PNWS-AWWA

Water 2026

Tacoma, Washington • May 6-8

WELCOME

Protecting Aquatic Systems Through Modeling and Management

- Modeling Thermal Impacts and Mitigation with CE-QUAL-W2 to Support Temperature Compliance in Oregon
- Protecting Fisheries: Addressing Low Dissolved Oxygen and Algal Blooms in Island Park Reservoir



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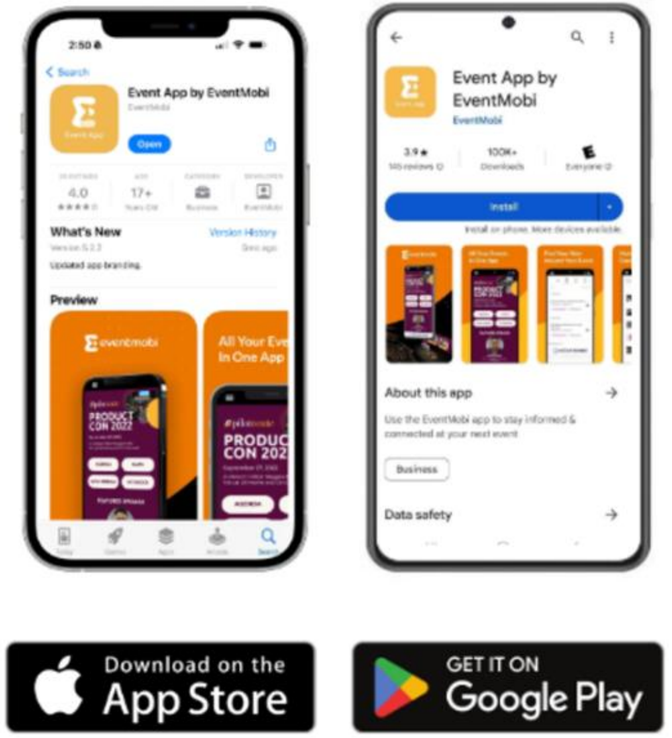
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Modeling Thermal Impacts and Mitigation Strategies Using CE-QUAL-W2 Hydrodynamic Model:

Supporting Compliance with Temperature Standards in Oregon

2026 PNWS-AWWA Conference (Tacoma, WA)
Friday, May 8, 2026

PRESENTED BY:

Rob Annear, PhD, PE
Annear Water Resources, LLC

ANNEAR WATER RESOURCES

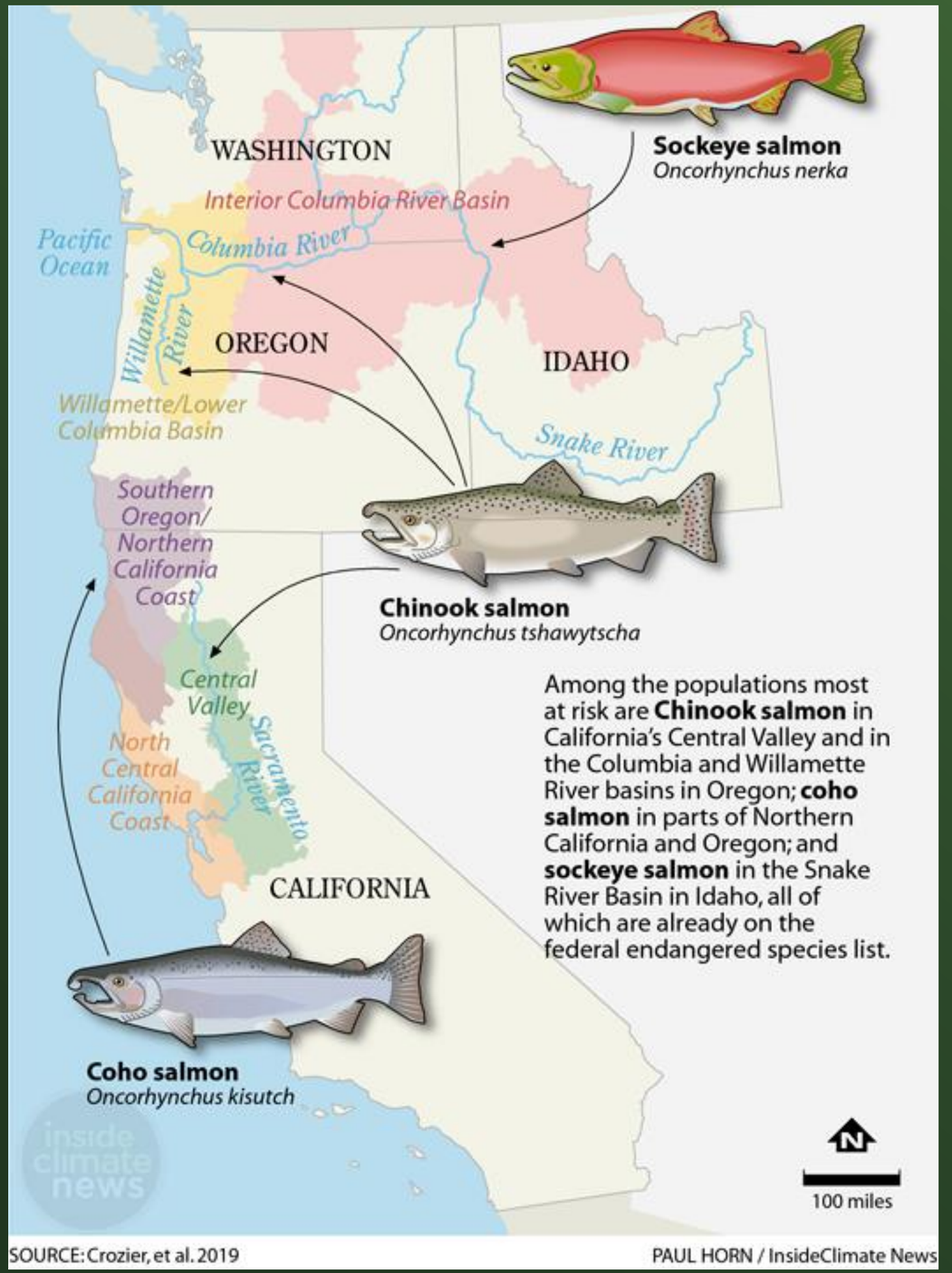
Agenda

1. Pacific Northwest Salmon
2. Oregon Temperature Standards
3. 401 Water Quality Certification Process
4. Introduction to CE-QUAL-W2 and Temperature modeling
5. Thermal Impacts Analysis
6. Thermal Mitigation Strategies
7. Questions/Discussion



Pacific Northwest Salmon
Habitat & Value

- Economic value of commercial salmon fishing
  - $1.1B per year, >40,000 jobs
- Cultural value
- Essential role in ecosystem function and diversity
- Several salmon species are Endangered Species Act (ESA) listed

