Waterpower

HYDRO BASICS COURSE

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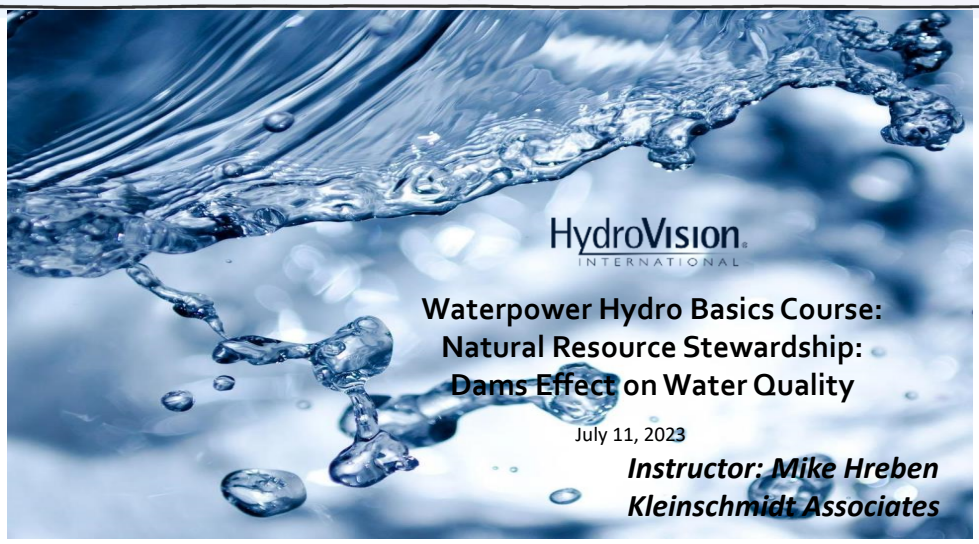
JULY 10-11, 2023 // Charlotte, North



Waterpower Hydro Basics Course: Natural Resource Stewardship: Dams Effect on Water Quality

July 11, 2023

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Kleinschmidt Associates

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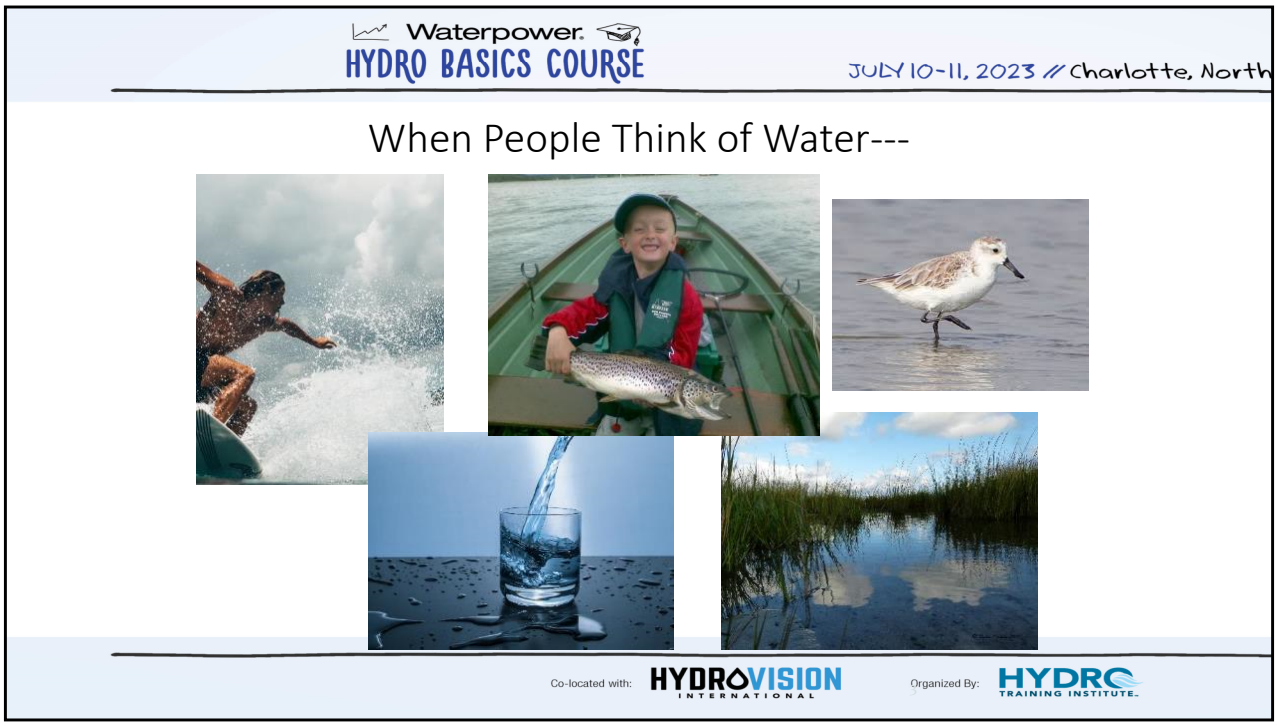
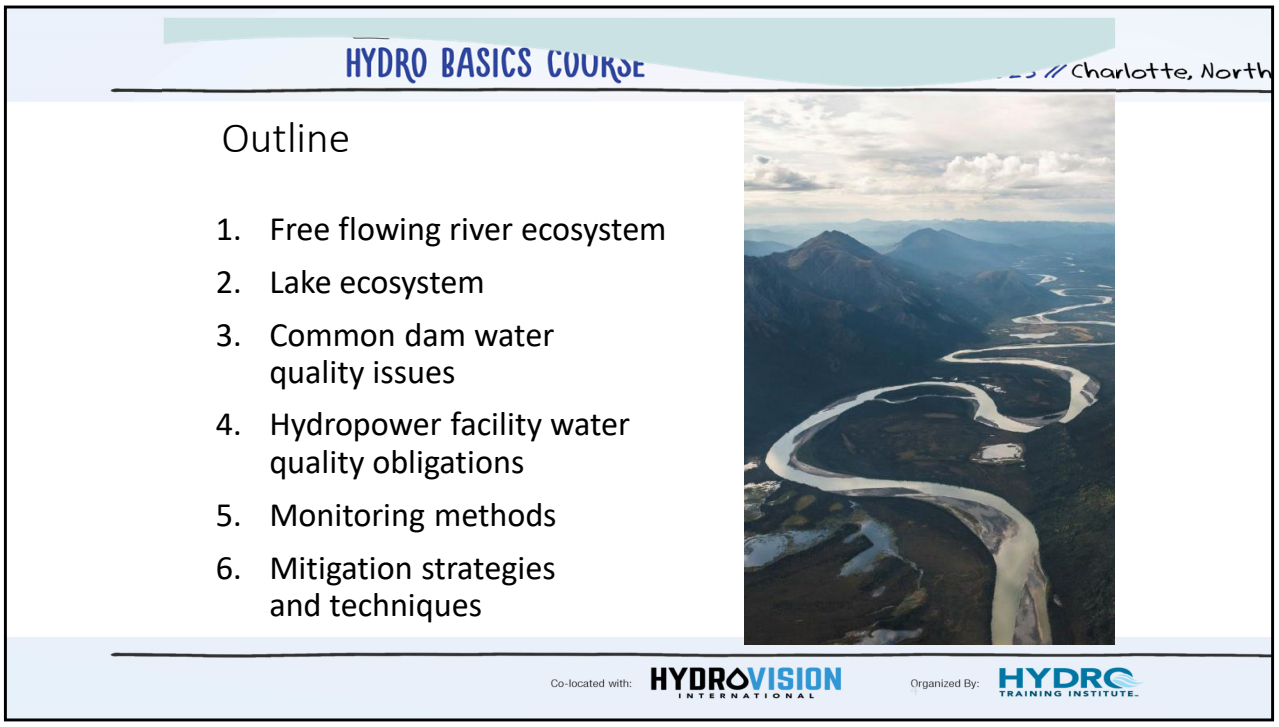


