Lake Dynamics
“Limnology 101”

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What makes a lake and what types of lakes are there?
Lake Morphology and Morphometry
Major Lake Types

G. E. Hutchinson, father of modern limnology, identified 76 ways lakes may form

- Glacial – ice scour, ice block, morainal
- Tectonic – geologic processes: crustal movements, uplifted sea beds
- Volcanic – caldera
- Reservoirs – dams on rivers and streams
- Oxbows – remnant river channels
- Backwater – river connectivity
- Modified Glacial – water levels altered
- Excavated – Gravel Pits, Strip Mines, etc.
- Other – Beaver dams, Solution (Karst), etc.
Lakes in Illinois include:

- Glacial & Modified Glacial Lakes
- Reservoirs
- Farm Ponds
- Strip Mine Lakes
- Gravel Pit Lakes
- Oxbow Lakes
- Backwater Lakes
- and one of the Great Lakes - Lake Michigan
Glacial, Gravel Pit, Strip Mine, & Backwater
A Lake is a *Reflection* of its Watershed

- Watershed: the land area that drains into a body of water
- Rainfall collects within the lake basin
- Water runs downhill – both over and under ground
- Runoff carries nutrients, soil, & other pollutants with it
- Watershed slope, soils, vegetation, land use & geology affect runoff
Hydraulic Residence Time (HRT)

- The average time required to completely renew a lake’s water volume

\[
\text{HRT (years)} = \frac{\text{lake volume (acre-ft)}}{\text{mean outflow (acre-ft/yr)}}
\]
Lake volume and its effect on hydraulic residence time

- A large, deep lake with moderate inflow has a long hydraulic residence time; whereas, a small, shallow lake with a similar inflow will have a short residence time.

Flushing rate = 1 / HRT
Watershed size and its effect on hydraulic residence time

Small Watershed

Lake Surface Area = 100 acres
<runoff
<sediment and nutrient loading
>hydraulic residence time

Large Watershed

Lake Surface Area = 100 acres
>runoff
>sediment and nutrient loading
<hydraulic residence time
Lakes with Small Watersheds (e.g., glacial lakes)
Lakes with Large Watersheds (e.g., reservoirs)
Large Watershed = Lots of Inflow
How does the type of lake impact it?
How does the type of lake impact it?

- **Major Players**
  - Oxygen
  - Hydrogen
  - Carbon
  - Nitrogen
  - Phosphorus

- **Others**
  - Calcium, Iron, Magnesium, Manganese, Potassium, Silicon, Sodium, Sulfate
  - Chloride
Nutrients

- Phosphorus
  - Total phosphorus
  - Dissolved/Soluble phosphorus

- Nitrogen
  - Organic
  - Inorganic
Trophic States

• Primarily determined by nutrients (i.e., Phosphorus)
  – Most lakes in IL are eutrophic
  – Carlson’s Trophic State Index

<30 TSI

Oligotrophic

Mesotrophic

Eutrophic

30-49 TSI

50-70 TSI

> 70 = Hypereutrophic
The Impact of Impervious Land Cover*

Natural Ground Cover

10% Runoff

10-20% Impervious Surface

20% Runoff

35-50% Impervious Surface

30% Runoff

75-100% Impervious Surface

55% Runoff

*roads, parking lots, sidewalks, roof tops, patios, etc.
Large Watershed

Small Watershed

Lake Surface Area = 100 acres
<runoff
<sediment and nutrient loading
>hydraulic residence time

Lake Surface Area = 100 acres
>runoff
>sediment and nutrient loading
<hydraulic residence time
Lake Zurich Land Use

**Landuse**
- Water: 38.2%
- Single Family: 19.8%
- Transportation: 14.8%

**Runoff**
- Transportation: 39.5%
- Retail/Commercial: 21% (only 7.8% of watershed)
- Single Family: (18.9%)
How does the location of the lake impact it?
How does the location of the lake impact it?
CaCO$_3$
H₂O / CO₂ / O₂ / CaCO₃

H₂CO₂
(Carbonic Acid)

Ca(HCO₃)₂
(Calcium Bicarbonate)

HCO₃⁻
(Bicarbonate Ion)

CO₃²⁻
(Carbonate ion)
Photosynthesis  
Upptake of CO₂ reduces carbonic acids

Respiration  
Release of CO₂ increases carbonic acids

Rainfall  
Rainfall is naturally slightly acidic

**Calcium Carbonate acts as a buffer in this process**

Decrease in pH (more acidic) produces more bicarbonate ions from CaCO₃

Increase of bicarbonate ions increases pH (more alkaline)
How does the type of lake impact the fishing?
How does the type of lake impact the fishing?

