water is caused by a variety of suspended materials. The material can be both organic (plankton, sewage) and inorganic (silt, clay). The suspended material will scatter and absorb light passing through the water. The light scattered back to the observer can be affected so that the water will have a color dependent upon the type and amount of suspended matter. The cloudiness and color can be observed if a sample of water in a transparent container is held between the observer's eye and a light source. It is this phenomenon that is used in the turbidity meter.

How is Turbidity Measured?

A nephelometer or spectrophotometer (turbidity meter) measures the cloudiness or opaqueness of a water sample. A nephelometer contains a source of light, a photocell, and a meter. Light is beamed through a water sample. The path of the light is 90 degrees to the direction in which the photocell points. When a sample is placed in the light beam, light scattered by the suspended material in the sample is detected by the photocell. The photocell converts the scattered light into an electrical current that is sent through the meter. The position of the needle on the meter or a digital read-out gives an indication of the turbidity of the water sample.

Turbidity determined by the technique described above is referred to as the nephelometric method from the root meaning "cloudiness". This word is used to form the name of the unit of turbidity, the NTU. This acronym stands for Nephelometric Turbidity Unit.

The meter reading cannot be used to compare the turbidity of different water samples unless the instrument is calibrated. The Science Instructors calibrate the meter regularly. Calibration consists of adjusting the meter reading to a known value when a standard sample is placed in the light beam. A standard suspension is often made from a polymer called Formazin, which has stable reproducibility.

What is the significance of turbidity?

Turbidity relates to the effect that suspended particles have on water clarity. High turbidity readings (low clarity) can indicate erosion and sedimentation problems. Rainfall and runoff can increase the suspended solid load in a river and make the river appear cloudy or muddy. High biological productivity related to increases in nutrients and temperature can result in increases of diatoms and other algae that contribute to turbidity. Turbidity meters can be used to estimate plankton density.

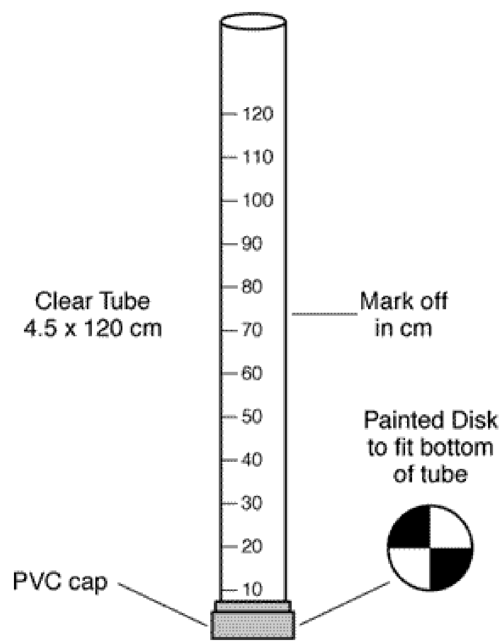
River plumes that are rich in organic matter and suspended solids are clearly differentiated from the Lake Michigan water as they enter they lake. Turbidity readings in Lake Michigan are likely to range from 0.1 to 2.5 NTU. The Grand River often ranges from 2 to 9 NTU. Spring Lake and Muskegon Lake have typical readings ranging between 0.1 and 4 NTU.

Elevated turbidity can cause an increase in temperature since suspended particles absorb heat. Reduction of light penetrating the water column due to turbidity can decrease the rate of photosynthesis. This, in turn, can decrease the amount of dissolved oxygen in the water. As suspended particles settle, they can impair the habitat needed for fish spawning and aquatic macroinvertebrates. They can also clog the gills of fish and the breathing apparatus of invertebrates. Particles serve as places of attachment for harmful microorganisms and toxic materials. Turbidity in drinking water is decreased through the process of flocculation, which involves addition of alum or a mixture of iron, lime, and chloride to cause solids to settle out.

Instructions for use of a Turbidity Tube

Another way to study water clarity is to use a turbidity tube (Figure 12).
To use the turbidity tube:

1. Pour water drawn in a bucket into the tube until the black and white image at the bottom of the tube is no longer visible when looking directly through the water column.
2. Rotate the tube while looking down at the image to see if the black and white areas of the decal are distinguishable.
3. Record this depth of water to the nearest 1 cm.
4. Enter data for each observer, and calculate the average of the different observations. If you can still see the image on the bottom of the tube after filling it, simply record the depth as greater than (>) the depth of the tube.



Source: Global Learning and Observations to Benefit the Environment (GLOBE)

Conductivity

What is conductivity?

Conductivity or specific conductance is the measure of the water's ability to conduct an electrical current. Conductivity depends upon the number of ions or charged particles in the water. The ease or difficulty of the flow of electrical current through liquids makes it possible to divide them into two broad categories: electrolytes and nonelectrolytes. Electricity passes easily through water that is high in electrolytes or ions, and poorly through low electrolyte materials such as pure water or many organic solvents such as alcohol or oil. The opposition to the flow of electricity is called resistance and it is measured in units called ohms. Substances with low resistance and high conductivity pass electricity easily.

How is conductivity measured?

A conductivity meter is used to measure the ability of the water sample to conduct electricity. The specific conductance is measured by passing a current between two electrodes that are placed into a sample of water. The unit of measurement for conductivity is expressed in either microSiemens (μS/cm) or micromhos (μmho/cm) which is the reciprocal of the unit of resistance, the ohm. The prefix "micro" means that it is measured in millionths of a mho. MicroSiemens and micromhos are equivalent units. Distilled water has a range of conductivity from 0.5 to 2 μS/cm. Drinking water is generally between 50 to 1500 μmS/cm and domestic wastewater may have conductivities above 10,000 μmS/cm. The warmer the water, the higher the conductivity with an increase of about 1.9% per Celsius degree. Conductivity is reported at standard temperature of 25.0° C.

What is the significance of conductivity?

Conductivity determinations are useful in aquatic studies because they provide an estimate of dissolved ionic matter in the water. Low values of specific conductance are characteristic of high-quality, oligotrophic (low nutrient) lake waters. High values of specific conductance are observed in eutrophic lakes where plant nutrients (fertilizer) are in greater abundance. Very high values are good indicators of possible pollution sites. For instance, industrial discharges, road salt, and failing septic tanks can raise conductivity. A sudden change in conductivity can indicate a direct discharge or other source of pollution into the water.

Conductivity readings do not provide information about the specific ionic composition and concentrations. Water, itself, contains hydrogen (H^+) and hydroxide ions (OH^-) with relative amounts reflected in the pH readings. Chloride, phosphate, sulfate, and nitrate anions (negative ions) as well as calcium, magnesium, iron, aluminum, and sodium cations (positive ions) contribute to overall conductivity as well. Lakes and rivers vary in conductivity based on the geology of an area. Water bodies underlain by granite have lower conductivity than those areas of clay soils. Conductivity in rivers in the United States range from 50 to 1,500 μmS/cm, and measurements taken in waters sampled by the GVSU vessels usually range from 110 to 600 μmS/cm.

Measurement of pH

What is pH?

A natural body of water can be acidic, neutral, or basic. Many factors determine this condition including the composition of the material forming the basin holding the water, acidity of rain falling into the water, and the condition of water flowing into the body of water from streams, rivers, or storm runoff. The standard measurement used to indicate acidic or basic conditions is called pH with "p" referring to the "power" (puissance) of the hydrogen ion activity.

Ions are electrically charged atoms or groups of atoms that are capable of conducting an electrical current in a solution. Pure water has a small number of water molecules that break up into positively charged hydrogen atoms (H^+) and negatively charged hydroxyl ions (OH^-). Since an equal number of negative and positive ions will be formed, the water remains electrically neutral; it is neither acidic or alkaline. Careful measurements show that pure water at 25°C ionizes so that 0.0000001 mole of positive hydrogen ions are liberated per liter of water. This number when written in scientific notation becomes 1×10^{-7}. If this number is expressed on a negative logarithmic scale, it becomes 7.

The pH scale is a series of numbers ranging from 0 to 14 which denote various degrees of acidity or alkalinity. Values below 7 and approaching 0 indicate increasing acidity. Values from 7 to 14 indicate increasing alkalinity. Since the scale is logarithmic, the difference between pH 5 and pH 6 is not one but rather ten, that is, pH 5 is ten times more acidic than pH 6 (Table 3).

Table 3: pH Scale

pH	H^+ moles/L	pH	H^+ moles/L	pH	H^+ moles/L
0	1×10^{0}	5	1×10^{-5}	10	1×10^{-10}
1	1×10^{-1}	6	1×10^{-6}	11	1×10^{-11}
2	1×10^{-2}	7	1×10^{-7}	12	1×10^{-12}
3	1×10^{-3}	8	1×10^{-8}	13	1×10^{-13}
4	1×10^{-4}	9	1×10^{-9}	14	1×10^{-14}

How is pH measured?

There are several ways to measure pH, which include pH paper, pH pen, and pH meters. For pH paper, strips of paper are saturated with an indicator that changes color with varying degrees of acidity. The color of the paper is compared to a color scale that is specific to the range and type of paper used. This means of determining pH usually measures only to about 1 pH unit; however, it is inexpensive. A pH pen is basically a simple electrode similar to that found in a pH meter. Both measure electrical potential associated with the hydrogen ion activity across an electrode immersed in the water sample. Accuracy ranges from 0.1 to 0.01 pH units.

A basic pH meter will have a device to measure voltage, a glass electrode to immerse in the water, a reference electrode that provides a constant electric potential, and a temperature compensation device. The pH readings are temperature dependent. The results are given in either pH units or millivolts (mv).

Many kinds of pH meters have been used on the D. J. *Angus* and the *W.G. Jackson*. Specific instructions for the model carried on-board are posted next to the instrument. Before it is used, the Science Instructors calibrate the pH meter. Two standard buffers (pH 7 and pH 10) are used to calibrate the instrument. Buffers are standard solutions of a known pH value.

What is the significance of pH?

Changes on pH can be associated with wastewater discharges and sources of pollution. However, natural changes in pH occur with variations in levels of carbon dioxide. Carbon dioxide is very soluble in water. It enters the water from the atmosphere and is also generated from animal and plant respiration and decomposition. Dissolved carbon dioxide can combine with water to yield carbonic acid. Plants reduce amounts of carbon dioxide through photosynthesis making surface waters more basic.

Water quality standards generally call for a pH between 6.0 to 9.0. A pH between 6.7 and 8.6 will support a well-balanced fish population. Only a very few species can tolerate pH values less than 5.0 or greater than 9.0 (Table 4). Lake Michigan water samples typically have a pH range of 7.0 to 8.6.

Table 4: Effects of pH on Fish and Aquatic Life

Limiting pH values		
Minimum	**Maximum**	**Effects found in some scientific studies**
4.0	10.1	Limits for the most resistant fish species
5.0	9.0	Tolerable range for the most fish
4.5	9.0	Trout eggs and larvae develop normally
4.6	9.5	Limits for perch
4.1	9.5	Limits for trout
--	8.7	Upper limit for good fishing waters
5.4	11.4	Fish avoided waters beyond these limits
6.0	7.2	Optimum (best) range for the fish eggs
7.5	8.4	Best range for the growth of algae

Source: Water Quality Criteria, California Water Quality control Board 1963.

Our area experiences acid rain, precipitation with a pH less than 5.6. An interesting question is why acid rain is not as much of an issue for the Lake Michigan as it is for some lakes in New York and Canada. The actual effect of adding a highly acidic pollutant to a body of water is related to the acid neutralizing or buffering capacity of the water which is reflected in alkalinity measurements. The water of Lake Michigan has a much higher acid neutralizing than lakes threatened by acid rain. The limestone (calcium carbonate) in the Lake Michigan basin is a natural buffer that helps to maintain soil and water pH near or above neutral.

Alkalinity

What is alkalinity?

Alkalinity is a measure of the capacity of water to neutralize acids. This is known as the acid neutralizing (buffering) capacity of water or the ability of water to resist a decrease in pH when acid is added. Alkalinity in water is due primarily to the presence of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide ions. It relates to the balance of carbon dioxide in water and is a function of pH. The HCO_3^--CO_3^{2-}-CO_2 equilibrium system accounts for the major buffering mechanism in water.

How is alkalinity measured?

Alkalinity is expressed as phenolphthalein alkalinity and/or total alkalinity. Both types can be determined by a titration with standard sulfuric acid to an endpoint pH. Indicators such as phenolphthalein and bromcresol green-methyl red define endpoints or a pH meter could be used for determination of endpoints. Phenolphthalein alkalinity is determined by titration to a pH of 8.3 and indicates the total hydroxide and half of the carbonate present. Total alkalinity is determined by titration to a pH of 5.1, 4.8, 4.5 or 3.7 depending upon the amount of carbon dioxide present. Generally, 4.5 is used. The total alkalinity includes all carbonate-bicarbonate alkalinity and hydroxide alkalinity. Bicarbonate is the major form of alkalinity. The unit of measurement for alkalinity is usually mg/L or ppm $CaC0_3$. Another measurement unit for alkalinity is milliequivalents per liter.

What is the significance of alkalinity?

Alkalinity is the measure of the resistance of water to the lowering of pH when acids are added to the water. Acid additions generally come from rain or snow, though soil sources are also important in some areas. Alkalinity increases as water dissolves rocks containing calcium carbonate such as calcite and limestone. Carbonates and hydroxide may be significant when algal activity is high and in industrial water.

When a lake or stream has too little alkalinity, typically below about 100 mg/L, a large influx of acids from an intense rainfall or rapid snowmelt event could (at least temporarily) consume all of the alkalinity. This results in a drop of the pH of the water to levels harmful for amphibians, fish or zooplankton. Lakes and streams in areas with little soil, such as in mountainous areas, are often low in alkalinity. These water bodies can be particularly sensitive in the spring during periods of rapid snowmelt. Because pollutants tend to wash out of a snow pack during the first part of snowmelt, there is often a higher influx of acidic pollutants in spring, which is also a critical time for the growth of aquatic life. Glacial till in the Great Lakes contains rocks containing calcium carbonate, which helps to buffer the effect of acid rain. High alkalinity can mitigate metal toxicity by using available bicarbonates and carbonates to take metal out of solution. The metals would thus be unavailable to fish and other aquatic organisms.

Dissolved Oxygen

What is dissolved oxygen?