When people think of water---they think of its uses.

Many of you manage reservoirs to accommodate these uses—recreation, Fish and Wildlife values, drinking water, irrigation AND create electrons

This is a Hydro Basics class so I plan on keeping it Basic, hopefully understandable and useful.



•Rivers & streams—defined by slope and gravity—Lotic

•Lakes & ponds are impounded or Lentic freshwater systems where gravity is less of a factor

• Water quality issues by dams are a result of the relationship between these two types of systems

•Water quality issues with many Hydro dams have made this a highly regulated industry and can take many years in the FERC process to settle them.

•Numerous engineered and management strategies have been developed to help address water quality issues and we will cover a few.

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River/Stream Ecosystems

- Unidirectional flow
  - Fast (large slope)
  - Slow (small slope)
- Seasonality
  - Low flow (summer)
  - High flow (spring/fall)
- Transports
  - Sediments
  - Nutrients
- Morphology
  - Dynamic
  - Diverse aquatic habitat

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•**Rivers constitute only 0.1% of the earth's land surface**, but play a major role in shaping it. (beach, flood planes, distribution of plants, animals and waterborne stuff)
•The key **characteristic of rivers is speed of water flow or velocity** (distance per unit time) and is determined by the **topography** of the land.
•The **flow (volume per unit time**) can be large or small depending on the **climate, the season and the size of the watershed**.
•Forces from flow in rivers transport sediment, build beaches, systems like the coastal LA marshes, and create constant dynamics for the physical and biological areas they influence.
•This **dynamically changing environment leads to diverse aquatic habitats** that in turn support a wide variety of **plant and animal species** --- when the **physical processes are disrupted**, species change

Lake/Reservoir Ecosystems

- Long Water Residence Time
- Seasonality
  - Small level changes
  - Large temperature changes
- Internal Processes
  - Sedimentation
  - Nutrient recycling
- Morphology
  - Smaller water surface to volume ratio
  - Static shoreline/habitat

•Lakes (and reservoirs) constitute <2% of the earth's surface and are characterized by longer water residence times. However, they do have flow depending on drainage areas, shape, depth and size