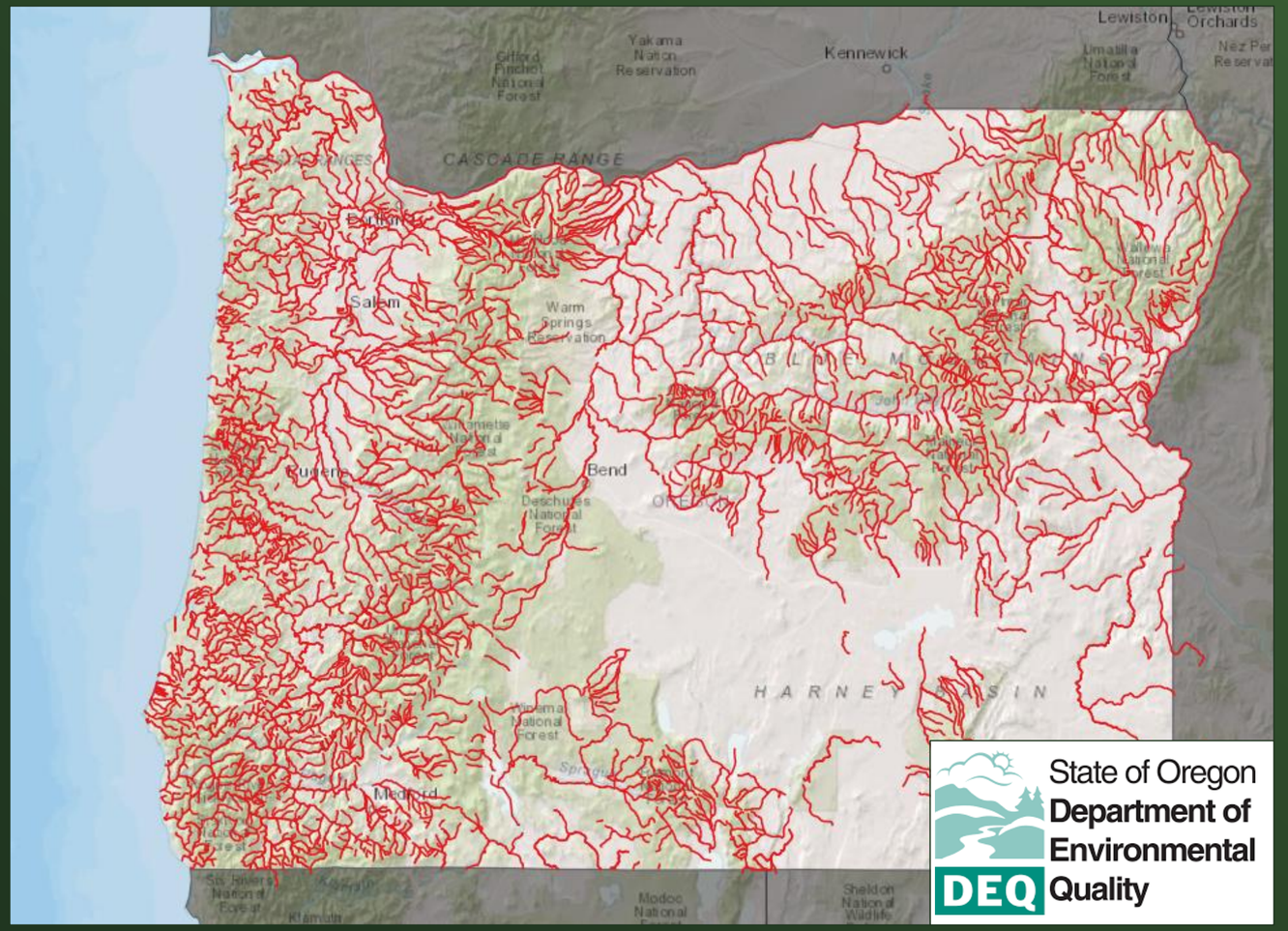


Pacific Northwest Salmon Habitat Distribution

Pacific Northwest Salmon

Rising Stream Temperatures

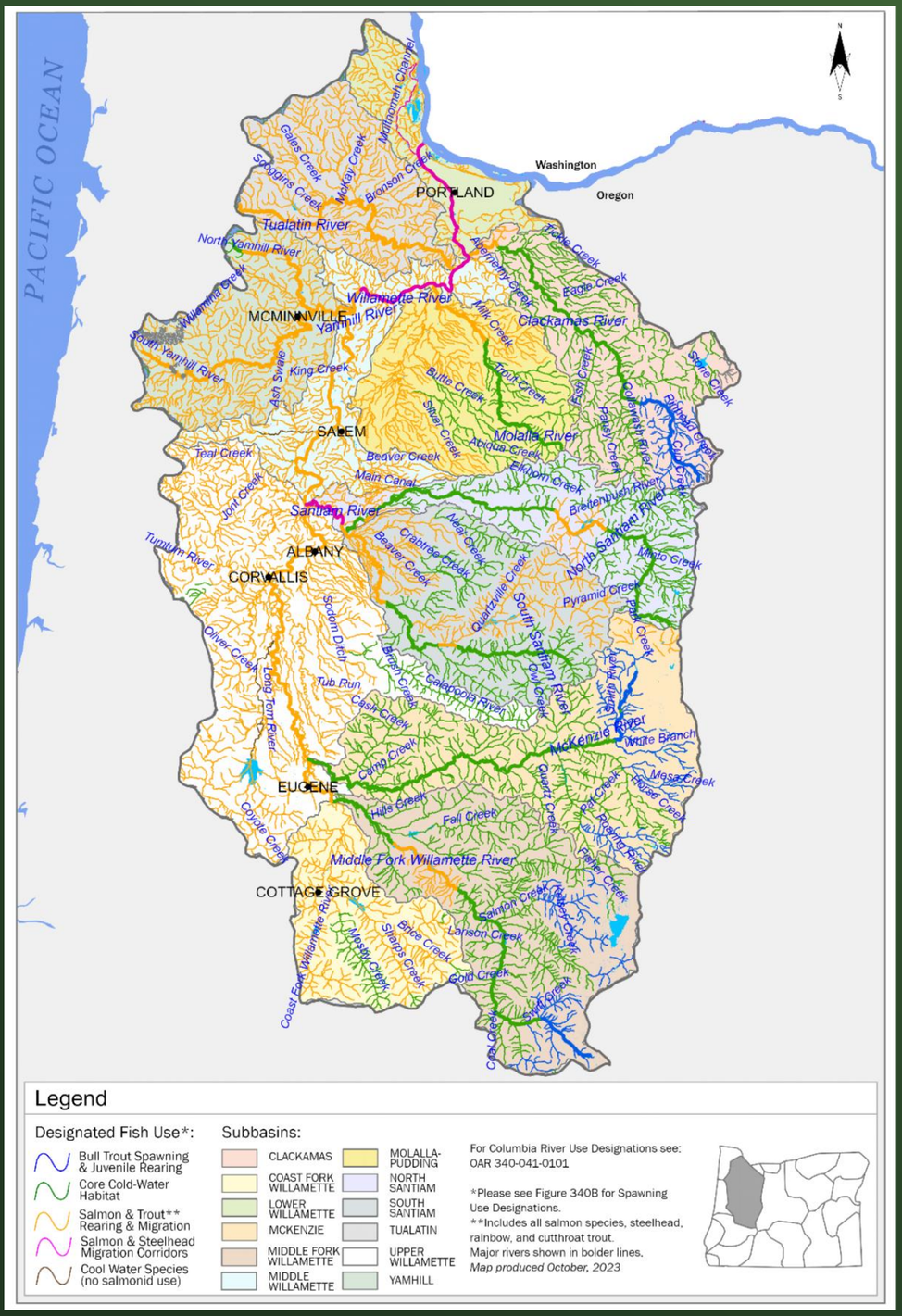
- Chronic exposure to elevated stream temperatures (>17.8^{o}C) can impair the ability of salmon to migrate, reproduce, grow, and survive.
- Acute exposure to higher temperatures (>21^{o}C) can be lethal.
- Approximately 81% of Oregon's rivers do meet water quality standards for temperature (DEQ, 2022).



Surface Waters on 303(d) List for Thermal Impairment, Oregon

OR Temperature Standards
Overview

- Driven by ESA listed fish species.
- Standard is based on the 7-day moving average of the daily maximum water temperature (7DMADM).
- Spatially and temporally explicit by fish species, time of year (spawning, rearing etc.).
- Example: Willamette River basin
  - Salmon and steelhead spawning: 13.0 °C.
  - Core cold water habitat: 16.0 °C.



401 Water Quality Certification Process

- Key Project example: A new drinking water intake to allow water provider to utilize more of their water right(s).
- The Project defines what permits are needed.
- The Permits and requirements are specific to the Project.
- Thermal impacts are specific to the Project.
- The 401 Water Quality Certification is specific to the Project.
- A condition of the 401 Water Quality Certification may be a Thermal Trading Plan, outlining impacts and high-level mitigation strategies.