Oxygen gas dissolves freely in fresh water. Thus, oxygen from the atmosphere as well as that produced as a by-product of photosynthesis may increase the dissolved oxygen concentration in water. Oxygen is removed from the water through the processes of respiration by plants, algae, and animals, as well as the microbes responsible for the decomposition of organic wastes entering the water.

The distribution of dissolved oxygen (DO) within an aquatic environment varies horizontally, vertically, and with time. Its distribution is dependent upon atmospheric contact, wave and current actions, thermal phenomena, waste inputs, biological activity, and other characteristics of a lake or stream. High levels of oxygen are likely in surface water on windy days. Dissolved oxygen levels are temperature and pressure dependent. Cold water has the capacity to hold more oxygen than warm water.

Photosynthesis contributes to an increase in dissolved oxygen levels during the day. However, there are biological processes in water that consume oxygen such as respiration by organisms and decomposition of organic matter by microorganisms. The oxygen consumed by these processes is called the Biological Oxygen Demand or BOD. When demand for oxygen is high and oxygen production from photosynthesis is not occurring such as before sunrise, dissolved oxygen readings can be low. Dissolved oxygen in the littoral zone may show a 4-6 mg/L diurnal fluctuation.

Deep areas of a lake would be expected to yield low dissolved oxygen readings. In summer, there are times when the dissolved oxygen at the bottom of Spring Lake approaches zero. During spring and fall turnovers, horizontal and vertical variation of dissolved oxygen is likely to be less than during the summer.

How is dissolved oxygen measured?

Since an adequate supply of oxygen is necessary to support life in a body of water, a determination of the amount of oxygen provides a means of assessing the quality of the water with respect to sustaining life. A standard chemical method to determine the amount of oxygen dissolved in a water sample is a type of titration, the Azide Modification of the Winkler Method. Precisely measured amounts of chemicals (reagents) are added to a water sample until a color change is achieved. A color change (or electrical measurement for other types of titration) marks the endpoint of the test. Another way to measure dissolved oxygen is to use a dissolved oxygen (DO) meter and probe. Units for measuring dissolved oxygen are parts per million (ppm) or milligrams per liter (mg/L).

Because the solubility of oxygen in water is dependent upon temperature, pressure, and ionic concentrations, it is also important to calculate percentage saturation. The accompanying nomogram will permit you to quickly approximate oxygen saturation values (Figure 13). The saturation point indicates the level at which water will not generally hold any more oxygen at a given temperature. Supersaturation occurs when the water holds more oxygen molecules than usual for a given temperature. Sunny days with lots of photosynthesis or turbulent water conditions can lead to supersaturation. A water sample is "saturated" at 100% and "supersaturated" above 100%.

What is the significance of dissolved oxygen?

Dissolved oxygen levels provide information about the biological, biochemical, and inorganic chemical reactions occurring in aquatic environments. Most aquatic organisms are highly dependent upon dissolved oxygen and will experience stress, or perhaps even be eliminated from a system, when dissolved oxygen levels fall below about 3.0 ppm (parts per million). Trout species normally require an oxygen concentration greater than 10 ppm (10 mg/L) whereas carp can live in water containing as little as 1-2 ppm (1-2 mg/L) oxygen.

Poor water quality is also indicated by low percent saturation readings. Levels below 60% may happen with rapid biological processes such as decomposition or high temperatures. Supersaturation can be a problem for organisms in that blood oxygen levels can increase resulting in gas bubbles in the blood.

A general guideline for interpretation of dissolved oxygen readings is:

For ppm or mg/L:

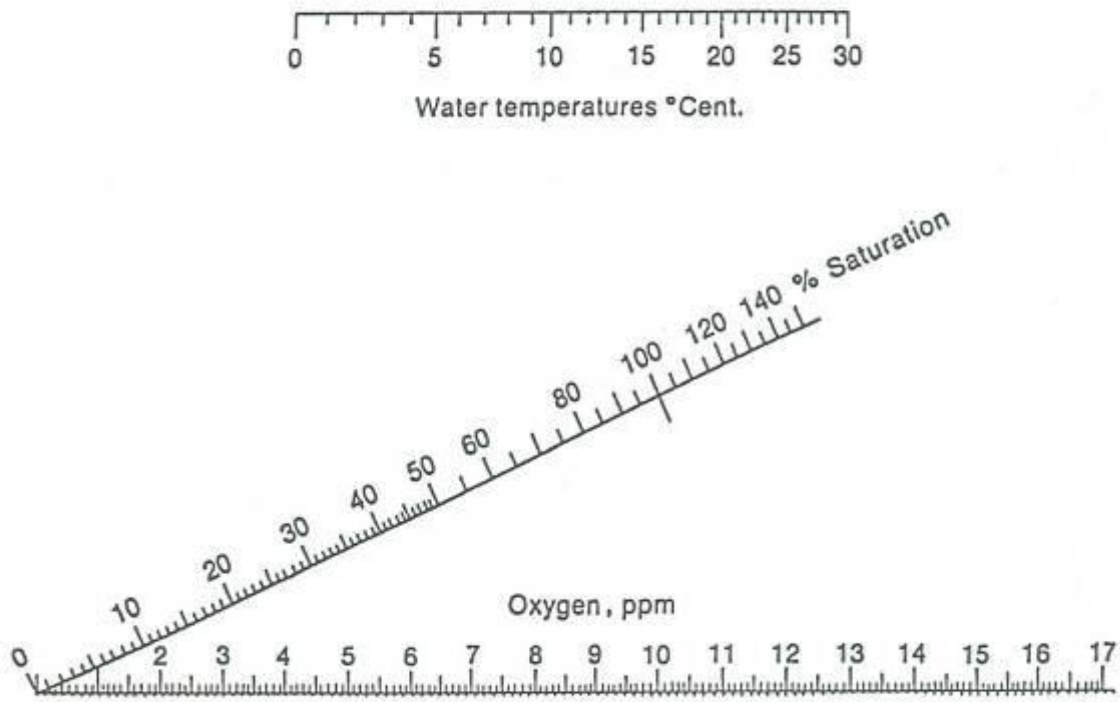
- 0-2 ppm: not enough oxygen to support life
- 2-4 ppm: only a few kinds of fish and insects can survive
- 4-7 ppm: acceptable for warm water fish
- 7-11 ppm: very good for most stream fish including cold water fish

For percent saturation:

- Below 60%: poor; water too warm or bacteria using up DO
- 60-79%: acceptable for most aquatic organisms
- 80-120%: excellent for most aquatic organisms
- 120% or more: too high; may be dangerous to fish

Adapted from *Testing the Waters*, S. Behar, River Water Network, 1996

Figure 13: Nomogram for Dissolved Oxygen Saturation



Hold a ruler or a dark thread to join the observed temperature on the upper scale with the dissolved oxygen reading on the bottom scale. The percent saturation is read where the ruler or thread intersects the middle scale.

Source: *Environments in Profile: an aquatic perspective*, W. Kaill and J. Frey, Canfield Press, 1973

Bottom Sampling

How are materials on lake and river bottoms sampled?

In order to obtain a rough analysis of the bottom material in a body of water, a variety of devices have been invented. Among them are grab samplers, dredges, corers, and drills. The PONAR Grab sampler is the main bottom sampling device used on the vessels to study the composition of the bottom of a lake or river. A Phleger Corer is sometimes used on advanced cruises where the stratification of the sediment layers is studied (see Appendix B).

Dredges and grab samplers make it possible to obtain samples of material found on the bottom of a body of water (ocean, lake, or river). Dredges are weighted equipment that are dragged over the bottom to scrape off samples of the surface material. This technique is satisfactory for obtaining bulk materials. Because dredges bounce and skip as they are dragged across the bottom, samples collected do not provide a well-defined or quantitative sample. The dredge is used when a bulk sample of material lying on the bottom is desired.

The grab sampler provides a means to obtain a somewhat quantitative and undisturbed sample of the bottom material. It takes a bite of known surface area and penetration depth, providing the bottom material is neither too hard or too soft. It is called a grab sampler because of the manner in which it obtains samples.

What is a PONAR Grab Sampler?

Early studies on Lake Michigan used oceanographic and freshwater grab samplers that were not always satisfactory for the lake conditions. Research scientists from the Great Lakes Research Division of the University of Michigan devised a new sampler, the PONAR grab sampler, that was first available for sale in 1966. The sampler is named after Great Lakes scientists, Charles E. **P**owers, Robert A. **O**gle, Jr., Vincent E. **N**oble, John C. **A**yers, and Andrew **R**obertson.

The PONAR grab sampler consists of two opposing semi-circular jaws that are normally held open by a trigger mechanism. The sampler is lowered to the bottom where contact with the bottom sets off the trigger and a strong spring snaps the jaws shut trapping a sample of the bottom inside. Fine copper screen covers the top of the jaws so that the trapped material will not wash out as the sampler is retrieved.

The deckhand normally places the PONAR grab sampler on deck at the start of the cruise. It is placed in an out of the way location until a sample of the bottom material is desired. Samples are taken while the vessel is on station and not moving through the water.

When a sample is to be taken, the PONAR grab sampler is taken to the hero platform where the deckhand attaches it to the hydrographic wire (winch line). The sampler is "cocked", that is, the jaws are opened and the trigger is set. The sampler is then swung over the side and lowered to the bottom. The jaws snap shut upon reaching the bottom and a sample of material is obtained.

As long as the PONAR sampler is hanging freely from the hydrographic wire, the trigger mechanism will keep the jaws open. However, as soon as there is slack in the winch line, the trigger will be released. When the winch starts to raise the PONAR grab sampler, the jaws will close thus taking a "bite" (sample) from the bottom of the lake. Sometimes when lake waters are rough, the rocking action of the vessel may cause the winch line to become slack enough to release the trigger prematurely thus allowing the jaws to close before the sampler has reached the bottom. In such instances the PONAR grab sampler must be brought back aboard the vessel to reset the trigger and a second sampling attempt is carried out.

When a successful PONAR grab sample is brought aboard, the sampler is lowered into a rectangular stainless steel box that has a very fine screen on the bottom side. The deckhand will empty the contents of the PONAR grab sampler into the stainless box and rinse the grab sampler with a hose to make sure that all of the sample is rinsed into the stainless steel box. The bottom sample is now ready for examination.

NOTE: The PONAR grab sampler is a piece of equipment that is operated by the deckhand. It is very heavy. Please stay out of the way when it is being used.

How is bottom material studied?

The material brought up from the bottom can be examined in several ways. A quick visual inspection can give a qualitative description of the kind of material retrieved: sand, silt, clay, mud, decayed organic, or a combination. In many cases, the sample will reveal the presence of small animals. These can be found by washing the fine sediments through the fine mesh screen and leaving the organisms on the screen where they can be picked from the screen and placed in a plastic Petri dish. When all of the organisms have been collected in the Petri dish the dish can be taken into the main cabin and examined under the stereo microscope. With the video camera attached the entire group will be able to see these bottom (benthic) organisms on the color monitor. Students may be able to identify some of the organisms by checking the laminated diagrams of typical benthic organisms that are on display in and around the microscope area.

The composition of bottom sediment can also be studied by separating the samples through the use of a graded series of fine-mesh brass sieves. The sediment particles sort out by size:

Sediment Class	**Diameter (mm)**
Sand	2.00 to 0.05
Very coarse	2.00 to 1.00
Medium	1.00 to 0.10
Very fine	0.10 to 0.05
Silt	0.05 to 0.002
Very coarse	0.05 to 0.02
Medium	0.02 to0 0.01
Very fine	0.01 to 0.002
Clay	<0.002

Sediment that is sand will have distinct grains that are easily seen and felt. Silt will form a cast when moist but will not form a ribbon when moist. Clay is sticky and plastic when wet and forms a ribbon when squeezed. Some sediment samples may have high concentrations of organic matter (muck) indicating slow decomposition rates and low oxygen conditions. Sediments contain minerals (e.g., iron, calcium), which over time, are transformed to limestone, shale, and sandstone.

What organisms are found in the bottom material?

Samples taken from Spring Lake or Muskegon Lake provide the possibility of observing anaerobic decay. This is especially true in August when biological oxygen demand depletes oxygen in the water above the bottom. If anaerobic decay is present, the odor of hydrogen sulfide (hard boiled or rotten egg odor) can be detected. The material from the bottom of these two lakes seldom has a great diversity of easily detected life forms.

Chironomid (midge fly) larvae are sometimes found. They can be identified by their blood red color leading to the common name "bloodworms." The presence of a hemoglobin-like compound, erythrocruorin, in their “blood” causes the red color in these organisms. The erythrocruorin enables them to withstand lower oxygen levels as the chemical has a high affinity for whatever oxygen is present. Bloodworms (midges) live head down in tubes on soft bottoms where they feed on bottom organic matter. They have a complex life cycle (Figure 14). Adult midges resemble adult mosquitoes in general appearance and size. However, they have more feathery antenna, generally do not have biting mouth parts, and do not have wing scales. Midge larvae are very important in aquatic ecosystems in that they are consumed by fish.

Lake Michigan provides many possibilities for bottom material study. Near shore, the material is basically sandy. Oligochaetes (segmented worms related to earthworms), fingernail clams, and scuds (small shrimp-like arthropods) are found there. Some samples will have zebra and quagga mussels. Farther out from the shore, the sand is mixed with silt and/or clay. At greater depths, the sediments are a mixture of clay and fine-grained sediment. The profile of the bottom sediment in Lake Michigan (Figure 15) illustrates this point. Lake Michigan experiences recurrent episodes of massive sediment resuspension and transport caused by storm-induced waves and currents. This brings nutrients and contaminants back into the water column.

Samples taken from the bottom of other bodies of water may show a greater species diversity. In a river where a strong current is present, the bottom material will most likely be sandy or rocky. In still water, silt is commonly found. Shells are usually found in these samples. Streams can harbor many benthic macroinvertebrates including a great variety of immature insects, sponges, flatworms, roundworms, annelids, and mollusks (see Appendix D for drawings.)

Sediments also contain minerals which, over time, are transformed to limestone, shale, and sandstone. Sediments are an important source of nutrients that are released when organic matter decays. When too much organic matter decays, excess oxygen is consumed and eutrophication is stimulated.