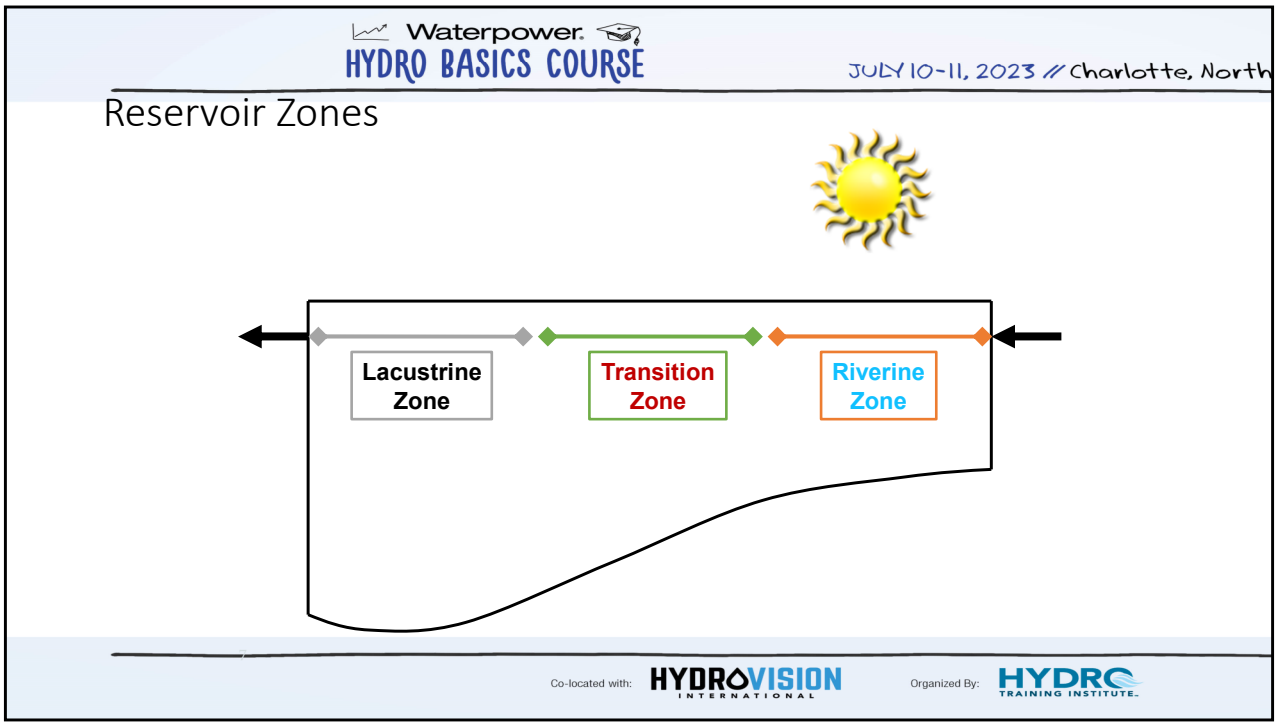
•Some lakes actually have predictable currents due to bottom configuration and span

•While most lakes have stable hydrodynamic regimes, they can exhibit large temperature gradients within the water column in deeper systems

•Typically, sedimentation within a lake is much larger than sediment transport out of the system (biological, atmospheric, landscape inputs) thus the high school biology pictures of lakes turning into marshes and bogs

•Due to longer residence times, nutrients are efficiently recycled within the water column---no place to go except into the sediments

•Habitats in lakes may be diverse and complex, but typically do not change rapidly—of course all bets off when we consider exotics.



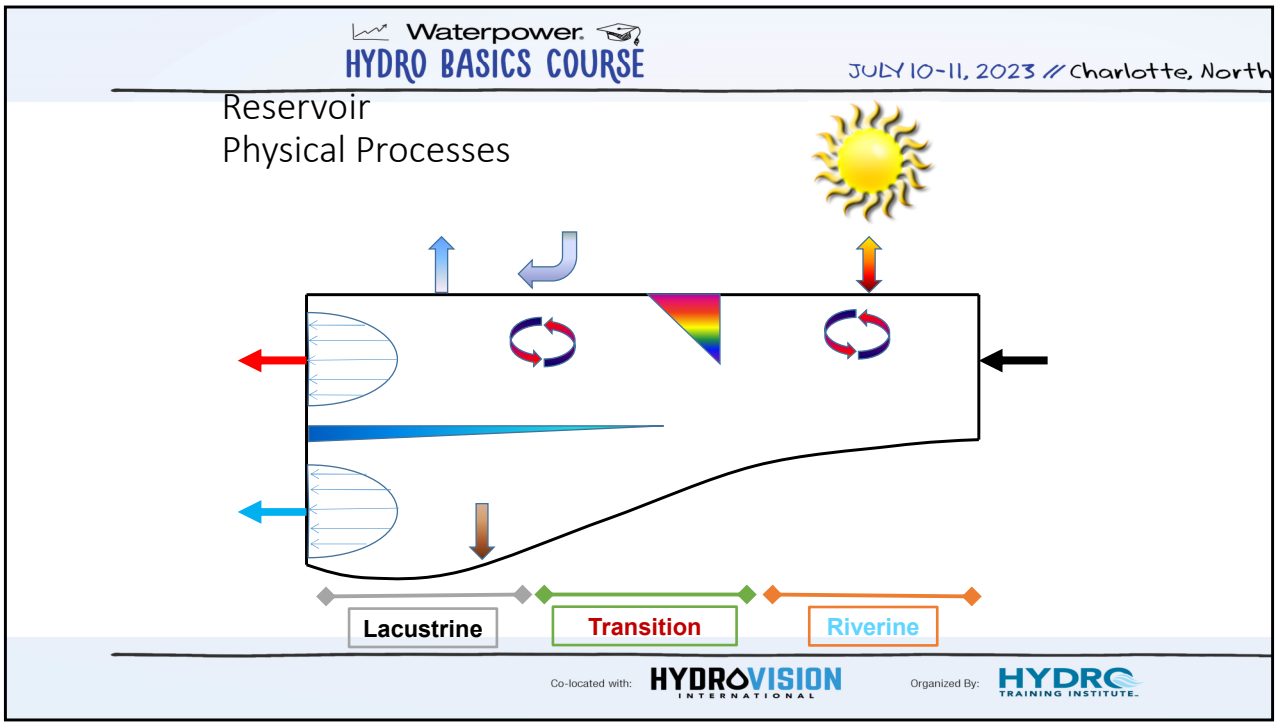
•A dam across a river essentially converts a section of river into to a lake. Depending on the height of the dam and the size of the reservoir, velocities can be almost imperceptible. The time water stays in a system can be hours, weeks, months or even longer

•As the river enters the reservoir, there is a gradually changing continuum of physical, chemical, and biologically unique zones

•The Riverine Zone is characterized by a well-mixed water column, the shore to shore distance is narrower than other zones, fine sediment transport occurs, there is lower primary productivity, and high decomposition rates

•Within the Transition Zone, sediment starts to drop out, on that sediment, is shallow, more plants may grow.. The transition zone remains pretty well mixed though water density gradients can occur like if a cold stream flows in or conversely the watershed warms up faster than the lake

•In the Lacustrine Zone, the system resembles a lake. This can be impacted by withdrawal locations within the water column that can affect reservoir water quality, the temperature, and the quality of the discharge.