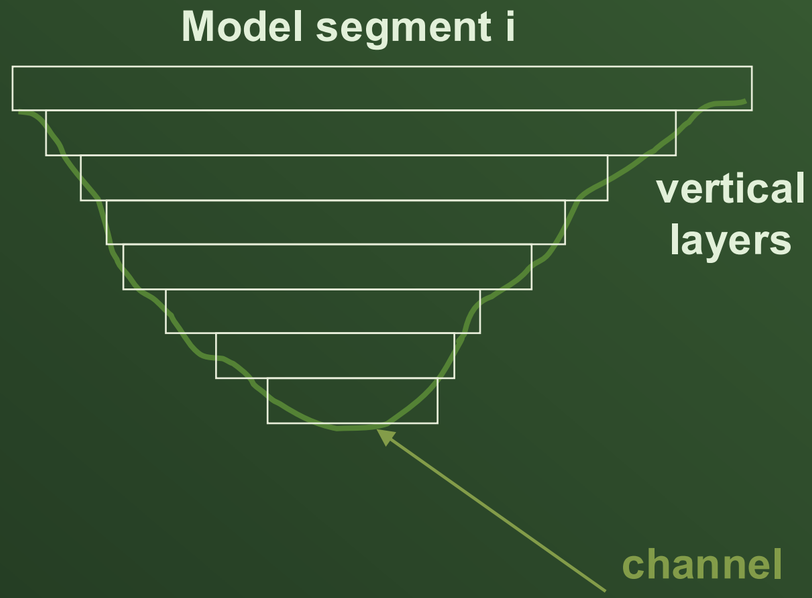
How do you analyze potential thermal impacts?

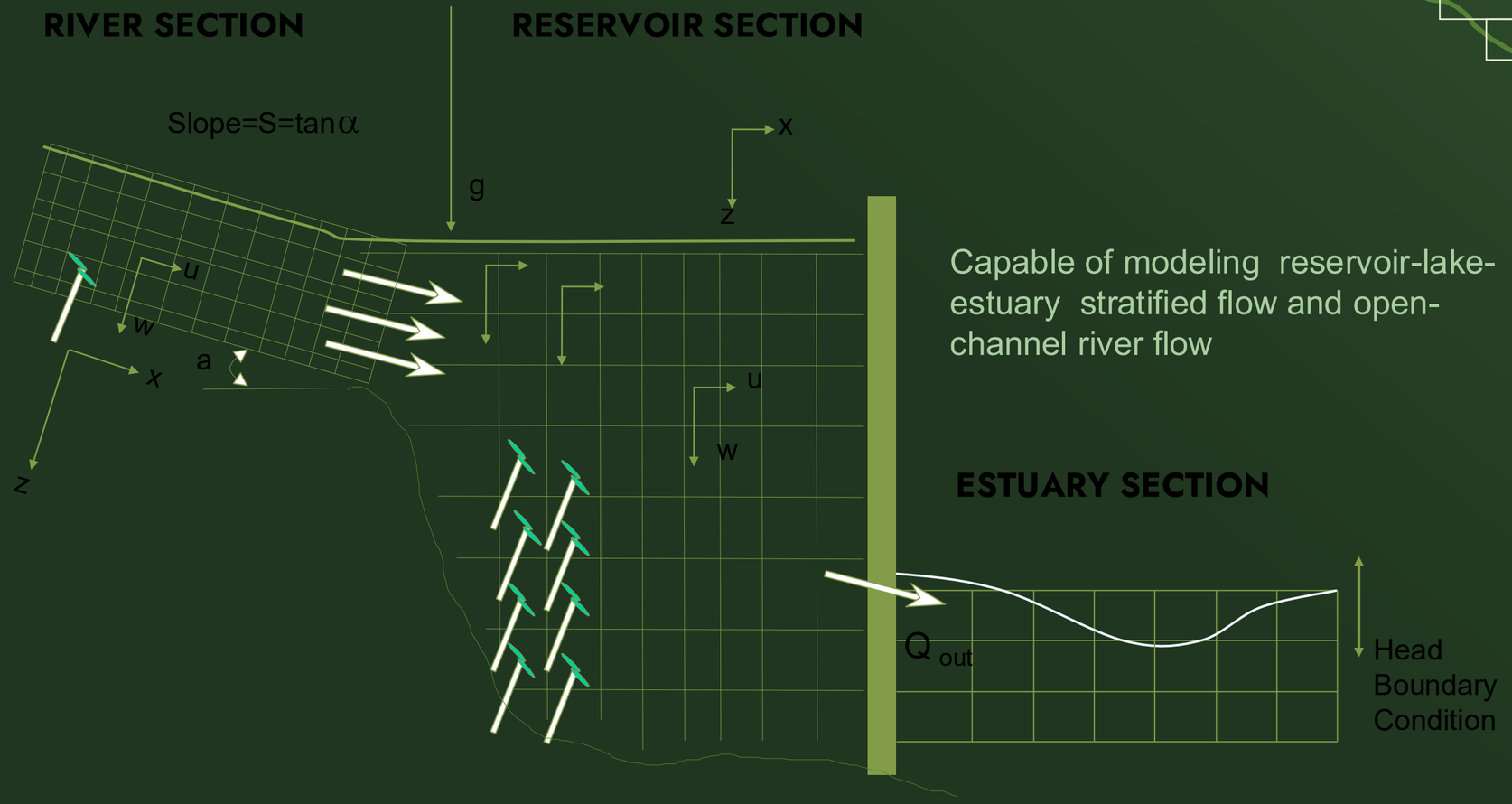
Introduction to CE-QUAL-W2

- A 2-D (vertical-longitudinal), unsteady finite difference model for hydrodynamics and water quality of rivers, reservoirs, lakes, and estuaries.
- Portland State University has been the prime developer of CE-QUAL-W2 for the U.S. Army Corps of Engineers Waterways Experiments Station for the last 30+ years.
  - History: 1986 to 2026+
  - Active model development continues in 2026.
- Over 1,000 applications worldwide (all 7 continents, 100+ countries).
- Free and open-source.
- Used by ID DEQ, WA Ecology and OR DEQ for TMDLs.

CE-QUAL-W2, Model Grid

River Basin Reservoir Model
2-D longitudinal-vertical



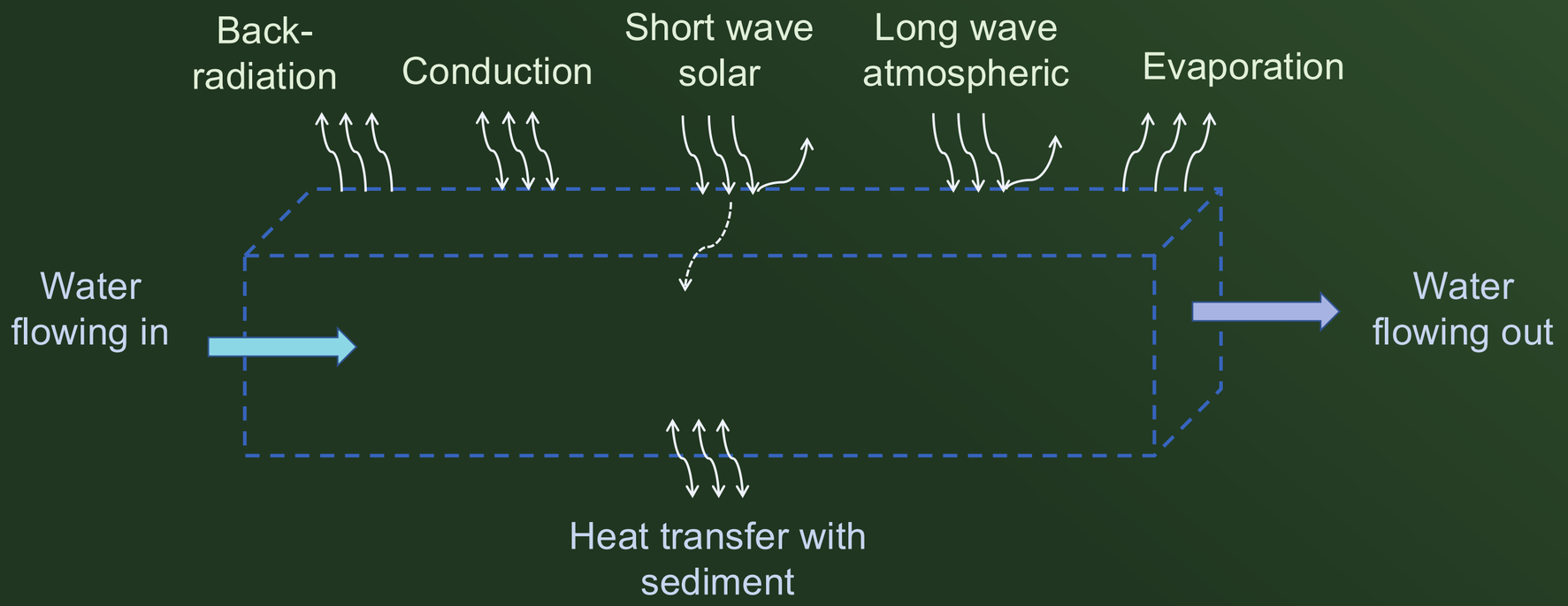


Capable of modeling reservoir-lake-estuary stratified flow and open-channel river flow