Figure 14: Midge Life Cycle

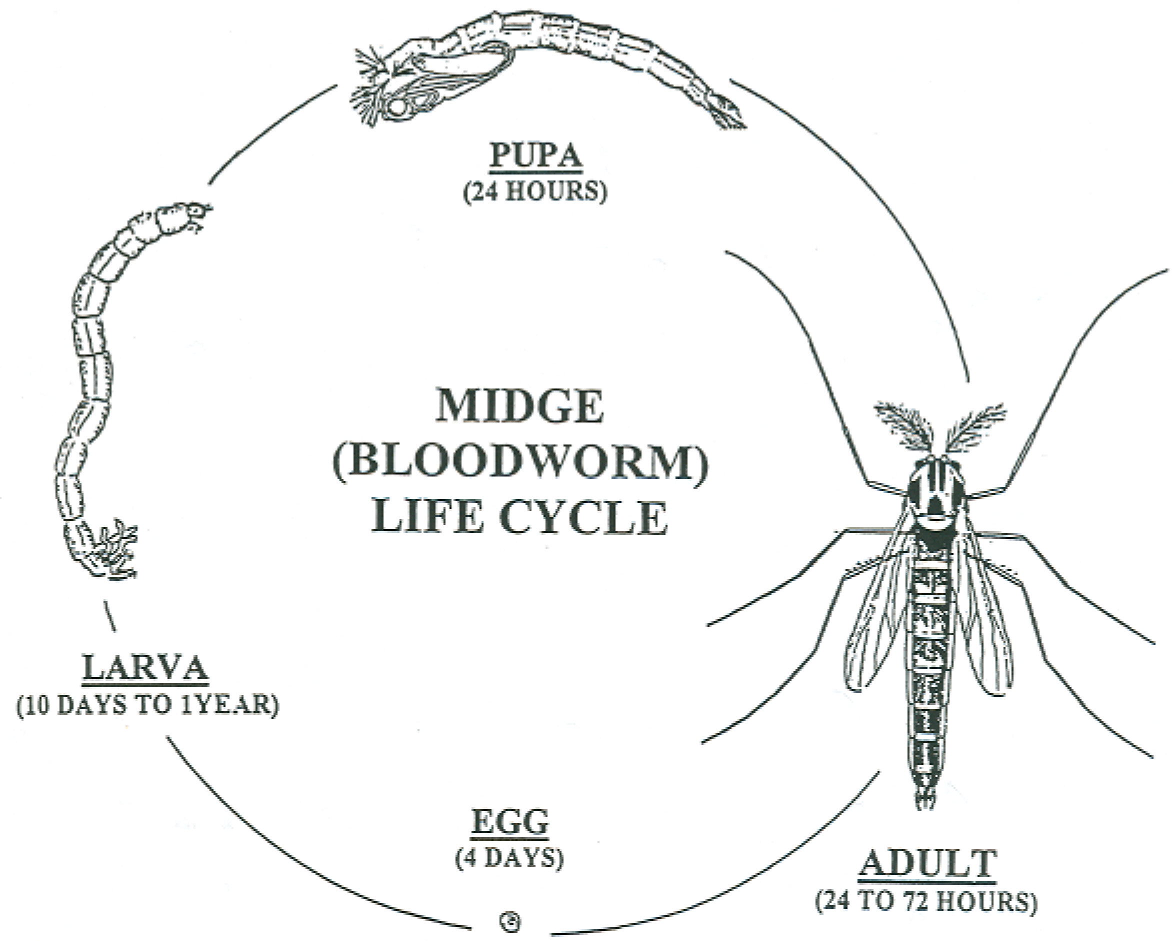
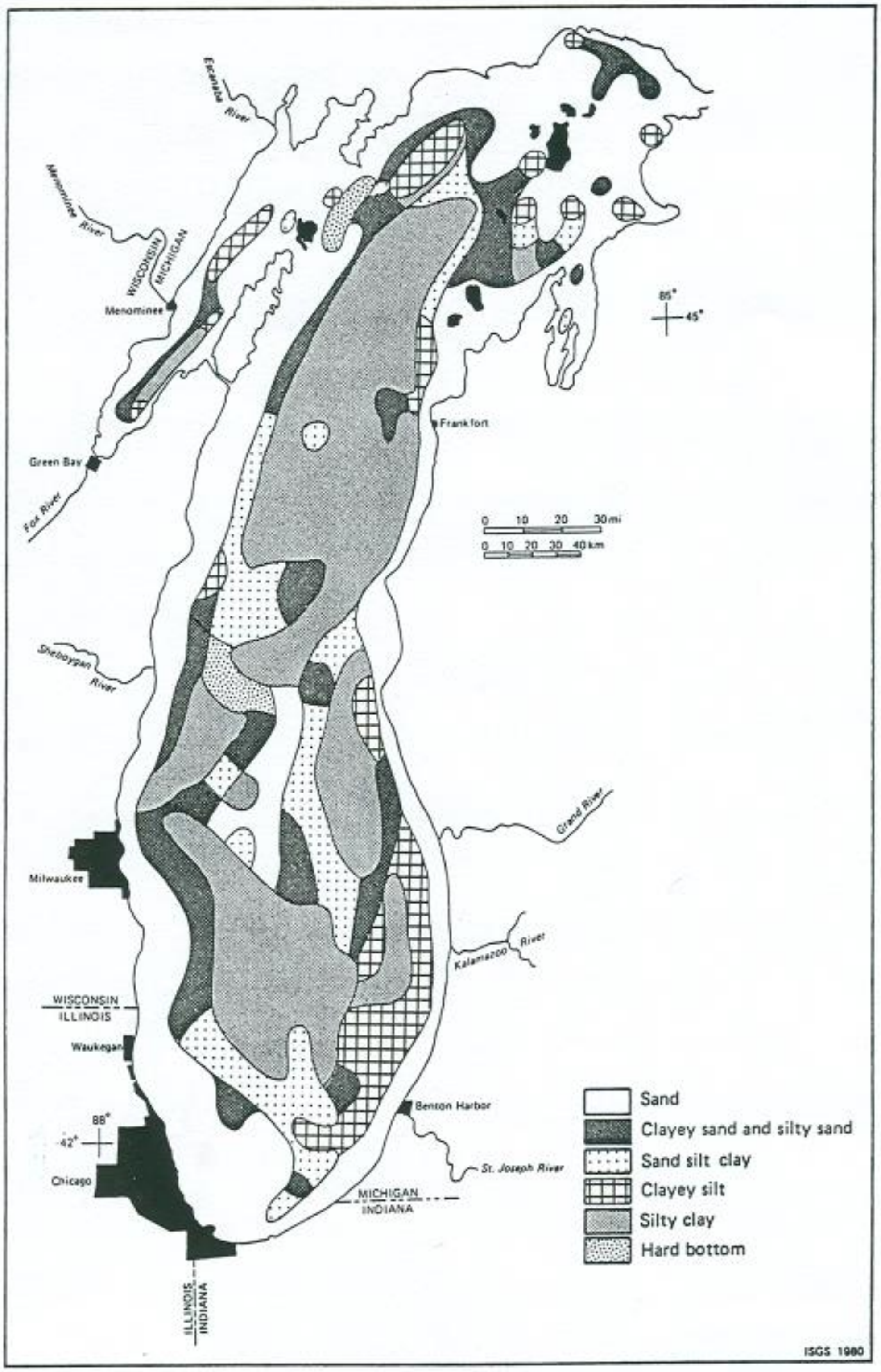


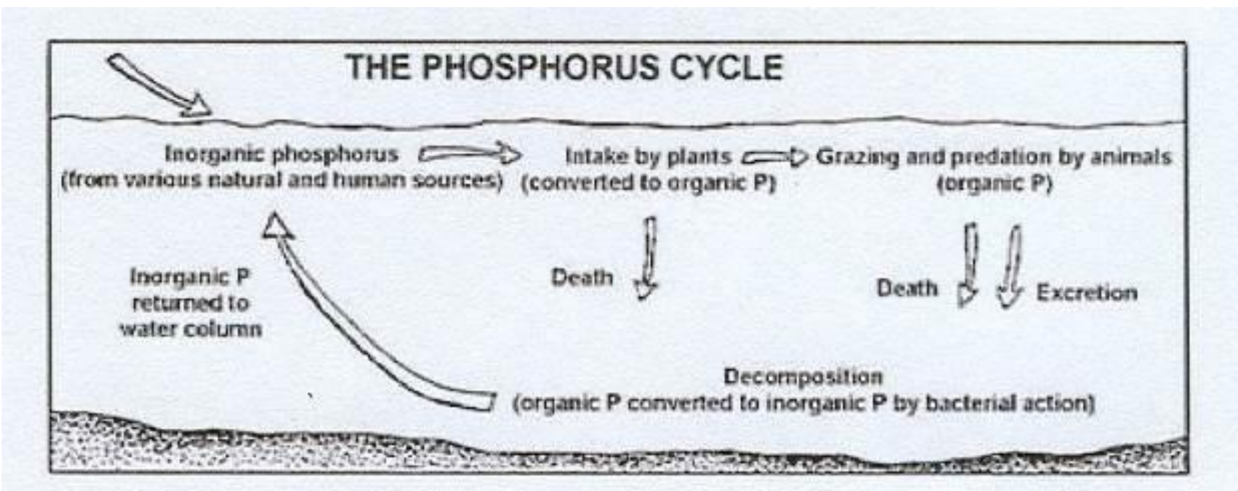
Figure 15: Lake Michigan Sediment



What is the connection between sediments and nutrients?

Sediments are an important source of nutrients that are accumulated when they are released from the decay of organic matter. Decay of organic matter consumes oxygen, which can accelerate eutrophication. The "quality" of a lake is shaped by many factors such as its origin and morphology, shoreline development, historical contamination, amount of recreational use it receives, and its overall water quality. According to the Michigan Department of Environment, Great Lakes, and Energy (EGLE), problems most commonly reported by lake residents are excessive plant growth, algal blooms, and mucky bottom sediments. These can be caused by water quality factors often linked to inadequate management of a lake, which lead to increased lake fertility or productivity. Increased nutrient (nitrogen and phosphorus) loading leads to degraded water quality and ecosystem health. This loading can be from external (runoff, leaching) and internal sources (sediments) as noted in Figure 16.

Figure 16: Phosphorus Cycle



Source: U.S. Environmental Protection Agency

The stratification of lakes often leads to reduced dissolved oxygen (DO) in the hypolimnion of lakes because aquatic organisms continue to respire (consuming DO in the process) but very little new DO from the atmosphere is able to penetrate the thermocline and reach the hypolimnion. One of the consequences of depleted DO layers is the bottom lake sediments often go anaerobic. Under oxygenated conditions, the phosphorus in the sediments is often bound to iron. However, when the sediments become anaerobic, the iron becomes reduced (changing from Fe^{3+} [ferric iron] to Fe^{2+} [ferrous iron]), and releasing the bound phosphorus (P) in the process. The free phosphorus molecules are then able to diffuse from the sediments, often resulting in very high P concentrations in the hypolimnion. Once the lake turns over, either in the fall as temperature gradients disappear or during the summer during large storm events, this P enters the upper layers of the lake, where the phytoplankton reside, and can trigger algal blooms. This process of P leaving the sediments and entering the water column is referred to as internal phosphorus loading.

Plankton Sampling

What are plankton?

Plankton, a word loosely meaning, "to drift", are distributed throughout the lake. They are found at all depths and are comprised of both plant (phytoplankton) and animal (zooplankton) forms. Plankton show a distribution pattern that can be associated with the time of day and seasons.

There are three fundamental sizes of plankton: nannoplankton, microplankton, and macroplankton. The smallest are nannoplankton that range in size from 5 to 60 microns (millionths of a meter). Because of their small size, nannoplankton will pass through the pores of a standard sampling net. Special fine mesh nets can be used to capture larger nannoplankton.

Most planktonic organisms fall into the microplankton or net plankton category. The sizes range from the largest nannoplankton to about 2 mm (thousandths of a meter). Nets of various sizes and shapes are used to collect microplankton. The nets collect the organisms by filtering water through fine meshed cloth. The plankton nets on the vessels are used to collect microplankton.

The third group of plankton, as associated with size, are called macroplankton. They are visible to the unaided eye. The largest can be several meters long.

How are plankton sampled?

The plankton net or sampler is a device that makes it possible to collect both phytoplankton and zooplankton samples. For quantitative comparisons of different samples, some nets have a flow meter used to determine the amount of water passing through the collecting net.

The plankton net or sampler provides a means of obtaining samples of plankton from various depths so that distribution patterns can be studied. Quantitative determinations can be made by considering the depth of the water column that is sampled. The net can be towed to sample plankton at a single depth (horizontal tow) or lowered down into the water to sample the water column (vertical tow). Another possibility is oblique tows where the net is lowered to a predetermined depth and raised at a constant rate as the vessel moves forward.

What is commonly found in plankton samples?

The base of the food chain for Lake Michigan is plankton. The phytoplankton are the producers and they are typically green algae, cyanobacteria (previously known as blue green algae), and diatoms. Cyanobacteria, such as *Microcystis*, prefer warm water and high nutrients. Some cyanobacteria can fix nitrogen and produce toxins. There are times when Spring Lake and Muskegon Lake experience algal blooms. During these episodes, the lakes turn green as if green paint had been spilled. Crustaceans such as water fleas (*Daphnia*), cyclops, and copepods are representatives of the consumers or zooplankton found in samples. Examples of species collected in plankton tows can be found in the plankton data sheet and the drawings in Appendix B.

Data Analysis

What data from the vessels are available?

On a majority of the trips of the *D.J. Angus* and the *W.G. Jackson*, a data sheet is prepared listing information about all the parameters that were measured. At the end of a season, these data are entered into an Excel spreadsheet. Information is available on the sampling date, location, latitude, longitude, and depth at each sampling site. Both top and bottom measurements are available for turbidity, conductivity, temperature, pH, and dissolved oxygen. Secchi disk readings, Forel-Ule color scale numbers, listing of benthic organisms, relative plankton density, and sediment types are also in the data set. Alkalinity and nitrate measurements are listed when they have been taken.

Where are the data found?

The Annis Water Resources Institute maintains databases of student generated data that go back to 1986 for the D. J. Angus and to 1996 for the W. G. Jackson. There is an online version of data for downloading that can be found on the Water Data page found at AWRI's website (http://www.gvsu.edu/wri/education). These data are for educational use only. AWRI has other data sets for research purposes. Requests for data can be made by contacting AWRI at (616) 331-3749 or (231) 728-3601.