Simple Question Right?

- Two primary types of Lakes, several subsets
  - **Natural Lakes** - Kettle Lakes, oxbows, backwater
  - **Artificial Lakes** - Created by flooding land behind a dam, impoundment or reservoir, pond, etc.
- Each subtype has unique properties that require a mixed bag of fishing techniques and high level of skill to be successful
• Water Temperature
• Feeding Habits
• Life Cycles
Temperature exerts a major influence on water quality, biological activity and growth rates. It governs the kinds of organisms that reside, as fish, invertebrates, and other aquatic species all have a preferred temperature range. As temperatures increase above or decrease below this preferred range, the number of individuals decreases.
Warm-water, Cold-water, and Cool-water Species

- **Warm-water fish species:** Adapted to a wide range of conditions. Largemouth bass, bluegill, catfish, crappies and sunfish; thrive best when water temperatures are around 60 °F.

- **Cool-water fish species:** Adapted to warmed temps than coldwater species, but thrive best in water temperatures that range in the 60's and 70's °F. Muskellunge, northern pike, walleye, and yellow perch are among the most common cool-water game fish species.

- **Cold-water fish species:** Require cold water year round to survive. Cold-water species prefer water temperatures that are in the 50 to 60 °F.
• Dissolved oxygen, pH, nutrient (mg/L), and fish species can be highly variable between layers
• Upper and middle/lower layers can function as 2 separate lakes
• Some lakes offer opportunities to catch warm and cool season species from within the same lake, due to depth and stratification
Power Plant Cooling Lakes

- Built to cool the electric generators
- **Warmer later in the year and earlier in the spring** = Longer feeding and growing seasons
- Water is the warmest near the plant and cools as it goes around the lake
- Generating **activity** = how warm the water is flowing from the plant
- Can be **detrimental in summer** (thermal loading)
- The IDNR fisheries **biologists stocking the right species of fish**, managing adequate food sources and monitoring weed growth.
- **Winter**: Powerton Lake, Clinton Lake, Lake Springfield, Lake of Egypt, Sangchris Lake, Newton Lake, Coffeen Lake, and Baldwin Lake
- **Spring**: Braidwood Lake and LaSalle Lake
Feeding Habits

- **Bony fishes** = diverse range of food preferences. planktivores; carnivores; omnivores; detritivores; herbivores?

- Each species fits into various “feeding guilds” and is placed at various trophic levels in the food chain.
Feeding Habits

• Tend to concentrate where food is plentiful and easy to acquire
• Primarily Generalists and Opportunistic; hatching insects, migrating frogs, inflows of worms from small streams, fish eggs, and schools of baitfish
• Weather, moon phase, and season play a HUGE role
• Generally prefer low light conditions morning/evening compared to bright sun of midday. Especially in clear lakes.
• Cloud cover creates a twilight of its own and may encourage fish to bite.
• Murky lakes are less influenced by light penetration and are less likely to be spooked.
• Catfish, bass, crappie and many other species of fish will bite day or night; however fishing pressure or heavy recreational use can shift feeding to night time in some lakes.
• Big fish seem to be less selective and easier to catch when it is dark.
• Fishing at night is difficult even for experienced anglers, but once mastered can be very rewarding!
Fish need to **survive and grow large** enough to reproduce.

Fish that survive to adulthood use a **range of strategies** to ensure successful spawning.

Each species **favors certain habitat types** for spawning; larval fish development; and YOY.

Use **shallow water habitat**, during some part life cycle.

**Particularly spawning habitat**

Some, prefer wetlands with aquatic vegetation, shallow rocky reefs

Provide rich areas for food and protection for the eggs and the fry
Life Cycles by Regions and Lake Types

- **Eggs**: Most eggs do not survive; Larval: Larval fish live off a yolk sac until it is fully absorbed.
- **Fry**: Fry are ready to start eating on their own and are generally considered fry during their first few months to just less than one year in some species.
- **Juvenile**: The time fish spend developing from fry into reproductively mature adults varies among species. Most fish do not survive to become adults.
- **Adult**: When fish are able to reproduce, they are considered adults. The time it takes to reach maturity varies among species and individual fish. Fish with shorter life spans reach maturity faster.
- **Spawning**: Female fish release eggs into the water (water column or into a nest) and male fish fertilize eggs by releasing milt. Not all eggs are fertilized. Some fish spawn each year after reaching maturity, others spawn at intervals, or once then die.
- **Threats to Spawning**: Changes in water temperature and oxygen levels, flooding or sedimentation, loss of habitat.
Life Cycle of the LMB