CE-QUAL-W2, Temperature Modeling

Components

- Surface heat exchange
- Short-wave solar
- Shading algorithm
- Ice cover routines
- Sediment heat exchange



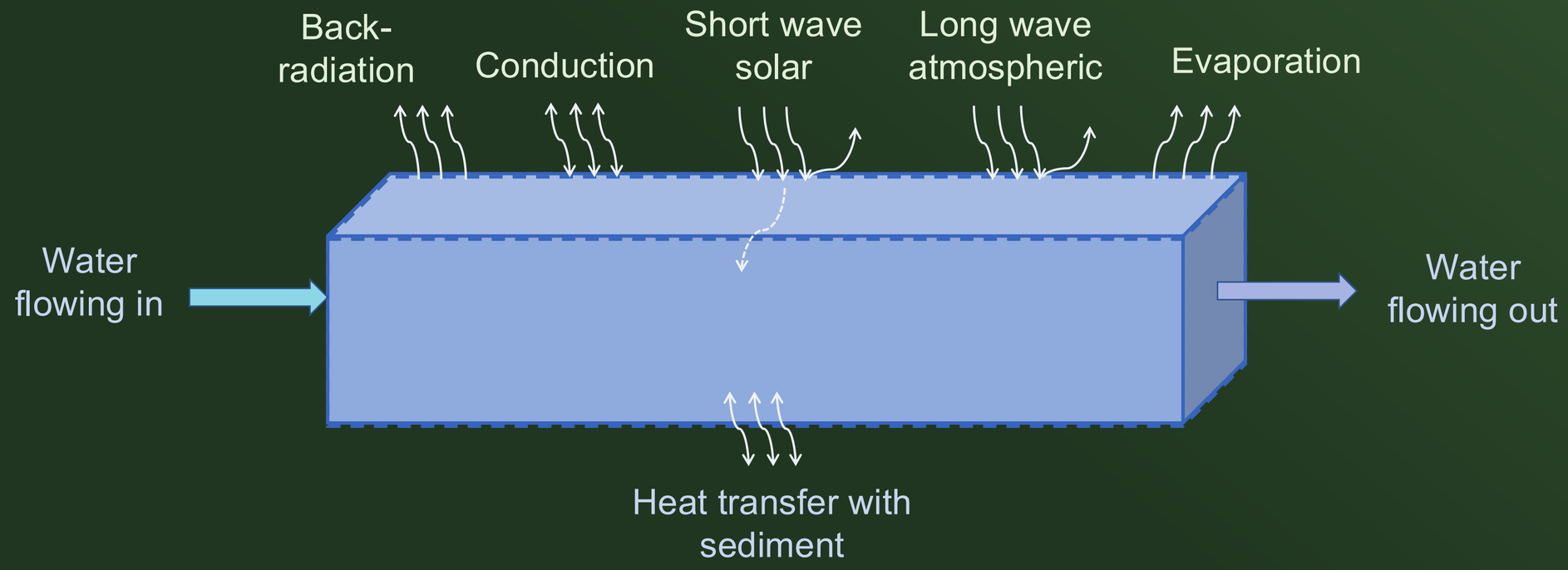
(Heat energy in – Heat energy out = Heat energy stored)

Thermal Impact Analysis, Basic Approach

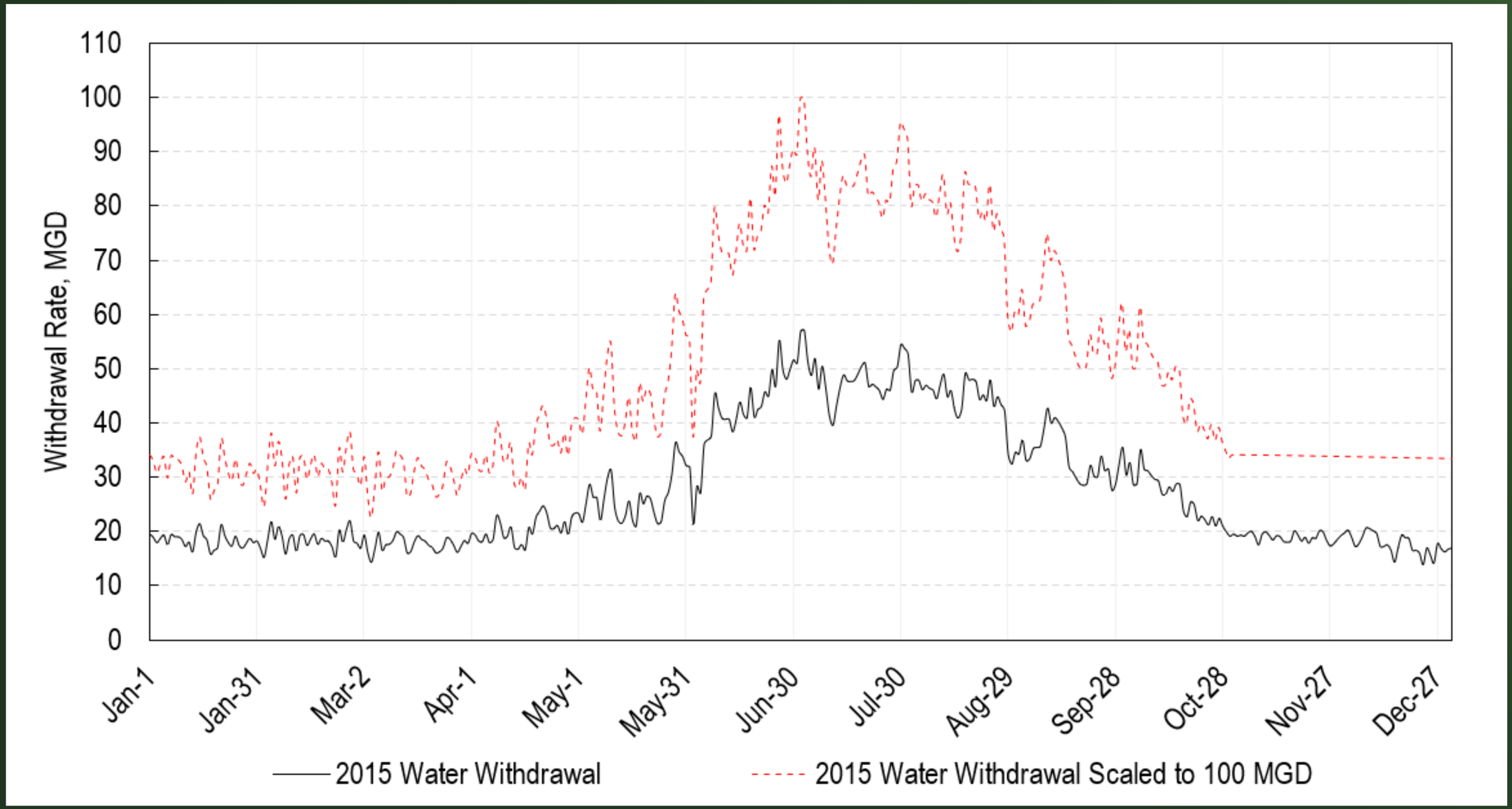
- Start with a well-calibrated hydrodynamic and temperature model:
  - Identify if a surface water model has been developed.
  - Review the calibration and update as needed.
  - Assess if the model was used in a TMDL (critical condition) – adds credibility if the same model and model year used in the TMDL is applied in the thermal impact analysis (e.g., 2015 was a very dry year and used for some TMDLs in Oregon).
  - Target April 1 to October 1 (summer period of elevated temperature).
- Develop a Baseline Scenario:
  - Include whatever withdrawals you are already permitted (previous 401 WQ Certification) to use.
    - Not what you are actually using.
    - Not your current full water rights.
    - If it's a new withdrawal then it's zero.
- Develop a Future Scenario(s):
  - Include the maximum withdrawal amount your Project is designed for.

Thermal Impact Analysis, Baseline

- What you need:
  - Daily withdrawal pattern for the critical low flow year (e.g., 2015 if the model was developed for 2015).
  - Scale up to maximum withdrawal currently permitted for (see next slide).