Through a Great Lakes Restoration Initiative grant, AWRI has installed and operates a buoy in Muskegon Lake that provides an online data set (http://www.gvsu.edu/wri/buoy/). A variety of parameters at different depths are tracked as well as weather conditions.

What can be done with the data?

Data analysis is a logical extension of the vessel experience. For instance, a statistics student analyzed a year of data for several locations and determined trends. Classes have used the data for hypothesis testing and to understand how water quality parameters vary by location and season. A variety of statistical measures, charts, and graphs can be generated using the data.

GVSU Research Vessels Data Sheet – 2 Depths

GVSU AWRI RESEARCH VESSELS DATA SHEET

D.J.ANGUS Date: ____________ School: ______________________ Teacher: ____________________

Grade: ________ AWRI Instructor(s): ____________________ Trip Length: ____________ [College Course # ______]

Clarity		Turbidity (NTU)	Conduct. (μS/cm)	pH (units)	Temp. (°C)	D.O. (mg/L)	% Sat (%)	Alkalinity (mg/L)	Nitrates (mg/L)	Biotics	Sediment
Secchi (m)	TOP									Blood Worms	Sand
Turb. Tube (cm)										Zebra Mussels	Sand & Organics
Color Forel-Ule	BOTTOM									Quaggas	Organics
Plankton Density										Others	

Station 1: Sky Conditions: **C** [< 1/10] **SC** [1/10-5/10] **BC** [5/10-9/10] **OC** [> 9/10] **FOG PREC.** Wind Speed & Direction: __________ GLOBE YES NO

Latitude: ______________**N** Longitude: ______________**W** Wave Height: _________ft. Time: ____________am pm Oligotrophic

Lake: ________________ Area: ____________________ Water Depth: _________ft. Air Temp. ________°C Mesotrophic Eutrophic

Clarity		Turbidity (NTU)	Conduct. (μS/cm)	pH (units)	Temp. (°C)	D.O. (mg/L)	% Sat (%)	Alkalinity (mg/L)	Nitrates (mg/L)	Biotics	Sediment
Secchi (m)	TOP									Blood Worms	Sand
Turb. Tube (cm)										Zebra Mussels	Sand & Organics
Color Forel-Ule	BOTTOM									Quaggas	Organics
Plankton Density										Others	

Station 2: Sky Conditions: **C** [< 1/10] **SC** [1/10-5/10] **BC** [5/10-9/10] **OC** [> 9/10] **FOG PREC.** Wind Speed & Direction: __________ GLOBE YES NO

Latitude: ______________**N** Longitude: ______________**W** Wave Height: _________ft. Time: ____________am pm Oligotrophic

Lake: ________________ Area: ____________________ Water Depth: _________ft. Air Temp. ________°C Mesotrophic Eutrophic

GVSU Research Vessels Data Sheet – 3 Depths

GVSU AWRI RESEARCH VESSELS DATA SHEET

DJA **WGJ** Date ____________ School ________________________ Teacher ____________________

AWRI Instructor(s) ________________________ Trip Length ____________ College Course ____________

Clarity		Turbidity (NTU)	Conduct. (μS/cm)	pH (units)	Temp. (°C)	D.O. (mg/L)	% Sat (%)	Alkalinity (mg/L)	Nitrates (mg/L)	Phosphorus (mg/L)	
Secchi (M)	TOP										
Color Forel-Ule	MID										
	BOT										

Station ____ Sky Conditions **C** [< 1/10] **SC** [1/10-5/10] **BC** [5/10-9/10] **OC** [> 9/10] **FOG** **PREC.** Wind Speed & Direction: ____________

Latitude: ____________ **N** Longitude: ____________ **W** Wave Height: ________ ft. Time: ____________ am pm

Lake: ____________ Area: ____________ Water Depth: ________ ft. Air Temp. ________ °C

Clarity		Turbidity (NTU)	Conduct. (μS/cm)	pH (units)	Temp. (°C)	D.O. (mg/L)	% Sat (%)	Alkalinity (mg/L)	Nitrates (mg/L)	Phosphorus (mg/L)	
Secchi (M)	TOP										
Color Forel-Ule	MID										
	BOT										

Station ____ Sky Conditions **C** [< 1/10] **SC** [1/10-5/10] **BC** [5/10-9/10] **OC** [> 9/10] **FOG** **PREC.** Wind Speed & Direction: ____________

Latitude: ____________ **N** Longitude: ____________ **W** Wave Height: ________ ft. Time: ____________ am pm

Lake: ____________ Area: ____________ Water Depth: ________ ft. Air Temp. ________ °C

GVSU Research Vessels Benthos & Sediment Data Sheet

(For Advanced Trips)

Date:____________________Time:__________________ Group:____

Latitude:____________________________N Longitude:______________________________W

Lake:____________________ Area:___________________________________Water Depth:_____________ft

Temperature of Sample:_______________ Color of sample:___________________

Odor: None Sulfur (rotten eggs) Petroleum Decaying Materials

Size Range of Particles: Pebbles Sand Silt Mud/Clay Other

Sorting: Excellent Good Poor

Sample Water: Muddy Clear

Volume of PONAR Sample: Full 75% 50% 25% <25%

Major Constituents of Sediment:

Mineral	Description
_____ Quartz	Clear, glassy grains, transparent
_____ Feldspar	Light colored, opaque
_____ Magnetite	Black, shiny, metallic, rounded; magnetic; opaque
_____ Silts/Clays	Fine, light colored or olive-green; shapeless
_____Quartz grains with iron coatings:	Large size, orange or yellow coated
_____ Other mineral grains	

Organic Materials in the Sediment

_____ Black mud, ooze, fine grained organic materials
_____ Shell fragments from various mollusks, as clam, snail, mussel
_____ Plant fragments (leaves, stems, wood chunks)
_____ Coal or Clinkers
_____ Gas Bubbles

Benthic Organisms	Number
_____ Scuds (side swimmers)	______
_____ Zebra mussels	______
_____ Midge larva	______
_____ Phantom midge larva	______
_____ Tubifex worms	______
_____ Fingernail clams	______
_____ Snails (high spiral)	______
_____ Snails (low spiral)	______
_____ Native mussels	______
______ Shrimp (*Mysis*)	______

GVSU Research Vessels Plankton Data Sheet (advanced trips)

GVSU Research Vessel: D.J. Angus – W.G. Jackson **Plankton Data Sheet**

Date:__________ Group:____________________________

Station 1: Lake:________ Area:____________ Time:____ Lat.________ Long.________

Station 2: Lake:________ Area:____________ Time:____ Lat.________ Long.________

PHYTOPLANKTON

(Plant drifters)

GREEN ALGAE

(Chlorophyta)

	1	2	
1.			Actinastrum sp.
2.			Pediastrum sp.
3.			Scenedesmus sp.
4.			Spirogyra sp.
5.			
6.			

Others: **(Desmids)**

	1	2	
7.			Closterium sp.
8.			Staurastrum sp.
9.			

DIATOMS

(Chrysophyta)

	1	2	
1.			Asterionella sp.
2.			Fragilaria sp.
3.			Melosira sp.
4.			Synedra sp.
5.			Tabellaria sp.
6.			
7.			

Other Chrysophytes:

	1	2	
8.			Dinobryon sp.

BLUE-GREEN ALGAE

(Cyanobacteria)

	1	2	
1.			Anabaena sp.
2.			Aphanizomenon sp.
3.			Microcystis sp.
4.			Oscillatoria sp.
5.			Spirulina sp.
6.			
7.			

PYRRHOPHYTA

	1	2	
1.			Ceratium sp.

ZOOPLANKTON

(Animal drifters)

ROTIFERS

	1	2	
1.			Asplanchna
2.			Conochilus
3.			Euchlanis
4.			Kellicottia
5.			Keratella
6.			Polyarthra
7.			Synchaeta
8.			

PROTOZOANS

	1	2	
1.			Stentor
2.			Vorticella
3.			Carchesium
4.			
5.			

BENTHOS

(And others)

LARVAE

	1	2	
1.			Biting Midge (Bezzia sp.)
2.			Blood Worms (Chiornomus sp.)
3.			Phantom Midge (Chaoborus sp.)

Worms

	1	2	
1.			Tubifex (Tubifex tubifex)

EXOTICS

	1	2	
1.			Adult Zebra Mussels
2.			Asiatic Clam (Corbicula sp.)
3.			Fishhook Water Flea (Cercopagis sp.)
4.			Quagga Mussels
5.			Spiny Water Flea (Bythotrephes sp.)
6.			Veligers (Immature Zebras)

Reference: Algae of Western Great Lakes
G. W. Prescott, 1982 reprint
Freshwater Algae of N.A. Wehr & Sheath, 2003

(Zooplankton and Benthos continued)

ARTHROPODA

(Class: Crustacea)

COPEPODS

(Subclass: Cephalothorax and abdomen = 2 parts)

	1	2	
1.			Cyclops sp.
2.			Diaptomus sp.
3.			

CLADOCERANS

(Order: Body not segmented) (1 part)

	1	2	
1.			Bosmina sp
2.			Daphnia sp.
3.			Leptodora sp.
4.			Polyphemus sp.

MALACOSTRACANS

(Subclass: Multi-segmented thorax and abdomen)

	1	2	
1.			Gammarus (Scuds)
2.			
3.			
4.			

MOLLUSCA

(Phylum)

GASTROPODS

(Class: Snails) (One shell)

	1	2	
1.			Pointed Winkle (Campeloma sp.)
2.			River Snail (Goniobasis sp.)
3.			Hairy Wheel (Gyraulus sp.)
4.			Orb Snail (Helisoma sp.)
5.			River Snail (Pleurocera sp.)
6.			Valvata ap.

PELECYPODS

(Class: Clams) (Two shells)

	1	2	
1.			Cyclonaias
2.			Fingernail Clam (Sphaerium sp.)

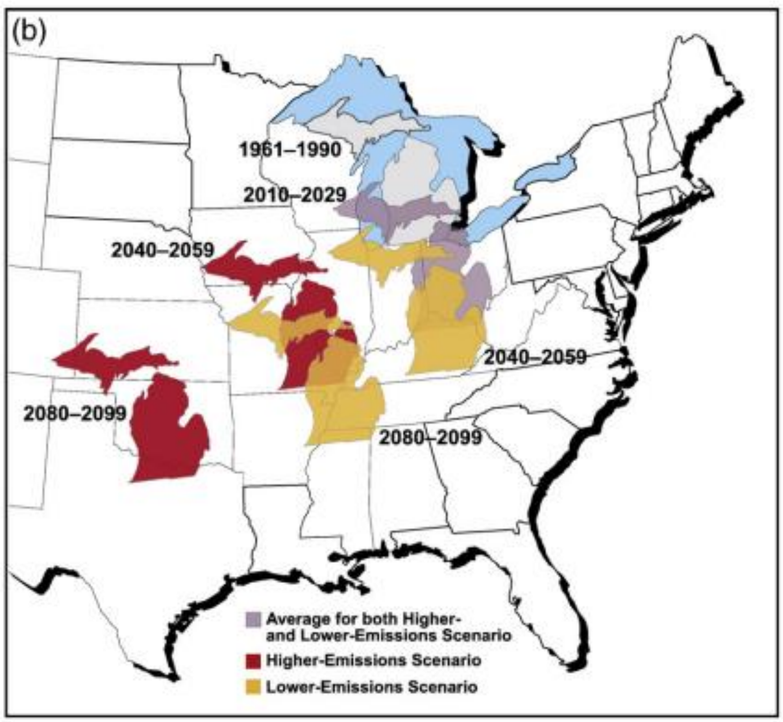
Reference: Fresh-Water Biology
Ward & Whipple, 1966, 4th printing.

Climate Change Impacts

The Great Lakes are influenced by larger climate change patterns affecting North America and the world (Great Lakes Literacy Principle 3). Climate patterns in the Great Lakes are changing, with warmer conditions predicted. Global climate change caused by greenhouse gas emissions (such as carbon dioxide and methane) is well established by scientific study. Scientists expect that these atmospheric changes will result in increases in global air and water temperatures, extreme weather events and increased climate variability, and biotic changes.

In the West Michigan region, increased variability in precipitation and changes in frequency and intensity of storms and floods are anticipated. We have already begun to observe some of these changes. Increased temperatures could cause Michigan to experience a climate more like Oklahoma by 2100 if carbon emissions remain unconstrained (Figure 18). A wetter climate is predicted, except during the summer where drier conditions are anticipated. These global and regional changes influence lakes in many ways. Freshwater aquatic ecosystems are complex assemblages of species that have evolved over many thousands of years, and are particularly vulnerable to rapid changes due to climate change.

Figure 17: Potential Changes to Michigan's Climate Due to Anthropogenic Climate Change



Source: Katharine Hayhoe, Jeff VanDorn, Thomas Croley, Nicole Schlegal, Donald Wuebbles. Regional climate change projections for Chicago and the US Great Lakes. Journal of Great Lakes Research. Volume 36, Supplement 2, 2010, Pages 7-21, ISSN 0380-1330, https://doi.org/10.1016/j.jglr.2010.03.012.

Many of the parameters that we observe and test for on AWRI cruises will be impacted in different ways by climate change. The table below provides examples of possible impacts. Climate change also causes decreased predictability and increased uncertainty in how systems will respond to change. This table is provided as a starting point for conversation about how the observations made on a vessel cruise may change over time in response to the pressures of climate change.

Many of the most severe impacts of climate change can be mitigated if our society takes action now to reduce carbon emissions. There are also many ways that each of us can reduce our own carbon footprint in our own lives. We can also reduce the vulnerability of aquatic ecosystems to climate change by minimizing other pressures, such as reducing habitat destruction and restoring habitats, preventing the spread of invasive species, and sound stormwater management.