Adult (Age 4 and older)

Nesting (May—June)

Egg (4-7 days)

Juvenile (Ages 1 to 4)

Young-of-the-year (First year of life)

Larvae (2-4 weeks)
How does the shape and formation of the lake impact it?
Lake Morphometry

- Along with watershed size, slope, and surrounding land uses, lake *morphometry* (physical characteristics such as lake size, depth, and volume) adds important factors toward understanding sedimentation rates, hydraulic residence time and flushing, and subsequent effects on lake quality.
Lake Morphometry

*bathymetric maps are a great source of information*

- Surface area
- Volume
- Maximum depth
- Mean (Avg) depth
- Shoreline length
- Lake shape
- Maximum length (fetch) & orientation of main axis
The size and shape of the lake matter

- Shoreline development
  - Habitat
  - Aquatic plants
  - Water movement
  - Erosion potential
  - Privacy for people

Here’s 40 acre Ice Lake compared to 14,500 acre Lake Minnetonka
Lake Shape and Shoreline Length

Round Lake
Area = 100 acres
Shoreline = 7,400 feet

Crooked Lake
Area = 100 acres
Shoreline = 12,000 feet
Lake Shape & Orientation and Wind Fetch

Wind Direction
- long fetch = more internal mixing

Wind Direction
- short fetch = less internal mixing
Shoreline Slopes, Soils, and Erosion Potential

- Natural lakes
Shoreline Slopes, Soils, and Erosion Potential

- Man-made lakes
Physical Properties & Dynamics Summary

• Lake Origin
  – Natural
  – Man-made

• Lake Watershed
  – Size
  – Land cover / use
    • hydrology
    • pollutant loading

• Lake Morphometry
  – Size
  – Shape
  – Depth
  – Volume
    • wind fetch
    • shoreline length
    • mixing & stratification
    • productivity
What are limiting factors?
Lake Response Models

Anoxic Factor

Internal Loading
Nurnburg Approach for Sediment Anoxia
- Calculate anoxic factor
- Sediment release rate

BATHTUB
Annual model

Loading

Outflow

Biogenic and Chemical Precipitation
Diffusion from Sediments when Hypolimnion is Anoxic
Solubilization by Decomposition, Low pH, Low Redox

Movement of Nutrients Within a Lake Ecosystem
Lake Management

- The 3 Legged Stool

- Watershed Management
- Internal Loading
- Ecosystem Structure
Nutrients - where do they come from?

- External
  - Origin and Morphology
  - Watershed
    - Lawns, fields, STPs, bank erosion, septic tanks, etc.
  - Atmospheric

- Internal
  - Recycling
• Nutrient Limitation

Total N : Total P

>15:1 = Phosphorus limited
<10:1 = Nitrogen limited

– Phosphorus limited lakes
  • Most lakes

– Nitrogen limited lakes
  • Not as common as phosphorus limited lakes if present
Internal Loading

Lake Stratified
Summer and Winter

Thermocline
no oxygen
Phosphorus

H2S, PO4, Fe
Alternative Stable States – “The Shallow Lake Flip”

• Plant vs Algal Dominated
Seasonal Growth Patterns in Phytoplankton

- Spring Maximum
- Spring Minimum
- Summer Maximum
- Fall Maximum

- Diatoms
- Green Algae
- Blue Green Algae

Relative Concentration (%)
# Harmful Algae Blooms (HABs)