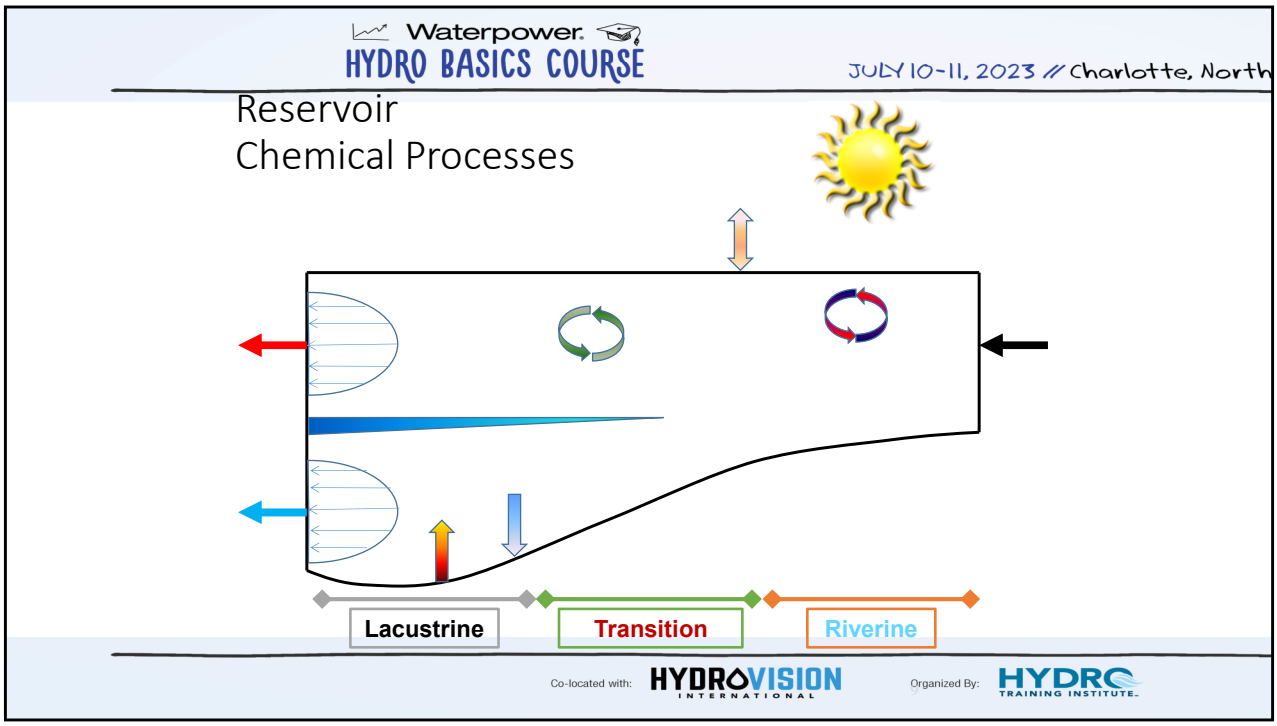
•In the riverine zone, mixing dominates such that the water column is uniform.

•In the transition zone, light penetration may not reach the bottom of the water column

•In the lacustrine zone, layers in water are based on temperature although there are some systems where chemical stratification occurs (salt). Above the stratification, the water column is warmer and well mixed. Below the stratification, the water column is colder and more stagnant.

•Sedimentation becomes more prominent.

•Evaporation rates increase due to more surface exposure.



•Gas exchange occurs readily across all three zones at the interface with the atmosphere, though turbulent mixing in the riverine zone aerates the entire water column

•After transitioning to the lacustrine zone, the water column may become chemically stratified usually measured by dissolved oxygen levels

• In the upper layers, photosynthesis dominates such that water can become supersaturated with dissolved oxygen during sunny days.

• In the lower layers, decomposition dominates and consumes the oxygen in the water column.

•High decomposition rates can lead to chemical releases from the sediment.

Summary of Reservoir Effects

Increases

- Residence time
- Sedimentation
- Temperature gradients

Changes

- Aquatic habitat diversity
- Connectivity
- Gas exchange

Main effects result from an increase in water residence time but the size, depth and shape of the reservoir also affect water quality. These effects include:

•Increased sedimentation throughout the three zones due to lower water velocity

•Due to the increase in the volume to surface area ratio and temperature gradients, gas exchange with the atmosphere is decreased and limited to the upper portion of the water column

•Temperature gradients, both vertically and horizontally, develop during the warm months of the year

•Aquatic habitat becomes more static. Heat exchange only occurs at the surface and due to the increased volume to surface area ratio, reservoirs can retain heat late into the year and take longer to initially warm in the spring. The result is a discharge at the dam or powerhouse that may change the natural temperature regime

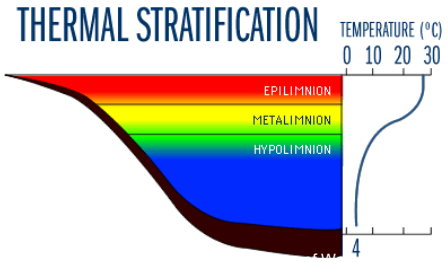
•Migratory fish may lose the ability to reach necessary habitats due to not only having a structure in the way but also due to temperature changes and DO.