Figure 18: Potential Climate Change Impacts to AWRI Vessel Cruise Observations

Parameter / Observation	**Possible climate change impact**	**Reason**	**Ecosystem impacts**
pH	Decrease	Increased CO2 in atmosphere is absorbed by water bodies and causes increased acidification	Species which prefer more basic waters will be constrained on their habitat
Conductivity	Increase	Warmer water causes higher conductivity Increased risk of pollutants entering water bodies during large precipitation events	Increased conductivity can indicate a new source of pollution Increasing salinity in freshwater has been a growing concern
Turbidity	Increase	Larger rainfall events can cause increased sediment loading Declining lake and wetland levels may increase re-suspension of bottom sediments	Species which prefer clearer waters will be constrained on their habitat Decreased aquatic plant growth due to decreased light penetration
Microscope observation of plankton	Variable changes	Changes in water quality parameters cause life cycle changes to fish, algal, and zooplankton. Growth rates should increase, but not at the same rate for each species.	Changes to food web Increased algal blooms, including harmful algal blooms
Water temperature	Increase	Increased air temperature means increasing water temperatures and changed lake dynamics	Plant and animal species responses will differ in response to changes in water temperature Increased algal blooms, including harmful algal blooms
Dissolved Oxygen	Decrease	Warmer water holds less dissolved oxygen Lake bottom water oxygen will be especially impacted during stratified periods	Alteration in the distribution of many fish species: cold and cool-water species will decline in regions on the southerly edge of their range, and warm-water species will expand northward. Coldwater fisheries in the region may be altered. Changing distribution of fish species may make ecosystems more vulnerable to invasive species. The duration of summer stratification will increase, adding to the risk of oxygen depletion over greater areas and for longer periods of time. Algal blooms can cause hypoxic (very low oxygen) conditions and fish kills.
Alkalinity	Increase	Increased CO2 in atmosphere is absorbed by water bodies and can cause greater solubility of alkalinity sources	Increased buffering capacity could provide greater protection from acid rain

Parameter / Observation	Possible climate change impact	Reason	Ecosystem impacts
Nitrate and Phosphorus	Increase	Larger rainfall events can cause increased nutrient loading due to increased runoff and sewer discharge	Increased algal blooms, including harmful algal blooms
Secchi disk	Decrease	Increased sediment loading and plankton density will mean more shallow Secchi depths	Species which prefer clearer waters will be constrained on their habitat
Forel-Ule Color Scale	Variable changes	Increased plankton density may result in greener colors Increased presence of filter feeding invasive species (e.g. mussels) have decreased the plankton density over time, resulting in bluer colors	
Plankton Density	Increase	Algal growth may increase due to several factors, including shorter periods of winter ice cover, declining lake levels, and increasing water temperature	Increased algal blooms, including harmful algal blooms
Benthic organisms	Variable changes	Life cycle changes to benthic organisms. Species will differ in how they respond to the water quality changes caused by climate change.	New invasive species introductions may become more likely as temperatures warm in areas where cold temperatures may have previously limited their range New combinations of native and nonnative species will be interacting, with unknown implications for the food web
Temperature Profile	Variable changes	Stratification dynamics in lakes will change in response	The duration of summer stratification will increase, adding to the risk of oxygen depletion over greater areas and for longer periods of time.

Sources consulted:
North American Lake Management Society, Climate Change Impacts on Lakes position statement. Adopted 2004, amended 2015. *https://www.nalms.org/nalms-position-papers/climate-change-impacts-on-lakes/*

Great Lakes Integrated Sciences and Assessments: Summary Climate Information https://glisa.umich.edu/summary-climate-information/, and Climate Impacts https://glisa.umich.edu/resources-tools/climate-impacts/

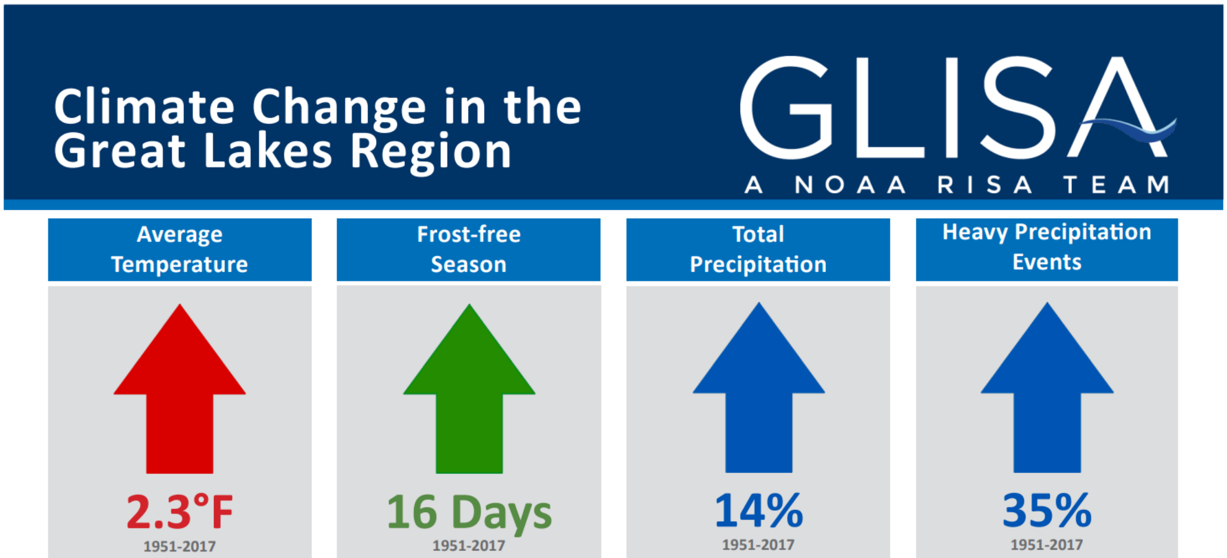
https://glisa.umich.edu/great-lakes-regional-climate-change-maps/

Fourth National Climate Assessment, Chapter 21: Midwest. https://nca2018.globalchange.gov/chapter/21/

https://www.freep.com/in-depth/news/local/michigan/2019/09/16/climate-change-transforming-great-lakes-fish-habitats/2223549001/

https://www.ipcc.ch/report/ar6/wg2/

Figure 19: Climate Change in the Great Lakes Region



Source: Climate Change in the Great Lakes Region Fact Sheet: https://glisa.umich.edu/wp-content/uploads/2021/04/GLISA-2-Pager.pdf

AWRI Research Highlights

AWRI researchers are conducting many studies on inland waters and the Great Lakes. The following are some examples of recent projects.

Testing for the COVID-19 Virus in Wastewater

Wastewater testing can serve as a reliable method to screen for COVID-19 infections in populations or facilities, as individuals will excrete the virus up to a week before symptoms are expressed. This type of testing can provide important data on the community spread of the pandemic and the emergence of variants. AWRI has been involved in a multi-year project with Muskegon and Ottawa Counties to monitor the SARSCoV-2 virus in wastewater, obtaining a significant grant from the Michigan Department of Health and Human Services (MDHHS) to collect and analyze weekly wastewater samples from Spring Lake, Grand Haven, Muskegon, Allendale, and the GVSU Campus. Droplet digital PCR (ddPCR) is used to measure viral RNA and track variants. Results are reported to local health departments and partners within 72 hours of collection. AWRI is part of a 23-lab network providing wastewater testing support to MDHHS in monitoring the COVID-19 pandemic in Michigan.

Tracking Lake Hypoxia in Muskegon Lake

The Muskegon Lake Observatory Buoy (www.gvsu.edu/buoy) monitors changes in water quality conditions throughout the water column. Since 2010, the buoy has provided high-resolution time-series weather and water quality data enabling detailed analyses of societally important issues, such as harmful algal blooms, hypoxia (oxygen depletion), and episodic and extreme weather events.

When summer temperatures heat up, lakes often stratify with warmer water near the surface and cooler water near the bottom. The onset of summer warms the surface waters that float over cooler and denser waters, creating “thermal stratification” or “layer effect” in temperate lakes. Consequently, atmospheric oxygen cannot penetrate to the bottom waters, resulting in low oxygen levels. While bottom water hypoxia is a natural, recurring phenomenon in Muskegon Lake, its severity depends on numerous environmental (e.g., air temperature, weather events) and anthropogenic (e.g., phosphorus loading, climate change) factors. The onset and expansion of hypoxia result in potentially serious ecological impairments. Further, episodic intrusions of oxygenated cold water from Lake Michigan can disrupt Muskegon Lake hypoxia, causing it to be highly dynamic in space and time.

We can now track the formation of this layering effect in Muskegon Lake and study its ecosystem consequences over intervals of hours to years using the power of time-series weather and water quality data from the Muskegon Lake Observatory. Analysis of the long-term, high frequency data reveals high variability between years, with a decreasing trend throughout the last decade. However, years in which stronger thermal stratification prevailed had more persistent and severe hypoxia – suggesting in a future world experiencing greater warming, we may see more severe hypoxia events. Studies, however, also revealed an encouraging trend of reduction in hypoxia duration in recent years.

Timeseries weather and water quality data from Muskegon Lake revealed that episodic storms may influence how long hypoxia lasts and where hypoxic waters move in the lake. High winds may cause nutrient-rich hypoxic bottom waters to mix with the surface, inducing algal blooms. Harmful algal blooms (HABs) are generally dominated by toxic, nuisance species of cyanobacteria (bluegreen algae) and are globally increasing in frequency, duration, and intensity. Increased nutrient inputs (mainly from agricultural and urban fertilizer use) and warmer temperatures stimulate HABs, which link them to anthropogenically-induced climate and land use change. HABs threaten humans and wildlife via their potential toxicity, impacts to the ecosystem and food web, and deterioration of water quality. Drinking water problems, beach closings, and fish kills are all possible outcomes of HABs, and it is important to understand what environmental factors contribute to their proliferation. Muskegon Lake, a Great Lakes Area of Concern since 1985, experiences annual HABs. With data collected from the Muskegon Lake Observatory Buoy, field sampling, and on site experiments, scientists can better understand HAB dynamics and help generate potential management and mitigation strategies.

Many desirable fish taken for sport or consumption require higher concentrations of dissolved oxygen to survive, and can be squeezed or driven elsewhere by this stratification. AWRI researchers sampled the bottom water fish community at the Muskegon Lake Buoy Observatory before, during, and after the hypoxic season. During hypoxia, there were fewer fish species, fewer total fish, and smaller fish as opposed to high dissolved oxygen periods in spring or fall. Hypoxia may act as a barrier that limits fish habitat in Muskegon Lake, affecting approximately a quarter of the lake volume during peak hypoxic periods. This would force fish to move to shallower, warmer waters where they may be at increased risk of predation or in suboptimal habitat for growth and reproduction.

Understanding Microplastic Impacts

Microplastics are found all throughout the world’s aquatic environments. Most research has been devoted to identifying how much and what types of plastics are in our waters, but a collaborative effort at AWRI is taking a different approach. Once microplastic enters an aquatic environment, a microbial biofilm forms on its surface. If these microplastics are ingested by other aquatic organisms, such as fish, this can potentially alter their natural gut microbial community, which can lead to negative health implications. AWRI research is exploring this topic to understand how microplastic pollution impacts aquatic wildlife in the Great Lakes. They are examining how ingestion of microplastics incubated in Muskegon Lake alter gut microbiomes of yellow perch, and assessing their impact on growth and other health parameters.

Another project is taking known quantities of three different plastics and incubating them in specially designed containers in two locations at two depths in Muskegon Lake. After incubating for either one month or three months, they are retrieved and examined for what types of chemicals and what organisms are attached to the small pieces of plastic. Because microplastics are easily ingested by larger organisms, there is concern that the chemicals may be toxic to aquatic life after they are consumed.

Figure 20: Close-up view of microplastic pellets and biofilm after 1 month in Muskegon Lake

Fish Monitoring in Muskegon Lake

AWRI initiated a study in 2003 to assess short and long-term trends in fish populations in Muskegon Lake. Each year fishes are sampled at three sites in shallow-water areas along the margins of the lake during spring, summer, and fall. The primary sampling sites in the lake are located near the mouth of the Muskegon River, across the lake from AWRI, and near Snug Harbor at the Muskegon State Park. The greatest benefits of this monitoring effort will likely be in future years when we will be able to quantify trends and repeatable patterns of fish populations in the lake.

Fish sampling is primarily accomplished at each site by "fishing" three fyke nets for one night. Fyke nets are what fisheries biologists refer to as passive sampling gear because fish must swim into fyke nets to be captured. Fyke nets have a series of mesh-covered, funnel-shaped throats that are directed inward from the mouth of the net, making escape difficult (though not impossible) once a fish enters the "trap." Each fish that is captured in a fyke net is identified, counted, and measured for length.

Figure 21: Installation of a fyke net

To date, the most abundant species in the catch have been the round goby (*Neogobius melanostomus*), pumpkinseed *(Lepomis gibbosus*), rock bass (*Ambloplites rupestris*), bluntnose minnow (*Pimephales notatus*), and juvenile largemouth bass (*Micropterus salmoides*). The high abundance of round gobies in the lake is somewhat troubling given that they were accidentally introduced into the Great Lakes from ballast water of ships in 1990 and are native to the Black and Caspian seas.

However, the representation of fish species caught in our nets does not perfectly correlate to the abundance of each species in the lake. This means to interpret catch data you must know the answer to this question: Is a species really abundant in the catch because it's really abundant in the lake or because the method used to sample it was highly effective? To begin to address this question, AWRI began sampling fish with another sampling technique (electrofishing) in spring 2004 to provide a better representation of the fish community inhabiting the margins of the lake and conducted a field study last summer to study factors that may affect the selectivity of the nets.

Boat electrofishing, a harmless technique, stuns fish long enough to catch them with a dip net. As with the fish collected using fyke nets, all individuals are released once they are identified, counted, and measured. Preliminary comparisons of the two methods suggests that fyke nets are well suited for sampling small fishes and boat electrofishing is more appropriate for sampling large fishes. Using both methods to sample fish should provide a better representation of fish populations in the lake than either method by itself.

Lake Sturgeon
Lake sturgeon (Acipenser fulvescens) are Michigan's largest native fish. Once abundant in Lake Michigan and its tributaries, the species was nearly extirpated in the late 1800s and is now considered threatened. They can grow up to 7 feet long, weigh 200 pounds, and live over 100 years.

A multi-year study by AWRI of the whereabouts of lake sturgeon found that adults use Muskegon Lake throughout the year and not just as a staging habitat during the spring spawning migration in the Muskegon River. This study builds on previous research by AWRI that showed Muskegon Lake is an important nursery habitat for juvenile lake sturgeon. Management strategies for invasive species occasionally conflict with native species conservation. The Muskegon River is periodically treated with a lampricide to control invasive sea lamprey. Unfortunately, the lampricide can be harmful to juvenile lake sturgeon. The Little River Band of Ottawa Indians worked with AWRI to hold juvenile lake sturgeon in AWRI's mesocosm tanks during a recent lampricide treatment of the Muskegon River. The juvenile lake sturgeon were released unharmed following the lampricide application.