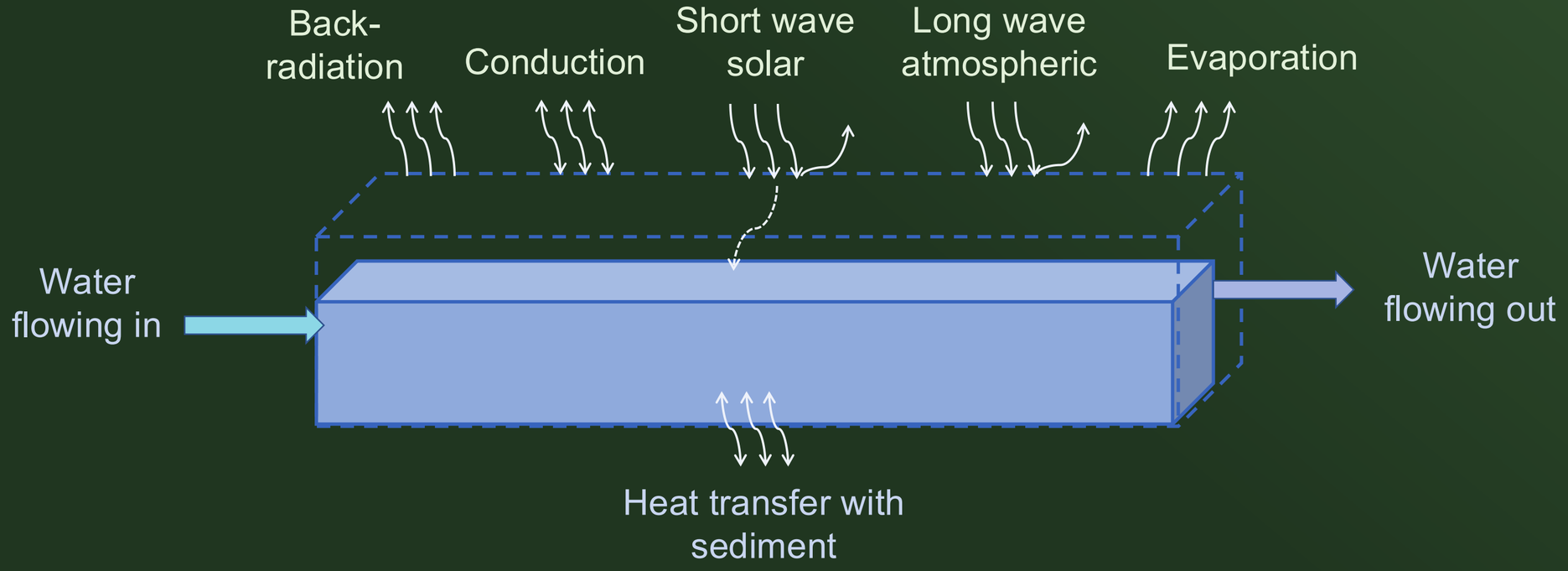


Thermal Impact Analysis, Baseline

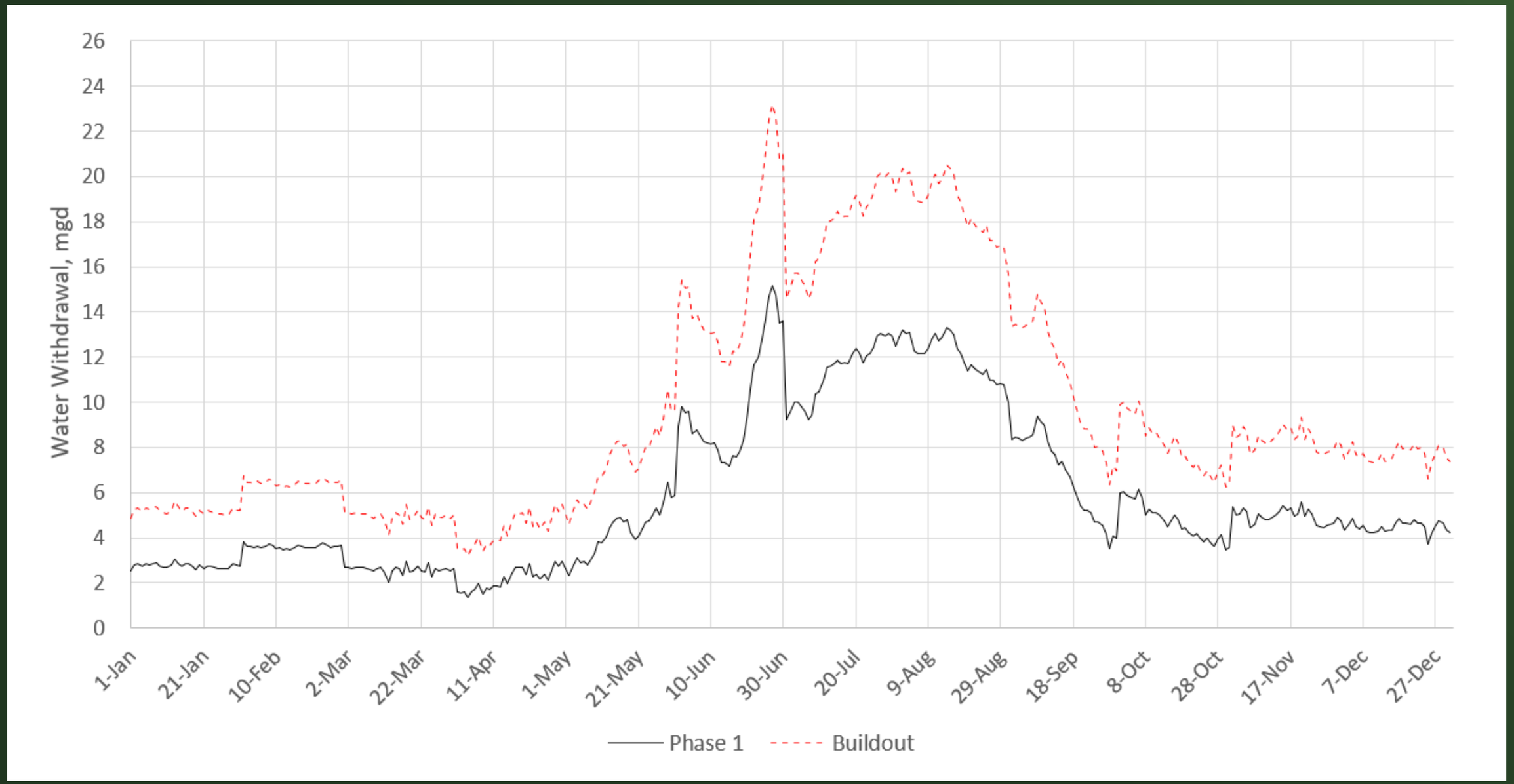


Thermal Impact Analysis, Future Scenario(s)

- Changes the velocity of the river (less flow => lower velocity).
- Thermal impacts continue downstream, but does decrease over distance.
- Less volume, same environmental forcings...
  - Results in warmer water after same time.
  - Results in less time to warm up to same temperature.