•Of course the configuration of the reservoir impacts these physical, chemical and thus biological characteristics.

Common Water Quality Issues

Temperature

- Increased water surface to shoreline ratio
- Decreased water surface to volume ratio and increased residence time
- Evaporative losses increase



•A reservoir's thermally induced mixing is largely a result of the climate and depth. Some reservoirs mix only once a year and can be found in either consistently cold or consistently warm climates with stratification occurring the remainder of the year (Monomictic)

•Others mix twice a year (spring and fall) in temperate climates with stratification occurring in-between (winter and summer). (Dimictic)

•And then again others mix multiple times during the year and can either be in consistently cold, consistently warm, or temperate climates with ephemeral stratification occurring during the year. (usually shallow lakes/ponds) (Polymictic)

•Other characteristics like it's surface area are important

•In addition to temperature, humidity and the nature of the shoreline can impact dynamics (i.e Lake Mead's ET). Stratification can cause significant water quality challenges in the lake and downstream of a structure.

Common Water Quality Issues

Dissolved Oxygen

- Fundamental to aquatic ecosystem health as water
- Produced by photosynthetic organisms and replenished by atmospheric gas exchange
- Consumed by aerobic organisms and reduced chemical species

A healthy ecosystem has ample dissolved oxygen.

- **Oxygen solubility is a function of water temperature,**
  - ❑ **At 4°C [O_2] ≈ 13 mg/l and at 20°C [O_2] ≈ 9 mg/l.**
- **However, warm water with high primary productivity (plant activity) can have high DO levels (>10 mg/l--supersaturation) and cold water with high decomposition rates can become anoxic (≈ 0 mg/l) .**
  - **•warm water ecosystems are populated by species that have adapted to lower DO concentrations**
  - **•cold water species have higher DO requirements.**
- **Therefore 4 to 5 mg/l of oxygen may support a healthy warm water ecosystem but would prevent a some species from flourishing in a cold water system.**
- **DO depletion in a reservoir can be caused by:**
  - **Lack of mixing between stratified zones;**
  - **Increased biological and chemical oxygen demand originating from sedimentation and excessive aquatic plants;**
  - **Decreased surface area to volume ratio (i.e. less gas exchange per volume of water);**
  - **And decreased DO saturation with increased water temperature.**

Common Water Quality Issues

Eutrophication

- Over-productive aquatic ecosystem
- Possible higher nutrient concentrations of free flowing rivers than lakes
- High sedimentation of dead plant cells increasing oxygen demand

- **Lakes recycle nutrients.**
- **The inflow from the river and surrounding watershed contains high nutrient concentrations that can cause hyper levels of primary productivity (i.e. algal blooms).**
- **Huge masses of algal cells eventually die and fall out of the water column over-loading the sediment microbial community with rich organic matter.**
- **This in turn increases the rate of decomposition to the point where oxygen consumption is faster than replenishment from photosynthesis or gas-exchange coming from higher in the water column.**
- **Bigger problem in stratified reservoirs with poor mixing of the upper and lower strata.**
- **The decomposition in the sediment also makes nutrients more bio-available thus promoting another algal bloom and the cycle continues…**

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Common Water Quality Issues

Temperature & Dissolved Gases

- Dam spill entrain air supersaturating the water column
- Discharge location changes character of downstream system
- Turbines NOT increasing TDG during operation

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•Releases from hydro facilities can lead to rapid changes in temperature, DO, and other water quality parameters

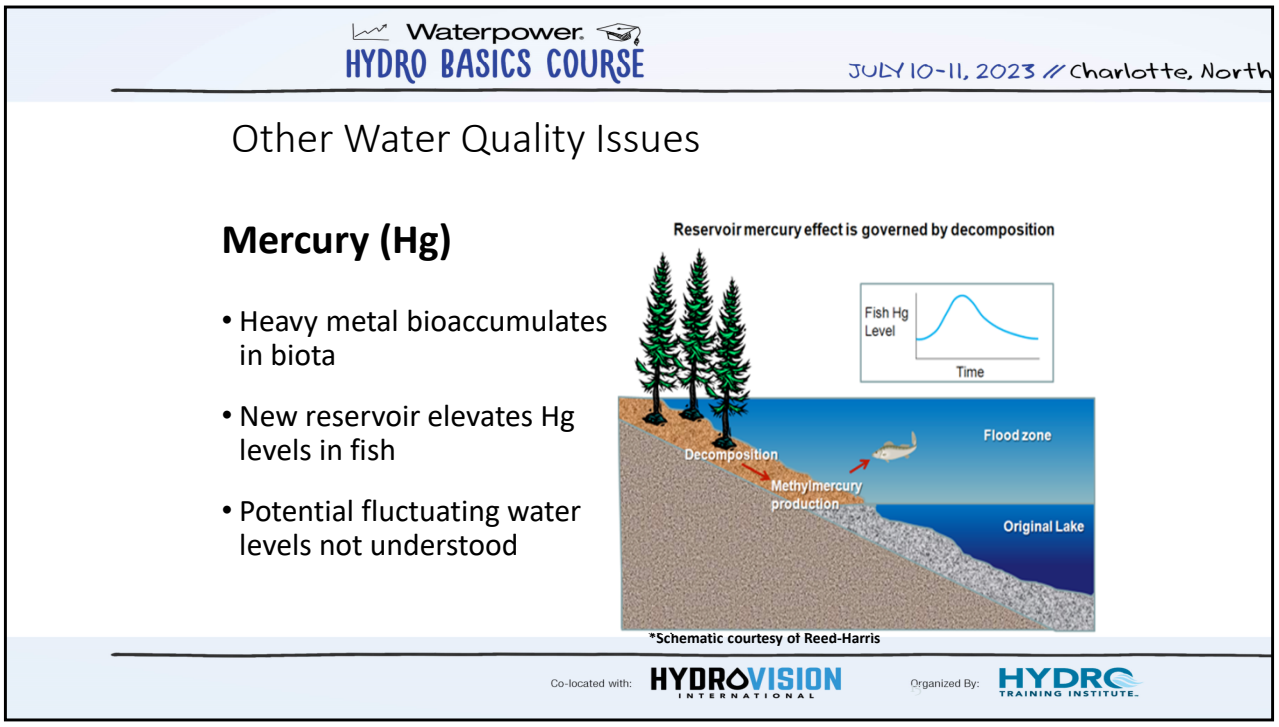
•Summer releases from the bottom of a lake may have low DO, cold temperatures, high nutrients, and corrosive or noxious chemicals.