Lake sturgeon also live and spawn in the Grand River.

Figure 22: Illustration of a Lake Sturgeon

Source: Michigan Department of Natural Resources

Internal Phosphorus Loading

Many lakes in west Michigan experience internal phosphorus loading, in which phosphorus is released from lake bottom sediments (as opposed to being introduced through runoff from outside sources). Phosphorus leads to unchecked algae and weed growth as accelerated eutrophication proceeds. Excess phosphorus can stimulate algal blooms, causing water quality impairments, restricting recreational activity, and negatively impacting economic vitality in the region.

Phosphorus loading is a big problem in Spring Lake, where studies have been conducted to determine how much phosphorus (P) actually leaves the sediments, and if there are ways to prevent the P from entering the water column. Sediment core tubes were collected from Spring Lake and placed in a growth chamber for measurement of internal P loading. Tubes extending above each core tube provide gas (oxygen for aerobic treatments; nitrogen for anaerobic treatments).

Using sediment cores taken from various locations in Spring Lake, and incubated in the lab under conditions with and without oxygen, AWRI scientists have determined that 1) internal P loading accounts for over half of the total P entering Spring Lake on an annual basis; and 2) applying a slurry of aluminum sulfate (alum) is very effective at limiting the amount of P entering the water column from the sediments. Based on these results, a whole-lake application of alum was conducted in Spring Lake in October 2005 to limit internal P loading. It is unclear how long the alum application will remain effective, but the Michigan Department of Environment, Great Lakes, and Energy (EGLE) is monitoring the results and AWRI will remain involved in measuring internal P loading in the lake.

In Muskegon Lake, recent samples from bottom waters reveal an upward trend in phosphorus concentration during summer months. This often is an indication that phosphorus is being released from lake sediment. If phosphorus concentrations exceed the restoration target for Muskegon Lake, this may prevent the Lake's de-listing as a Great Lakes Area of Concern, which is currently scheduled for some time in 2021. AWRI has measured phosphorus release from the sediments, and these data will help determine if control measures are needed to limit IPL in Muskegon Lake.

Figure 23: Sediment Core Tubes

Increasing Saltiness in Freshwater Lakes

Increased use of road salt as a deicer in winter has resulted in freshwater ecosystems becoming saltier. One such ecosystem is Church Lake in Grand Rapids, where salt accumulates due to runoff from the East Beltline Highway, resulting in high chloride concentrations. This prevents the lake from the normal turnover that occurs each spring and fall, trapping extremely high phosphorus concentrations at the lake bottom. An AWRI research study measured chloride and phosphorus concentrations in Church Lake water and sediments to create a roadmap for restoration management. Researchers also measured chloride retention in Church Lake tributary sediments and its impact on other nutrients and metals.

Closing Questions

The following questions may be used at the end of a cruise, or after the cruise to further process the experience and deepen student learning.

THEME: Comparing two aquatic systems – the similarities and differences

1. Of all the data that were collected, list the data that show the greatest similarities between the two aquatic systems. List the data that show the greatest differences between the two systems. After reviewing all these data, describe in your own words, why you think these aquatic systems are different?
2. Can you explain why two different aquatic systems share some similarities?
3. What is the trophic status (eutrophic, mesotrophic, oligotrophic) of the places you sampled?

CYCLES: Local hydrologic cycle

1. In which watershed do you live? What is the name of the nearest creek or stream to your home? What is the name of the largest stream or river in your watershed?
2. What kinds of industrial, agricultural, or other human activities occur in your area that might show up in the examination of water from your watershed as it is about to enter Lake Michigan?
3. When it rains or snows in your area, where does the water eventually go? What kinds of things are carried along in the water? Where does the water you drink come from and where does the wastewater go?
4. While you were on the vessel did you see any indications of water conditions that may have resulted from influences that entered the water long before you tested it?

CYCLES: Life cycles

1. Describe the life cycle of the zebra mussel and explain why exotics like this are very difficult to control.
2. Describe the life cycle of a midge (bloodworm). Explain how the bloodworm fits into the food chain.

GRAPHS OR CHARTS

1. Using the data collected on the vessel, plot the temperature at each sampling site. Compare the graphs and point out similarities and differences. Try to explain these similarities and differences.
2. Develop a chart that will allow you to show the types and relative abundance of benthic organisms that were collected from each sampling site.
3. Develop a chart that will allow you to show the type and relative abundance of planktonic organisms for each of the sampling sites.

FOOD CHAINS

1. Diagram the planktonic food chain for each of the sampling sites. How are they the same and how are they different?
2. Diagram a benthic food chain for each of the sampling sites. How are they the same and how are they different?
3. How have exotic species influenced food chains and food webs?

Questions for Students to Research

1. What are the five Great Lakes? Which has the greatest surface area? Which is the deepest? Which has the least surface area? Which is the shallowest? How deep is Lake Michigan?

2. How long is the Grand River or the Muskegon River? What percentage of the state of Michigan does the Grand River or the Muskegon River drain? Where does the river start? Where does it end?

3. What is the name of the watershed where your home is located? Where do you get the water for your house? Where does your wastewater go?

4. What size freighters come into the harbor? What size are the largest freighters on the Great Lakes? What modifications have been made to the harbor to accommodate the large freighters that enter this port? What do freighters deliver and what do they take out?

5. What environmental issues arise from the transportation of petroleum by water? What do we obtain from petroleum?

6. When a power plant burns coal, how is the coal soot prevented from escaping the smokestack? What does escape from the stack? Why is water taken by power plants from the river or lake? When water is returned to the river or lake, what precautions must be taken? What is made of recycled lime from power plants?

7. What are the various materials stored at the commercial docks along the water (black, gray, brown, orange, white, in the silos)? Why are some materials stored under a tarp? What are two possible properties of materials covered by the tarp? Which water quality parameter would change with leakage of this material to the lake or river?

8. Why are sand dunes so important? Why are they such fragile ecosystems? How were sand dunes formed? Why are they so pure (e.g., no gravel)? What do we make with sand? Why do we permit sand dunes to be mined? What advantages are there to sand dune mining? Disadvantages?

9. How has shoreline development such as marinas, hotels, condominiums, and houses impacted the aquatic ecosystem? What has been done in the area to promote tourism? How have these things impacted the area?

10. How large is Spring Lake or Muskegon Lake? Describe the bottom sediments from this lake. Why are these sediments like this? What organisms live in these sediments? How are they able to exist at such low oxygen levels?

11. Describe the bottom sediments from Lake Michigan. What organisms were found in these sediments? How does this differ from Spring Lake or Muskegon Lake?

12. What is biodiversity? What types of organisms live in the water of Lake Michigan? Spring Lake? Muskegon Lake? a river? What is the biodiversity of Lake Michigan as compared to the other bodies of water sampled?

13. What kinds of fish will you find in Lake Michigan? Why? What kinds of fish will you find in Spring Lake or Muskegon Lake? Why? How does dissolved oxygen relate to the fish?

14. What is the turbidity in NTUs for a vial of pure water? If you are given a vial of water from Lake Michigan, one from the Grand River, and one from Spring Lake, which will have the highest turbidity? Why? Which will have the lowest turbidity? Why?

15. What things will cause conductivity readings to be high? What range of conductivity should we expect in Lake Michigan? a river?

16. What is the plume line? What causes this line? How does the wind affect its size, shape, and sharpness?

17. Why are all of the pH readings taken in Lake Michigan above 7.0 (not acidic)? What happens to the acid rain that falls into Lake Michigan? Would the same be true in all of Michigan?

18. What is a thermocline? How do we find the depth of the thermocline? What causes the fall and spring turnovers of lakes?

19. What non-native species (both plant and animal) have entered the Great Lakes ecosystem? How did they arrive? From where did they come? What problems do they cause? Why do they cause such problems?

20. What is the Great Lakes Water Quality Agreement? What are Areas of Concern in the Great Lakes? What are PCBs? What is the Lake Michigan Lakewide Management Plan (LAMP)? What is the Lake Michigan Mass Balance Study?

21. How is climate change projected to influence water quality and food webs in the Great Lakes? How might we expect the data collected on vessel cruises to be impacted by climate change?

22. The following are basic questions frequently asked by the public about the Great Lakes that the U.S. Environmental Protection Agency and Environment Canada have identified in the annual State of the Great Lakes Report:
    - Can we swim, eat the fish that we catch, and drink the water?
    - Are the Lakes affecting human health?
    - Are the Lakes getting better?
    - Are the fish and birds healthy?
    - How are endangered species doing?
    - What are we doing about exotic (non-native) species?

Glossary

For maximum learning, cruise participants should be introduced to the following terms which are frequently used in this manual and aboard the vessel.

Acid	Any substance that can donate a hydrogen atom or proton (H^+) to any other substances. Examples are vinegar and hydrochloric acid. The acidic range of the pH scale are values less than 7.
Accuracy	The closeness of a measured value to a true value.
Aft Deck	Area in the back (stern) of the vessel as opposed to the area in the front of the vessel (bow).
Algae	Simple, photosynthetic aquatic plants that lack true roots, stems or leaves.
Algal blooms	Extensive growth of algae in a body of water often due to increased nutrients such as nitrates and phosphates from fertilizers.
Alkalinity	Alkalinity is a measure of the capacity of water to neutralize acids. This is known as the buffering capacity of water that is the ability of water to resist a change in pH when acid is added. Alkalinity in water is due primarily to the presence of bicarbonate, carbonate, and hydroxide ions.
Ambient Temperature	The current temperature of the surroundings. Ambient water temperatures may differ from the ambient air temperature.
Base	Any of various water-soluble compounds capable of reacting with an acid to form a salt and water. Bleach, baking soda, and ammonia are bases. A pH of more than 7 is considered basic.
Beaker	Container with a spout used to transport, pour, and/or mix liquids or solids.
Benthos	A term applied to organisms that live on or in a lake bottom and its sediment (benthic zone).
Bloodworms	Midge fly larvae found in the bottom of lakes. Their red color is due to a chemical like hemoglobin that is found in human blood.
Buffer	Standard solutions of a known value, such as pH 7 and pH 10, used to calibrate pH meters. Buffers resist changes in pH.
Buffering Capacity	The buffering capacity of water refers to the ability of the water to neutralize acids. Limestone (calcium carbonate) is a natural buffer that helps to maintain soil and water pH near neutral.

Calibration	Determination of the correct value of each setting on an instrument by comparison with a standard or known value.
Conductivity	The measure of a substance's ability (in our case, water) to carry electricity. Conductivity depends on the concentration of charged particles (ions) and temperature. It Is measured in microSiemens/cm (μS/cm) or micromhos/cm (μmho/cm). These are equivalent measurements.
Conductivity Meter	An instrument consisting of two electrodes (positive and negative) that measures the flow of electricity between them.
Consumers	Organisms that eat other organisms or plants for nutrition.
Cuvette	A special container (sample cell) used to hold a small volume of water for certain measuring instruments such as a turbidity meter.
Data	The information (numerical and observational) gained through research.
Deionized Water	Water that has had all of its charged particles (ions), other than hydrogen and hydroxide ions, removed.
Density	The ratio of the mass of a substance to its volume.
Depth Sounder	An instrument that sends and receives impulses indicating how deep the water is as well as the bottom contours.
Detritus	Dead and decomposing organic matter.
Diatoms	Single-celled microscopic plants with hard "shells" of silica.
Digital Titrator	An instrument used in the dissolved oxygen analysis that delivers a measured amount of chemical solution (titrant) to the water sample.
Dissolved Oxygen	Oxygen gas molecules dissolved in water that are available for living organisms to use. Abbreviated *DO*. Measured in parts per million (ppm) or milligrams per liter (mg/L). DO solubility varies with water temperature and pressure.
Ecosystem	A system of interrelated organisms and their physical and chemical environment. It includes both the biotic (living) community and the abiotic (non-living) environment.
Erlenmeyer Flask	Container having a wide bottom and smaller neck and mouth; used to mix liquids.
Erosion	The wearing away of land surfaces by running waters, glaciers, winds, and waves. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber cutting.
Euphotic Zone	That part of a lake or stream receiving at least 1% of incident surface light.

Eutrophic Lake — A lake that has high concentrations of nutrients; often shallow with periods of low oxygen.

Eutrophication — The natural or artificial addition of nutrients to a body of water resulting in increased growth of plants. Acts as an aging process in a body of water and may cause decreases in dissolved oxygen. Accelerated aging of lakes by human activity is called cultural eutrophication.

Exotic Species — Species or organisms found beyond their natural range or zone of potential dispersal. They have been intentionally or accidentally introduced outside their natural ranges. Also referred to as *non-indigenous species*. Examples are the zebra mussel, spiny waterflea, and sea lamprey.

Food Chain — A series of feeding relationships where organisms at one level serve as food for higher levels of organisms.

Food Web — The many interconnected food chains of a biological community.

Forel-Ule Color Scale — A uniform way to measure the color of water using glass tubes filled with colored solution. (See water color scale).

Global Positioning Systems (GPS) — A system of satellites, ground stations, and GPS receivers. Ground stations monitor satellites in "known" positions and triangulation is used to determine such things as latitude and longitude or the location of the vessel or other vehicles.

Graduated Cylinder — A cylindrical-shaped piece of laboratory equipment that is marked in units for measurement of liquids.

Head — Restroom and toilet. Unisex. Make sure door is locked when in use.

Hero Platform — A special restricted area extending out from the side of the vessel from which instruments are lowered into the water.

Hypothesis — A tentative statement made to test logical or empirical consequences.

Indicator Species — Certain organisms, in part, that help determine water quality (clean versus polluted).

Ions — Electrically charged atoms or groups of atoms that are capable of conducting an electrical current in water. They may be positively or negatively charged. In neutral water, there are equal concentrations of hydrogen (H^+) ions and hydroxyl (OH^-) ions. Salt water has significant amounts of sodium (Na^+) and chloride (Cl^-) ions.

Laboratory — Area inside the vessel (main cabin) where various tests are run and special equipment is maintained and used to collect data.

Latitude — A geographical measurement made up of degrees, minutes, and seconds or fractions of minutes. It is measured north or south with reference to the equator. This measurement is obtained from the GPS.

Life Vest — A garment worn to help a person float in case of a fall into the water. Also known as a Personal Flotation Device (*PFD*).

Limnology — The science of studying freshwater. Limnologists study freshwater systems and oceanographers study marine (salt-water) systems. The study of lakes, ponds and streams.