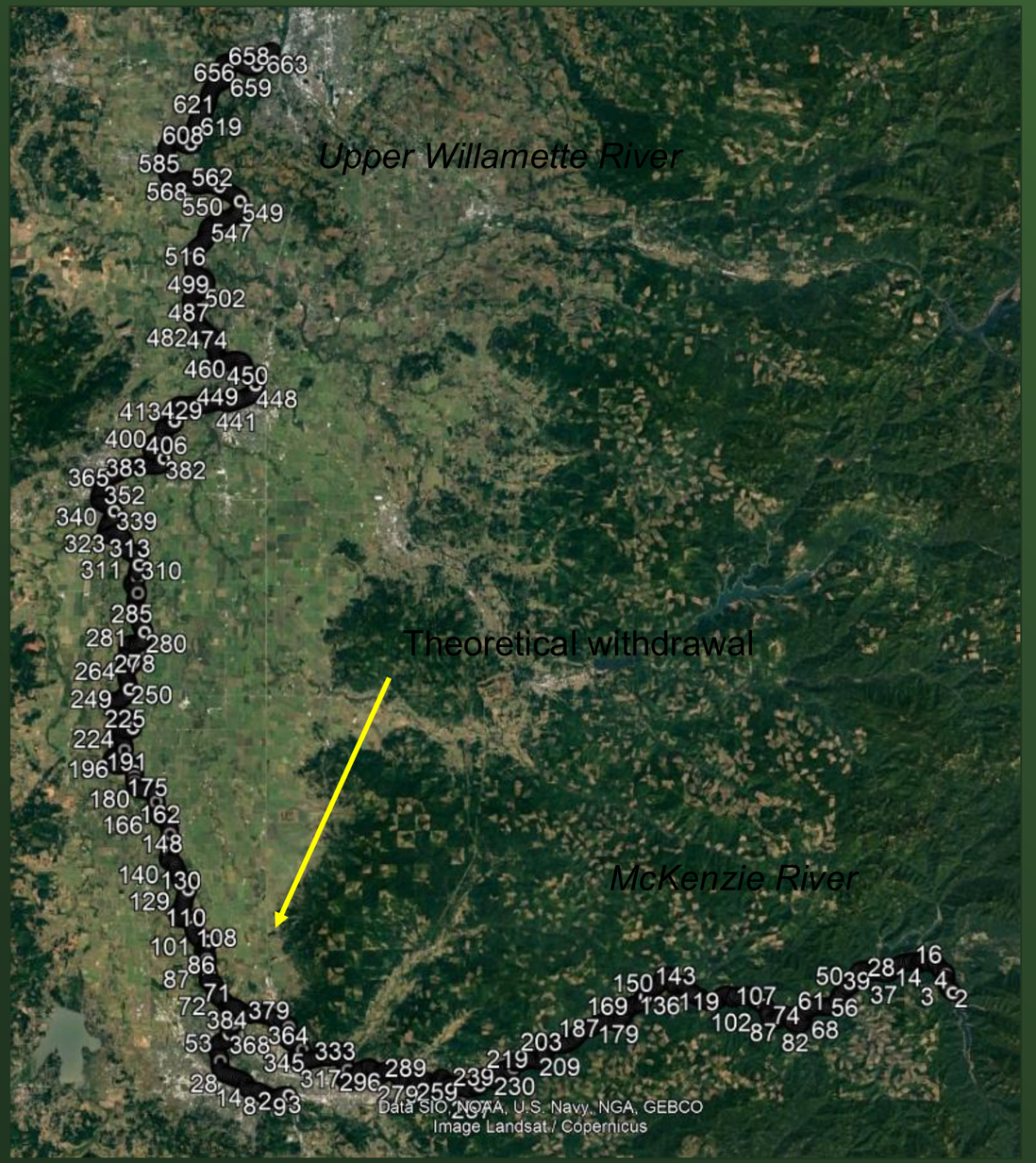


Thermal Impact Analysis, Future Scenario(s)



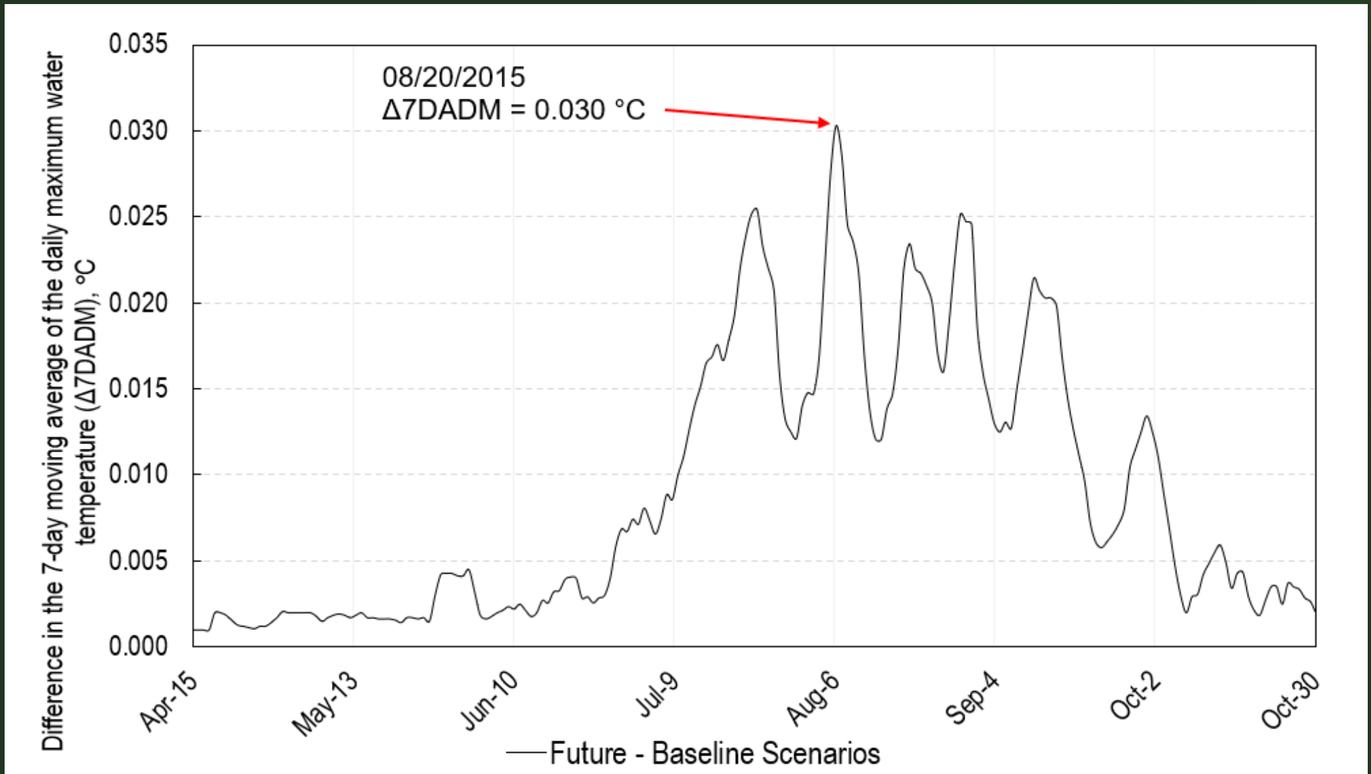
Thermal Impact Analysis
Compare Future to Baseline

- Model produces hourly water temperatures at each model segment.
- Identify the daily maximum water temperature at each segment and over the time period (April – October).
- At each segment calculate the 7-day moving average of the daily maximum water temperatures.
- Calculate Future – Baseline, and find the largest difference.



Thermal Impact Analysis
Compare Future to Baseline

- Calculate Future – Baseline, and find the largest difference.
- Model segment with the largest water temperature difference is called the Point of Maximum Impact (PMI).



Example Results - PMI

Parameter	**Future – Baseline Scenarios**
Maximum Δ7DADM, ℃	**0.03**
River Mile	117
Date	August 20

Thermal Impact Analysis
Calculation of Thermal Impact from Water Withdrawal

- Thermal Impact = Q_{river} x ΔT x CF
  - ΔT is the difference in the 7-day average of the daily maximum water temperature ($T_{future} - T_{baseline}$), in °C
  - Q_{river} is the daily average river flow (Q_{future}), in m^3/s or the 7Q10 flow
- CF: Unit conversion factor = 1,000 kg/m^3 x 86,400 s/day x (1 kcal)/(kg x °C)
  - Units of kcal/day.

Example Results

Month	Average Thermal Impact (Mkcal/day)
April	18.0
May	35.0
June	120.0
July	200.0
August	**250.0**
September	110.0
October	10.0

Thermal Impact Analysis
Next Steps

- Share modeling results and thermal impacts with regulators.
- Document accordingly.
- Based on DEQ review, may need to develop a Thermal Trading Plan (see last year’s talk).
- Thermal Trading Plan documents impacts and, at a high-level, lists mitigation strategies - NOT individual projects.

Thermal Mitigation Strategies
Trading Project Strategies Approved by DEQ

- Flow Augmentation:
  - Can use CE-QUAL-W2 to explore benefit of supplementing flow.
- Stream riparian shading:
  - Shade-A-Lator tool from Oregon DEQ.
    - Used to evaluate differences in streamside shading due to restoration.
  - If the impact is 50 Million kcal/day, DEQ requires a 2:1 ratio for riparian shading, so 100 Mkcal/day is needed to mitigate.
- Narrowing the stream channel.
  - Shade-A-Lator tool from Oregon DEQ.
  - Depending on the size of the project, a model like CE-QUAL-2 may be useful.
- Projects that mitigate water temperature directly.