•Summer releases from upper levels of a lake may have high DO, warm temperatures, and large amounts of organic matter.

•Fish can get the bends because of too much O2 in the water.

•In many hydro facilities, discharges can be large enough to dictate the conditions of the receiving water body, in terms of water quality, the species it supports, and other designated uses.

•Classic example is a coldwater fishery being well established down stream of a dam. Some best blue ribbon trout fisheries are below reservoirs.



- **Mercury (Hg) is a heavy metal that acts as a neurotoxin. methylated mercury (MeHg). The later is readily taken up by organisms and bioaccumulates into larger animals.**
- **The largest occurring sources are airborne emissions from sources like coal-fired power plants.**
- **All freshwater water bodies in Maine are listed as impaired for Hg. As such, regulators are concerned about the bioavailability and bioaccumulation in dammed reservoirs.**
- **Starting in the 1970's, high Hg concentrations in fish have been linked to the creation of hydroelectric reservoirs**
- **A silver lining to this for our clients is that once the reservoir has been created, Hg levels go up for only a few years and will return to pre-impoundment levels within one relicensing period (<30 yrs)**
- **My professional opinion is that in some situations water level fluctuations may have an effect on elevated Hg levels in biota, but in most cases these effects will be minor**

- **You will hear more about regulatory matters and the role of the Federal Energy Regulatory Commission (FERC) in the Regulatory Segment of Hydro Basics.**
- **Part of the FERC process requires obtaining a certification (or a waiver) that the project meets water quality standards of the State. Without this, FERC will not issue a license.**
- **Section 401 of the Clean Water Act enables states and tribes to protect their water resources by not allowing a licensee to be shielded by a federal license or permit.**
- **This provision was unanimously upheld in 2006 by the US Supreme Court in SD Warren Co versus the Maine Department of Environmental Protection.**
- **Other common Federal Permits and Licenses that trigger a 401 certification are:**

•CWA §402 National Pollution Discharge Elimination System administered by the EPA
•CWA §404 Dredge and Fill permits issued by the USACE
•And the Rivers and Harbors Act §9 and §10 permits by the USACE

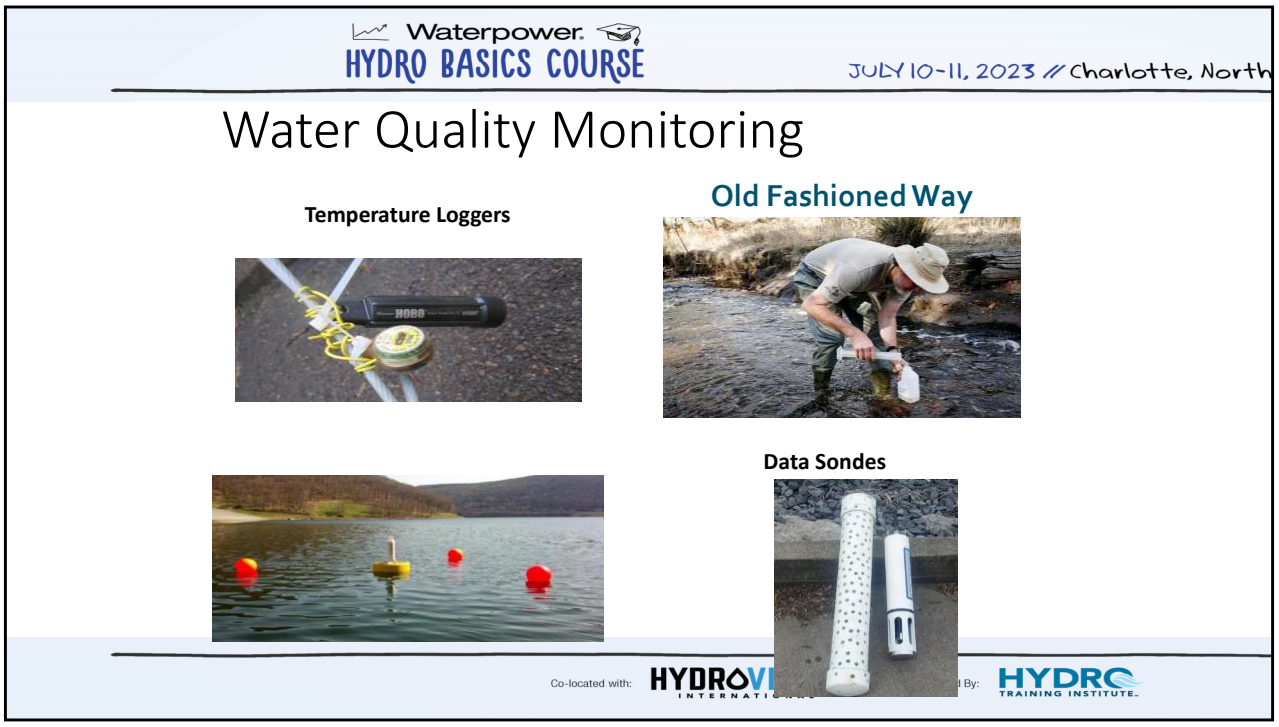
Hydro Facility
Water Quality Obligations