Logarithmic Scale — A scale in which each unit increment represents a tenfold increase or decrease such as a pH scale.

Longitude — A geographical measurement made up of degrees, minutes, and seconds or fractions of minutes. It is measured east or west of the Prime Meridian.

Macroinvertebrate — The term "macroinvertebrates" is traditionally used to refer to aquatic invertebrates including insects (e.g. larval Ephemeroptera and Trichoptera), crustaceans (e.g. amphipods), molluscs (e.g. aquatic snails) and worms (e.g. Platyhelminthes), which inhabit a stream or wetland. Their abundance and diversity are used as an indicator of ecosystem health and of local biodiversity.

Magnetic Compass — A device for determining directions by means of a magnetic needle swinging on a free pivot and pointing to the magnetic North.

Microorganisms — Organisms too small to be seen with the unaided eye, including bacteria, protozoans, yeasts, viruses, and algae.

Microscope — An optical device used to magnify very small objects. It may have one eyepiece (monocular) or two eyepieces (binocular or stereoscopic).

Milligrams per Liter — A unit (abbreviated as mg/L) used to measure dissolved oxygen and other chemicals. It is a measure of concentration, not absolute amounts. [Note: 1 mg/L = 1 ppm]

Nitrate — A salt of nitric acid (HNO_3). Nitrates are often highly soluble and can be reduced to form nitrites and ammonia.

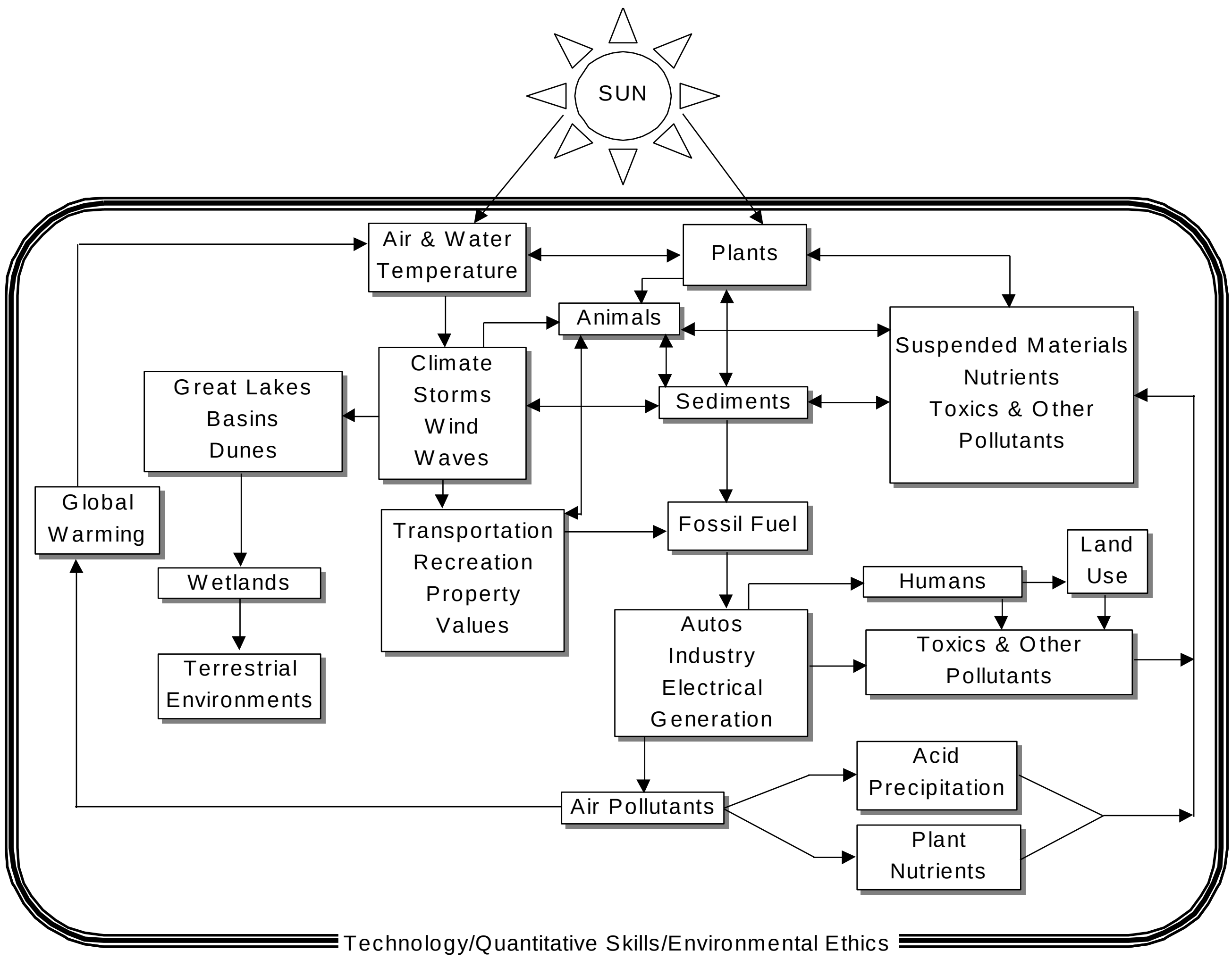
Nutrient — Chemical substances such as nitrates, phosphates, or potassium that are necessary for plant growth.

Oligotrophic Lake	Deep, clear lake with low nutrient supplies and little organic matter. Characterized by high transparency and high dissolved oxygen levels.
Organism	Any living being such as plants, animals, fungi, bacteria, etc.
Parts per Million	A unit (abbreviated as ppm) used to measure dissolved oxygen and other chemicals. It is a measure of concentration, not absolute amounts. For example, one inch in sixteen miles is one ppm. [Note: 1 mg/L = 1 ppm]
Pelagic	Open water zone.
Percent Oxygen Saturation	Percent of the potential amount of dissolved oxygen that water will hold at a given temperature.
pH	A numeric value that indicates relative acidity and alkalinity on a scale of 1 to 14. A pH value of 7.0 is neutral. Acids have pH values less than 7. Bases (alkaline solutions) have pH values greater than 7. Acid rain has a pH of less than 5.6.
Phleger Corer	A weighted hollow tube used to sample the bottom sediment layers.
Photosynthesis	Production of food (carbohydrates) and oxygen by plants from carbon dioxide and water in the presence of chlorophyll and sunlight.
Pilot House	The area or compartment in which the Captain operates the ship; sometimes called the wheel house.
Plankton	Plants (*phytoplankton*), animals (*zooplankton*), and other organisms that drift in the water column. They are often microscopic but range in size from single-cells to large oceanic jellyfish.
Plankton Net	A funnel-shaped device of fine meshed cloth which will permit water to pass through it, but not microscopic organisms.
Plume Line	The point of separation between river water and Lake Michigan water due to such factors as temperature, turbidity, or microorganisms.
Pollutant	Any substance introduced to the environment that adversely affects the usefulness of a resource.
PONAR Grab Sampler	A weighted, metal, jaw-like device used to take a “bite” out of the lake bottom. Used to collect bottom material or benthos.
Portside	When facing the front (bow) of the vessel, the left side.
Precision	A measurement of the degree of agreement or variation among a set of repeated measurements obtained under similar conditions.
Producer	An organism such as a plant which makes its own food through the process of photosynthesis.

Productivity	The rate of generation of biomass in an ecosystem. Productivity is related to how much life an ecosystem can support. Conversion of sunlight to energy through photosynthesis is considered *primary productivity,* while the generation of energy from consuming other organisms is called *secondary productivity.*
RADAR	Use of radio waves to provide information about objects on or above the surface of water; Radio Direction and Range.
Seasonal Turnover	A change in a lake that usually occurs in spring and fall when more dense, cooler or heavier surface water sinks forcing warmer and less dense bottom water upward. This results in a stirring and mixing of nutrients.
Secchi Disk	A small (20 cm) disk which is used to measure the transparency of water. It is lowered into the water until it is no longer visible.
Sediment	Materials such as soil, sand, and silt that are washed from land into water, usually after rain. The particles are deposited in areas where the water flow is slowed such as in harbors, wetlands, and lakes.
Side Deck	The right (starboard) or left (portside) passage from the front (bow) to the back (stern) on the vessel; off limits.
Solubility	The relative ability of a substance (solid or gas) to dissolve in water or another liquid.
Solution	A homogeneous mixture containing two or more substances.
Solvent	A substance that dissolves another substance to form a solution.
SONAR	Use of sound to determine depth of water as well as direction and distance to underwater features; Sound Navigation and Range.
Standard	A prepared sample with a known value; a known reference.
Starboard	When facing the front (bow) of the vessel, the right side.
Suspension	A mixture in which very small particles of a solid remain suspended without dissolving.
Thermal Stratification	Separation of water into different temperature layers. Upper layer: *EPILIMNION*, middle layer: *THERMOCLINE*, and bottom layer: *HYPOLIMNION.*
Thermometer	Used to determine temperature. May be calibrated in the Celsius and/or Fahrenheit scale. For scientific purposes, the Celsius scale is used.

Titration	The addition of small, precise quantities of chemical to a sample until an endpoint such as a color change is reached. The dissolved oxygen test involves a titration procedure using a digital titrator to add drops of a chemical to the water sample.
Transparency	The depth that light will penetrate water. A Secchi disk is used to measure the limit of visibility in water bodies such as lakes.
Tributary	A stream or river that flows into a larger stream, river, or lake.
Turbidity	A measure of how particles suspended in water affects its clarity. Microorganisms, soil particles, plankton, or other organic/inorganic matter causes the cloudy or muddy appearance of water.
Turbidity Meter	An instrument used to measure water clarity as related to light scattered by particles suspended in water. Light scattered by the suspended material is detected by a photocell. The photocell converts the scattered light into an electrical current that is sent through the meter producing a numerical reading in NTUs.
Van Dorn Sampling Bottle	A plastic cylinder with stoppers at each end that is used to collect water samples at various depths.
Water Color Scale	A number of standard colors (the Forel-Ule Scale) compared with lake water. The resulting number is related to water quality, dissolved or suspended matter, and biological productivity.
Water Column	Vertical arrangement of water from the surface to the bottom of a water body.
Water Cycle	Movement of water from the air to land and water and back to the air. Evaporation, transpiration, condensation, infiltration, and runoff are all parts of the water (hydrologic) cycle.
Water Quality	The physical, chemical, and biological characteristics of water as they relate to the use of the water.
Water Samplers	Metal or plastic cylinder-shaped containers with stoppers at each end used to collect a sample of water at selected depths or at the water's surface. Van Dorn bottles, and less frequently, Kemmerer water samplers, are used to collect water on the vessels.
Watershed	The land area in which water drains toward a lake, stream, or river at a lower elevation.
Winch	An electric powered hoist used for lowering and raising sampling equipment. The winch line is also called the hydrographic wire. VERY DANGEROUS. HANDS OFF.

Appendix A: Interrelationships of Topics Covered on Cruises



Appendix B: Drawings of Organisms Found on Cruises

Prepared by Roger Tharp, former AWRI Science Instructor

Living Things

Monerans

Includes
Cynobacteria
a. Blue-green Algae

Protista

Includes
1. Algae:
   a. Chlorophyta (Greens)
   b. Chrysophyta (Golden Browns)
   c. Pyrrhophyta (Fire Algae)
2. Protozoans

Plantae

Fungi

Animalia

Includes
Rotifera (Rotifers)
Mollusca (Snails-Clams)
Annelida (Worms)
Arthropoda (Crustaceans)

Plankton
("Drifters")

Phytoplankton
(plants)

Zooplankton
(animals)

Plankton may be classified by **SIZE.** Plankton size is usually measured in **microns (µm)**. One thousand (1000) microns equals one (1) millimeter (mm) or 0.03937 inches.

General groups	Size	Examples
Nannoplankton	0.2 µm to 20 µm	Cyanobacteria
Microplankton	20 µm to 200 µm	Diatoms
Mesoplankton	0.2 mm to 20 mm	Copepods, Cladocerans, Protozoans
Macroplankton	20 mm to 200 mm	Shrimp

Plankton may classified by the **TYPES OF ORGANISMS IT CONTAINS**:

Ichthyoplankton: Fish eggs, newly hatched eggs (fry), and small fish.

Holoplankton: Organisms that spend their entire life cycle as part of the plankton. (e.g. Asterionella and Fragilaria)

Meroplankton: Organisms that are planktonic part of their lives. Involves a resting stage. (e.g. the Blue-greens)

References: Plankton Definitions. Wildlife Supply Company.
Limnology. Horne and Goldman.

Division/Phylum: Chlorophyta

GREEN ALGAE

Grass-green in color. Great variety of forms: one-celled, simple or well organized colonies, simple or branched filaments. Moving or motile forms have whip-like hairs or *flagella.*
Size range: 40 to 400 µm.

ACTINASTRUM

PEDIASTRUM

SCENEDESMUS

SPIROGYRA

References: Algae of the Western Great Lakes Area. G.W. Prescott.
Algae in Water Supplies. U.S. Dept. Health, Education, & Welfare.
A Guide to the Study of Fresh-water Biology. Needham & Needham.

Division/Phylum: Chrysophyta
Class: Bacillariophyceae

DIATOMS

One-celled algae. Golden-brown in color. Cells single or in colonies, or filaments (threads). Cell wall of silica. Wall consists of two halves or valves held together by a band or girdle. Identification based on markings (striae) present on the siliceous cell walls. Size range: 0.5 to 200 µm.

ASTERIONELLA

FRAGILARIA

MELOSIRA

SYNEDRA

TABELLARIA

Other Chrysophytes:

DINOBRYON

References: Algae of the Western Great Lakes Area. G.W. Prescott.
Algae in Water Supplies. U.S. Dept. Health, Education, & Welfare.
Diatoms of the Streams of Eastern Connecticut. Hansmann.

Division/Phylum: Cyanobacteria

BLUE-GREEN ALGAE

One-celled or colonial. Filamentous or nonfilamentous. Poorly organized (diffused) nucleus (Prokaryotic). Color due to high concentration of the blue pigment *phycocyanin.* Produce a pungent (sharp) odor and bad taste in drinking water. Some individuals release poisons upon death (e.g. *Microcystis* sp. = microcystins). Size range: 0.2 to 20 µm.