Questions?

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Hazen



THE VOICE OF THE RIVER
SINCE 1984
HENRY'S FORK
FOUNDATION

Protecting Fisheries: Addressing Low Dissolved Oxygen and Algal Blooms in Island Park Reservoir

Alex Gerling and Ricky Wood, Hazen and Sawyer

May 8, 2026

Agenda

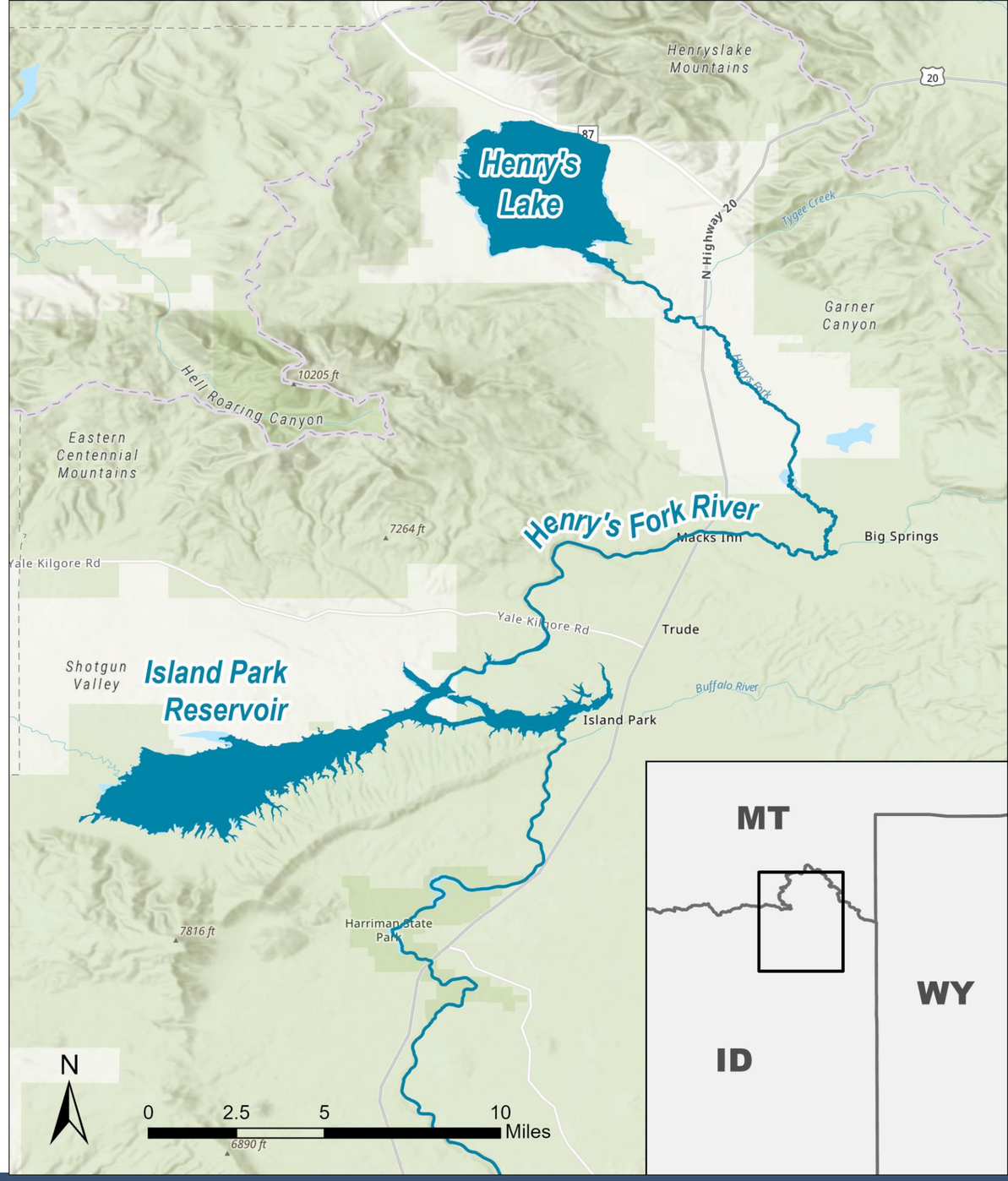
- Project Background
- Addressing Dissolved Oxygen
  - In-Reservoir Data
  - Oxygenation Systems: Alternatives Analysis
- Addressing Eutrophication
  - In-Reservoir Data
  - Management Strategies
- Conclusions



Project Background

Overview

- The Henry's Fork River is a premier destination for fishing
- Regional economy is tied to recreation and tourism
- Henry's Fork Foundation is a nonprofit dedicated to studying and maintaining fisheries on the Henry's Fork River
- Reservoirs such as Island Park Reservoir present challenges for managing fisheries

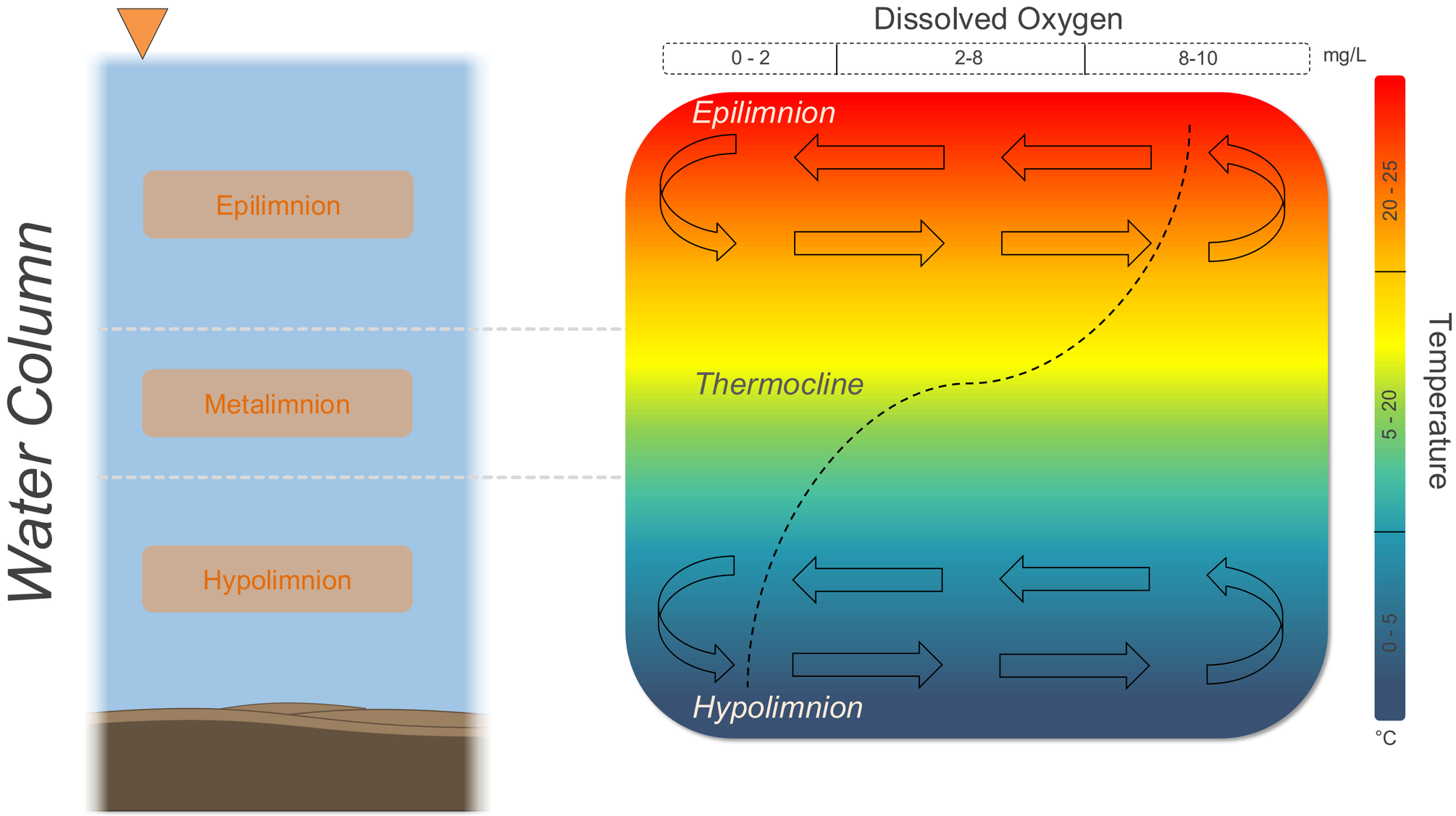


Fisheries and Habitat

- Primary fish species of concern are salmonids
  - Rainbow Trout
  - Cutthroat Trout
  - Brook Trout
  - Kokanee Salmon
- Habitat requirements are highly specific
  - Cold Water (< 23 Celsius)
  - High Dissolved Oxygen (> 5 mg/L)
  - Low turbidity
  - Healthy food chain (plankton, aquatic plants, invertebrates, fish)
- Conditions are even more critical during certain life cycle stages (spawning, egg, alevin, fry)