Water Quality Standards

- Vary by state and water resource type
- States Establish Standard
  - Designated uses
  - Anti-degradation policies and procedures

Water Quality Standards Database:
http://water.epa.gov/scitech/swguidance/standards/wqslibrary/index.cfm

- **States or tribes develop specific water quality standards and are used to justify §401 certification or denial.**
- **Designated uses describe the water body's use before the facility is in operation.**
- **The criteria can be numeric or narrative assessments based on the designated use.**
- **At a minimum, criteria must meet EPA (federal) criteria but they can be more stringent.**
- **Anti-degradation policies are established to help attain compliance with the set criteria.**
- **Theses standards protect aquatic life and human health and are based on the latest scientific knowledge.**



- **Grab Sample – sent to laboratory and require multiple site visits**
- **Temperature Sensors: Continuous recordings at predetermined intervals and are deployed as single units and/or as vertical strings**
- **DataSondes: Continuous recordings at predetermined intervals, Single deployment**
    - **Temperature ±0.1 °C**
    - **Dissolved oxygen ±0.1-0.2 mg/L**
    - **pH ±0.2 units**
    - **Conductivity ±0.5% of reading + 0.1 µS/cm**
    - **Turbidity ±1-5%**
    - **Total dissolved gas ±1.9 mbar**

Mitigation Strategies and Techniques for Dissolved Oxygen Levels

Operational Changes

- Unit and/or intake preferences
- Spill options
- Gate settings

Pros

- Low capital cost
- Utilize existing equipment and infrastructure

Cons

- Limit energy production
- Compensate for lost energy

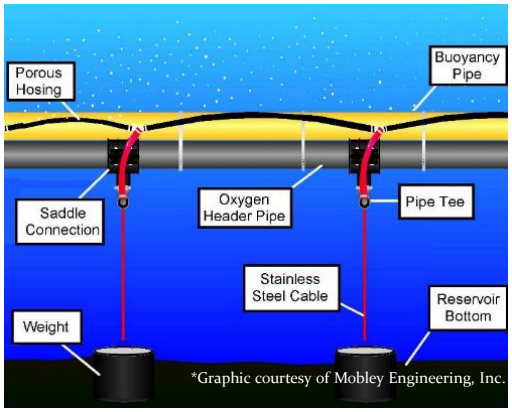
- **The first DO enhancement method that should be considered is operational changes. Potential operational changes may include unit and/or intake preferences, spill options, or limited gate settings.**

- **Pros – by far the lowest capital cost fix to DO problems. Existing equipment and infrastructure is used. However, long term costs may be substantial.**
- **Cons – may limit energy production when demand is highest (i.e. lost generation during hot summer conditions) and create the need to provide make up energy.**

Mitigation Strategies and Techniques

Oxygen Diffusers

Air diffusers installed to aerate bottom waters near vicinity of intake



•There are numerous engineering methods that can be used to help mitigate water quality issues

•For example several methodologies have been used to enhance DO and choice of the appropriate method is dictated by site conditions

•Oxygen or air diffusers have been successful in aerating bottom waters of reservoirs mainly to avoid low DO discharges. These systems typically use oxygen but can also use compressed air. No one system fits all needs:

•Some benefits are:

- **•increases oxygen concentration at the intake,**
- **•decreases the internal release of nutrients from the sediment, and**
- **•eliminates reduced chemical species such as hydrogen sulfide**

•The systems however can be costly to build, operate, and maintain

Mitigation Strategies and Techniques

Turbine Aeration Technology

- Newer models have auto-aeration
- Older models retrofitted to introduce oxygen or air

- **Turbine aeration (either turbine venting or direct oxygen inputs) can be successful at increasing discharge DO.**

- **Factors such draft tube length, tailrace depth, and runner orientation substantially affect oxygen uptake.**

❑Benefits: Leaves the reservoir unaltered while still increasing DO in the discharge.
❑Costs: Can be expensive to retrofit existing turbines and infrastructure or to install new turbines.
❑Can lead to supersaturation of Total Dissolved Gases

Mitigation Strategies and Techniques

Surface Water Pumps/Mechanical Mixing

Surface water pumps or propellers mounted on surface frames can drive warmer, well-oxygenated water deeper into the water column and potentially increases DO levels released through deep outlet works to bring tailwaters in to 401 compliance.