ANABAENA APHANIZOMENON MICROCYSTIS OSCILLATORIA SPIRULINA

References: Algae of the Western Great Lakes Area. G.W. Prescott.
Algae in Water Supplies. U.S. Dept. Health, Education, & Welfare.
The Fresh-water Algae of the U.S. Smith.

Division/Phylum: Chlorophyta

DESMIDS

Types of Green Algae. Most have a middle constriction dividing the cell into two halves that are joined together by a connecting zone. Most are one-celled with some types in colonies. Size range: 50 to 150 µm.

STAURASTRIUM CLOSTERIUM

References: Algae of the Western Great Lakes Area. G.W. Prescott.
A Guide to the Study of Fresh-water Biology. Needham and Needham.

Division/ Phylum: Pyrrhophyta

DINOFLAGELLATES

One-celled and with one or two whip-like hairs (flagella). Transverse or oblique groove. Some are toxic (e.g. " red tide"). Size range: 19 to 100 µm.

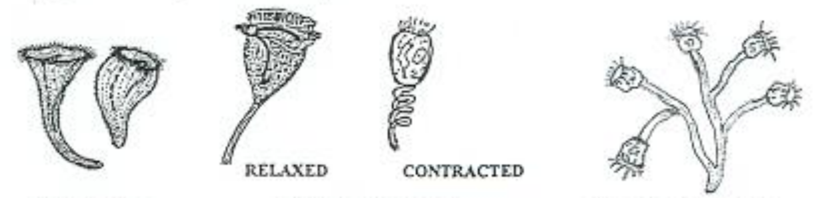
Reference: Fresh-water Algae of the U.S. Smith.

CERATIUM

Division/Phylum: Protozoa

PROTOZOANS

One-celled (unicellular) animals. Most living as single cells with some in colonies. Movement by means of short hairs (cilia), whip-like hairs (flagella), or protoplasmic streaming. Size range: 35 to 2000 µm.



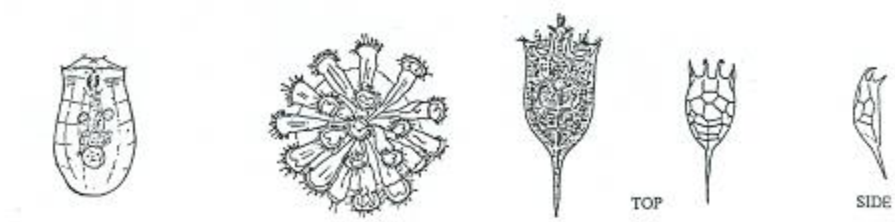
STENTOR **VORTICELLA** **CARCHESIUM**

Reference: Fresh-water Biology. Ward and Whipple.
Taxonomic Keys. Eddy and Hodson.

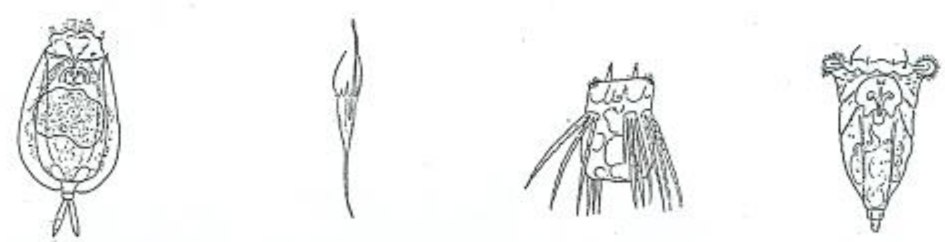
Division/Phylum: Rotatoria

ROTIFERS

Multicellular with head crown of short hairs (cilia) – "wheel bearing animals." Two classes: Digononta (two ovaries) and Monogononta (one ovary). All individuals shown here are Monogononta. Most naturally, encountered Rotifers are females. Parthenogenesis possible (production of unfertilized, haploid (n) males). Size range: 200 to 400 µm.



ASPLANCHNA **CONOCHILUS** **KERATELLA**



EUCHLANIS **KELLICOTTIA** **POLYARTHRA** **SYNCHAETA**

Reference: A Guide to the Study of Fresh-Water Biology.
Needham and Needham.

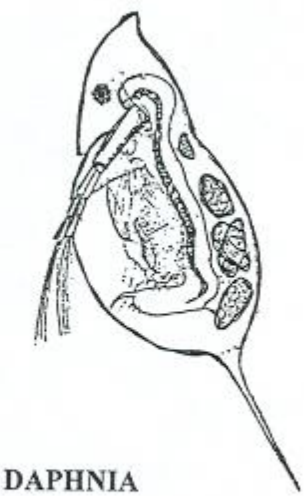
CRUSTACEAN ZOOPLANKTON

Characterized by a shell-like exoskeleton, segmented body (some individuals with fused segments), and segmented (jointed) appendages. Includes the CLADOCERANS, COPEPODS, and MALACOSTRACANS (MYSIDS, ISOPODS, AND AMPHIPODS).

CLADOCERANS

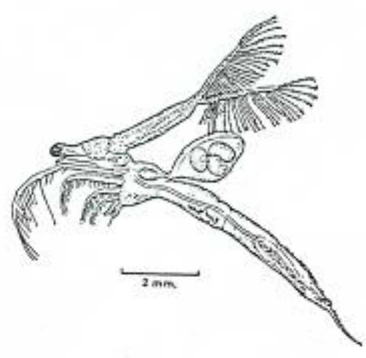
(Water fleas)

Generally 0.2 to 3.0 mm long. The body not distinctly segmented and is enclosed in a folded shell-like structure, the carapace, that opens ventrally (along the bottom). A single, darkly pigmented compound eye is present in the head.

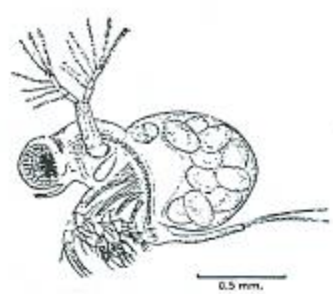


DAPHNIA

BOSMINA



LEPTODORA



POLYPHEMUS

(Crustacean Zooplankton continued)

COPEPODS
(Oarsmen)

Range 0.3 to 3.2 mm long. They have elongate cylindrical bodies clearly segmented. They are more alike in their general structure than the Cladocerans. Identification is based largely on anatomical details of the appendages.

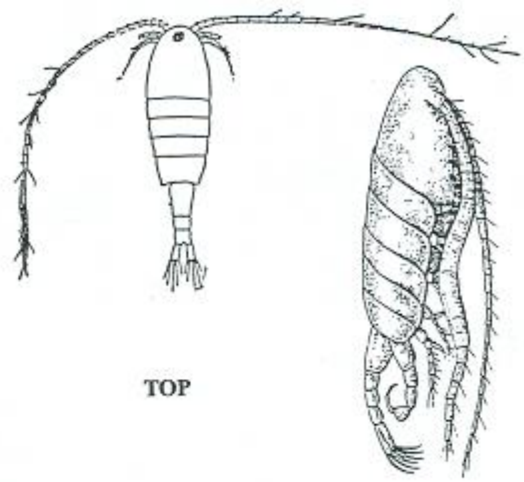
CYCLOPS

ADULT

LARVA

(NAUPLIUS)

DIAPTOMUS



TOP

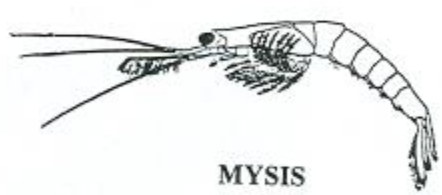
SIDE

MALACOSTRACANS
(Mysids, Isopods, and Amphipods)

Two large, paired lateral compound eyes. More or less transparent. Each body segment with a pair of appendages. Large animals ranging from 3 to 25 mm. Shrimp or scud-like.

MYSIS
(Opossum shrimp)

Resemble miniature shrimp or crayfish. Range 15 -25 mm long. A thin carapace covers most of the thorax but is not fused posteriorly to the thoracic segments. Eyes on stalks. Lack gills and respire through thin lining of carapace.



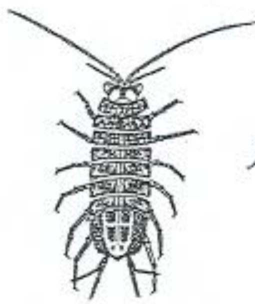
MYSIS

(Crustacean Zooplankton continued)

ISOPODS

(Aquatic sow or pill bugs)

Flattened top to bottom. The "head" is actually a cephalothorax since it represents a fusion of the true head and the first thoracic segment. The seven remaining thoracic segments are all similar. Size range: 10 to 15 mm.



Asellus sp.

AMPHIPODS

(Scuds or sideswimmers)

Mainly bottom or benthic dwelling. Body is laterally (sideways) compressed and consists of a cephalothorax, seven free thoracic segments, a six segment abdomen, and a small terminal telson. Well developed compound eyes. Size range: 5 to 20 mm.

GAMMARUS
(Scud)

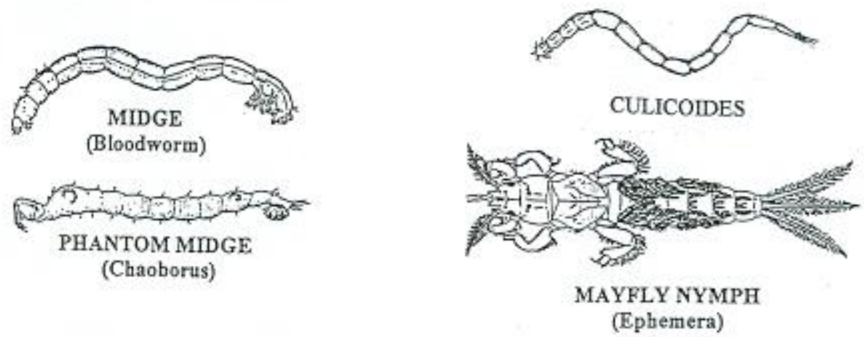
References for Crustacean Zooplankton:

Zooplankton of the Great Lakes. Balcer,Kordia, & Dodson. University of Wisconsin Press. 114 N. Murry. Madison, Wisconsin 53715.
Fresh-water Biology. 2nd Edition. Ward & Whipple. John Wiley & Sons, Inc. 1959.
A Guide to Fresh-water Biology. Needham & Needham. Holden-Day, Inc. 1962.
Fresh-water Invertebrates of the U.S. Pennak. The Ronald Press. 1953.
The Biology of Polluted Waters. Hynes. Liverpool University Press. 1966.
Aquatic Entomology. McCafferty. Jones & Bartlett Publishers, Inc. 1981.

INSECT LARVAE

(Diptera: two-winged flies and Ephemeroptera: Mayflies)

The four larvae considered here are bottom or benthic dwellers. Midges (Bloodworms) are tentatively used as "indicator species." That is, some species prefer living in high quality water while other species are more tolerant of degraded waters. Most adult Midges are non-biting but some like *Culicoides* sp. (punkies/"no-see-ums") are vicious blood feeders. Mayflies are herbivores and/or detritivores. They may be indicators of water quality and are important fish food. Size range: 1 to 30 mm.



References: Aquatic Entomology. McCafferty.
Field Book of Ponds and Streams. Morgan.

TUBIFEX

(Aquatic worms)

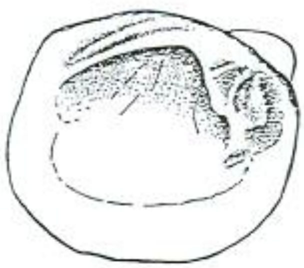
Tubifex are elongate, cylindrical, worms ranging from 30 to 100 mm long. Body is segmented, having up to 500 segments and typically bear a few bristles or hairs. They are benthic dwellers and are "indicators" of organic pollution tolerating low concentrations of dissolved oxygen. They feed primarily on detritus (dead or decomposing plant or animal material). On the bottom, they build vertical tubes from which the tail extends and waves about for aeration. They are also called *sludgeworms.*

References: Aquatic Entomology. McCafferty.
Fresh-water Invertebrates of the U.S. Pennak.
Standard Methods. 13th Edition. APHA. 1971.

(Mollusca continued)

PELECYPODS
(CLAMS)

Symmetrical mollusks with a double or bivalve shell, mantle, usually a keel-shaped foot, and without a head.



Inner shell

Outer shell

CYCLONAIAS
8.0 cm

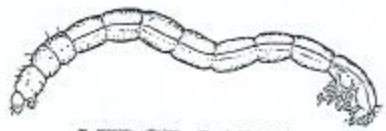
ASIATIC CLAM
(*Corbicula* sp.)
1.0 to 2.0 cm

FINGERNAIL CLAM
(*Sphaerium* sp.)
7.0 to 10 mm

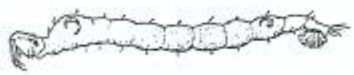
References for Mollusca: A Guide to the Study of Fresh-water Bilogy. Needham & Needham.
Fresh-water Biology. Ward & Whipple.
Fresh-water Invertebrates of the U.S. Pennak.
Pond Life. Reid. Zim & Fichter.
Taxonomic Keys. Eddy & Hodson.
Standard Methods. 13th Edition. APHA. 1971.

COMMON BENTHIC ORGANISMS

(Bottom)

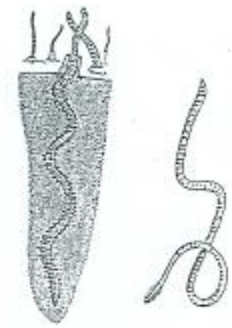


MIDGE LARVA
(Bloodworm)

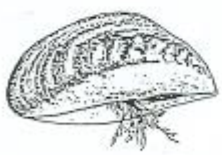


PHANTOM MIDGE LARVA
(Chaoborus)

"PUNKIE" LARVA
(Culicoides)



SLUDGEWORM
(TUBIFEX)



ZEBRA MUSSEL

QUAGGA MUSSEL

HAIRY WHEEL SNAIL
(GYRAULUS)

ORB SNAIL
(HELISOMA)

POINTED WINKLE
(Campeloma)

ASIATIC CLAM
(Corbicula)

FINGERNAIL CLAM
(Sphaerium)

VALVATA

RIVER SNAIL
(PLEUROCERA)

References for Mollusca: A Guide to the Study of Fresh-water Biology. Needham and Needham.
Fresh-water Biology. Ward and Whipple.
Fresh-water Invertebrates of the U.S. Pennak.
Pond Life. Reid. Zim. and Fichter.
Taxonomic Keys. Eddy and Hodson.
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