## The Primary Cyanotoxins and their Health Effects

<table>
<thead>
<tr>
<th>Cyanotoxins</th>
<th>Health effects</th>
<th>Most common cyanobacteria producing toxin</th>
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<tbody>
<tr>
<td>Microcystin-LR</td>
<td>Abdominal pain</td>
<td><em>Microcystis</em></td>
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<tr>
<td></td>
<td>Vomiting and diarrhea</td>
<td><em>Anabaena</em></td>
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<td></td>
<td>Liver inflammation and hemorrhage</td>
<td><em>Planktothrix</em></td>
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<td><em>Anabaenopsis</em></td>
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<td><em>Aphanizomenon</em></td>
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<tr>
<td>Cylindrospermopsin</td>
<td>Acute pneumonia</td>
<td><em>Cylindrospermopsis</em></td>
</tr>
<tr>
<td></td>
<td>Acute dermatitis</td>
<td><em>Aphanizomenon</em></td>
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<tr>
<td></td>
<td>Kidney damage</td>
<td><em>Anabaena</em></td>
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<td></td>
<td>Potential tumor growth promotion</td>
<td><em>Lyngbya</em></td>
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<td><em>Rhaphidiopsis</em></td>
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<td><em>Umezakia</em></td>
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<tr>
<td>Anatoxin-a group</td>
<td>Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death</td>
<td><em>Anabaena</em></td>
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<tr>
<td></td>
<td></td>
<td><em>Planktothrix</em></td>
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<td><em>Cylindrospermopsis</em></td>
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<td><em>Oscillatoria</em></td>
</tr>
</tbody>
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TROPHIC CASCADES

Clear-water state
- Pike
- Carp, minnows
- Invertebrates
- Algae
- Submerged plants
- Sediment resuspension

Turbid-water state
- Pike
- Carp, minnows
- Invertebrates
- Algae
- Submerged plants
- Sediment resuspension

Adapted from Metropolitan Council Environmental Services
Ecosystem Structure

• Total Phosphorus equal inside and outside enclosure

Clear water, plants, NO panfish

Turbid water, algae, LOTS of panfish
Food Chain
Plankton
Aquatic plants
Aquatic plants
What is the interaction between fish, water clarity, and aquatic plants?
Fish, Water Clarity, and Aquatic Plants

- Fewer plants = less food for many aquatic species, less oxygen, less niche habitat and cover;
- Turbidity blocks the sunlight that plants need to produce oxygen for fish and other aquatic life;
- Type and quantity of fish species often driver behind turbidity and aquatic plants;
- High turbidity = algal dominated systems devoid of plants populated by “rough fish” tolerant of poor water quality;
- Delicate balance between too much and too little turbidity – alternative stable states hypothesis.
Alternative Stable States Hypothesis

Total P(μg L⁻¹) concentration

- 0.5
- 5.0
- 10.0
- 100.0

Only submerged plants

Transparency and plant-associated mechanisms

Clear watersubmerged plants

Scarce plants

Turbid water

Phytoplankton

Phytoplankton dominance

Forward switches

Biomimicry

Higher probability of phytoplankton OR free-floating plants

Higher probability of submerged plants dominance
Stained Water vs Clear Water

- Stained lakes have more consistent fishing patterns and fish tend to spook much less than in clear water.
- Stained lakes dark color absorbs the sun's energy better than clear water, resulting in accelerated water temperatures in the spring.
- Effects light absorption and color selection for lures.
Stocking Species to Offset Impacts

• **No natural reproduction**, thus they must be stocked
• Migratory species dependent on larval drift
• Water quality or habitat not “good enough” to support some life stage
• limited successful reproduction due to predation, overfishing etc.
• Species such as hybrid crappie are often stocked to augment natural populations
• Put and take fisheries for cold-water species not suited to the climate outside spring and fall
Stocking Species to offset Impacts

• Habitat Loss

- Structures and vegetation reestablishment can improve habitat for various life stages important to achieving natural recruitment (both rearing and egg laying)

- Replacing Homogenous shorelines with a diverse mix of habitats helps
Stocking Species to Offset Impacts

- **Turbidity**: Degrading spawning beds, affecting gill function; prevent successful development of eggs and larvae; reduce growth rate, increase susceptibility to disease, etc.

- **Predation**: Nest robbing/disturbance; Larval fish susceptibility (no cover); and invasive species can also have significant impacts and “short circuit” successful recruitment.
Stocking Species to Offset Impacts

- Impact of feeding habits on plankton
- **Trophic cascade hypotheses** predict that fish will affect the structure and biomass of pelagic plankton communities
- Interrelationships within a food web can be very intricate
- Single species changes to complex food webs, can ultimately lead to a cascade of feeding habits—diet shifts—reduced growth
- Fish cohorts (age class) can swing dramatically and ultimately cause population extinction from the food web shifts and stocking would be required
What other cycles are going on in the lake?
What other cycles are going on in the lake?
Temperatur & Dissolved Oxygen
Where does the O$_2$ come from?

Primarily from:

- Atmospheric Pressure
- Rainfall
- Wind
Temperature and dissolved oxygen association with turnover cycle.
Thanks!

Questions?
Conceptual framework for lake water quality

(Adapted from Hutchinson 1991)