- **Benefits: increases oxygen concentration at the intake, decreases the internal release of nutrients from the sediment, and eliminates reduced chemical species such as hydrogen sulfide**
- **Costs: – costly deployment and operation/maintenance, plus may exacerbate eutrophication processes and may lead to discharges containing high organic matter. Additionally, systems may need to be removed on a seasonal basis in reservoirs with ice cover.**

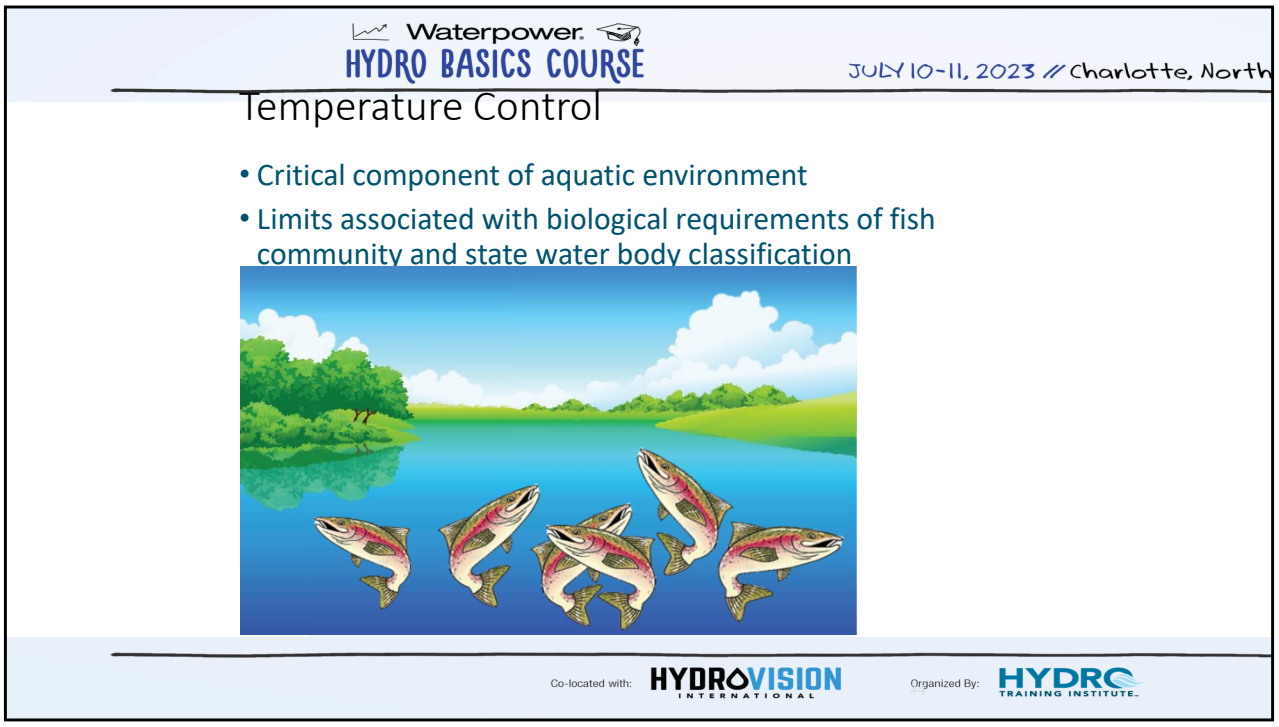
Mitigation Strategies and Techniques

Downstream Aeration

Before entering the receiving waters, the weirs and other aeration devices can be constructed in the tailrace.

❑Benefits: Increases DO (dissolved oxygen) without creating issues associated with TDG (total dissolved gas) and maintenance and operation is low-cost once installed.

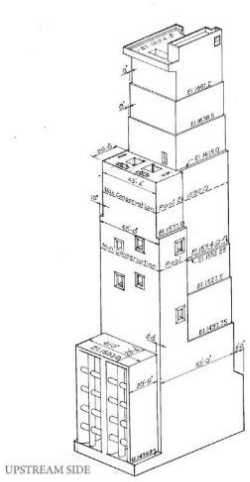
❑Costs: The amount of surface area required to handle turbine discharge volumes is significant and may not be practical for higher volume flows. As such, capital costs and permitting issues can be substantial.



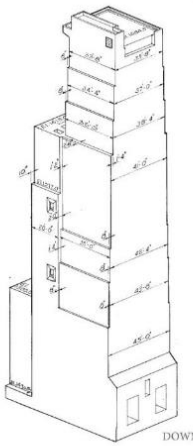
- **Water Quality Certificates frequently mandate water temperature limits**

- **These limits are usually associated with biological requirements of a given fish community and the State Classification of the water body – think trout want colder water but catfish utilize warmer water.**

- **Also, temperature control is often thought of as providing cooler water to mitigate for the warming that occurs in reservoirs but it can also pertain to the need to provide warmer water. For example, deep reservoirs with significant storage and a deep water intake may discharge colder water that impacts the down stream biology.**



UPSTREAM SIDE



DOWNSTREAM SIDE

Water Intake Towers

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Mitigation Strategies and Techniques

Watershed Management

- Stormwater management
- Properly sized shoreline buffers
- Exotic controls
- Proper road maintenance
- Agricultural management
- Monitoring and development of models to understand dynamics
- Public forums to influence behaviors

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•Often water quality in a reservoir can be enhanced or protected if watershed management is implemented.

• Large scale planning may help when there are multiple dams in series on a river. For example: Total dissolved gas can become excessively high to the additive nature of each dam increasing gas from spill during runoff.

• Understanding the stresses on reservoirs by land use in the watershed may be key to maintaining water quality in hydropower systems.

• Owners who take steps to address all the various sources of water quality problems will provide the most sustainable solution to clean water.

• Watershed planning is a challenging but important task to achieve these goals. It involves collaboration and problem solving among multiple stakeholders including municipalities, states, NGO's and landowner

• Reservoir water quality management, when you add stakeholders to the equation mixes social with traditional sciences. Managing the watershed is one way to protect and improve water quality---that may mean addressing expectations of waterfront, users and watershed residents that may often be advocating cross purpose practices----

Maintaining water quality provides conditions suitable for designated uses of a water body. These uses pertain not only to aquatic life but also affect the quality of life for those who live, work, or recreate on the water.

Questions?