Overview: Lake and Reservoir Stratification



Hypoxia:
DO < 3 mg/L

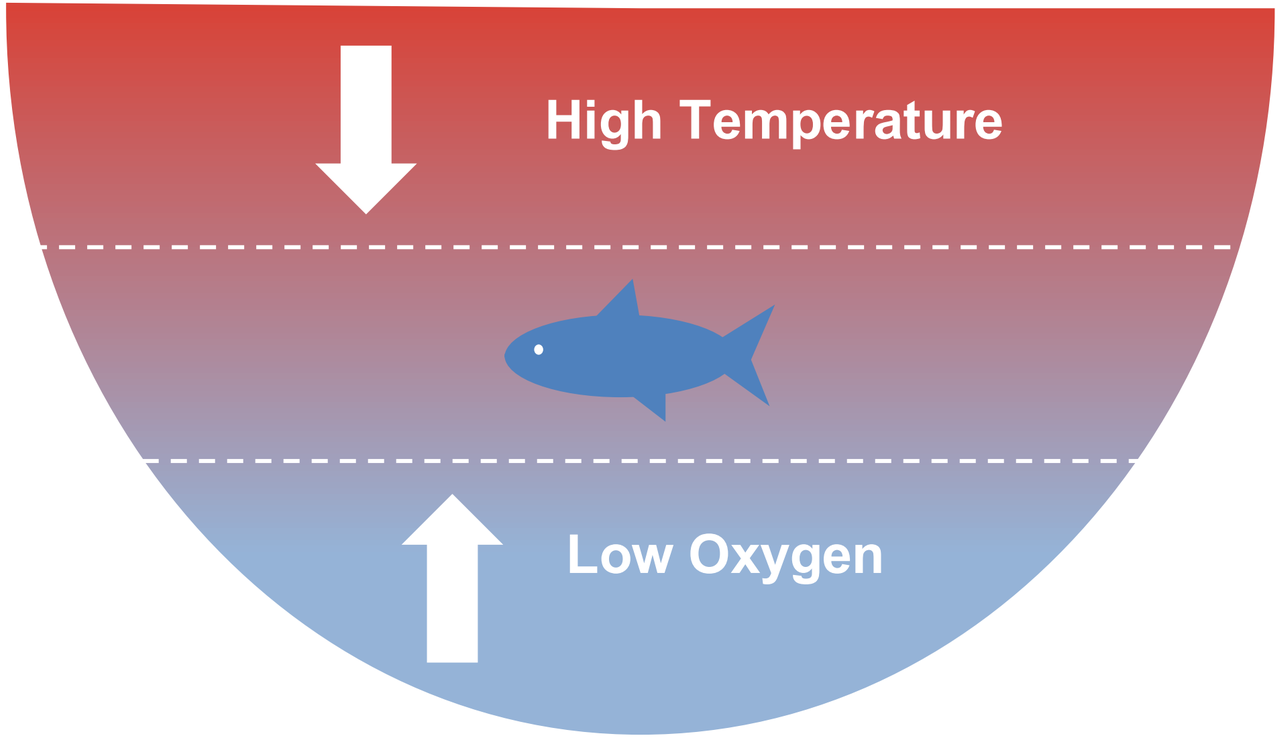
Anoxia:
DO < 0.2 mg/L

Water Quality in Island Park Reservoir

Two primary concerns:

- Small oxythermal area for fish to occupy
  - **Surface is too hot**
  - **Hypolimnion is too low-oxygen**
- Eutrophication
  - **Toxic cyanobacteria blooms**
  - **Disrupted food web**
  - **Increased oxygen demand**

- Oxygenation addresses habitat concerns and can help restore proper ecology through top-down control
- Eutrophication may require additional strategies to address

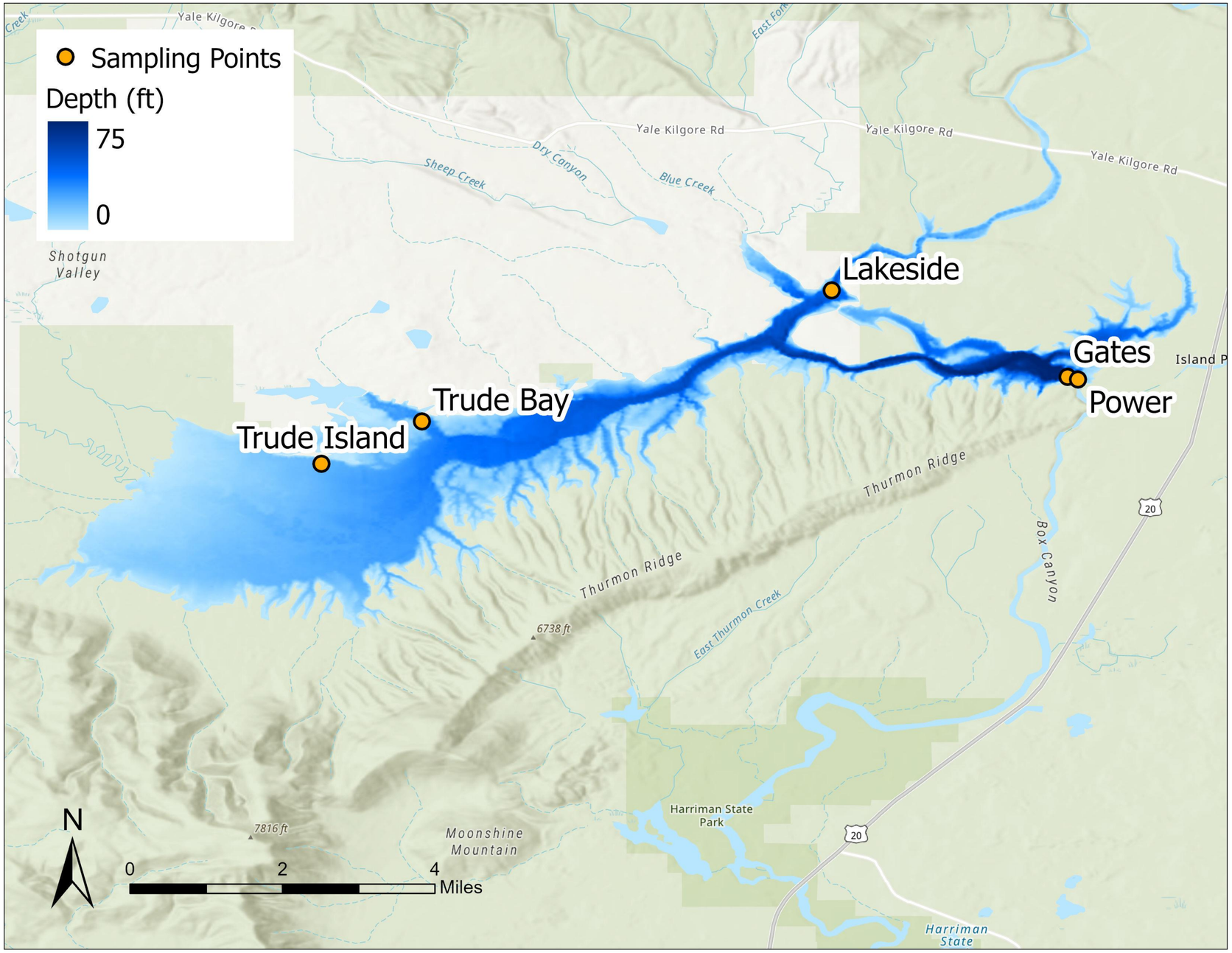


Addressing Dissolved Oxygen

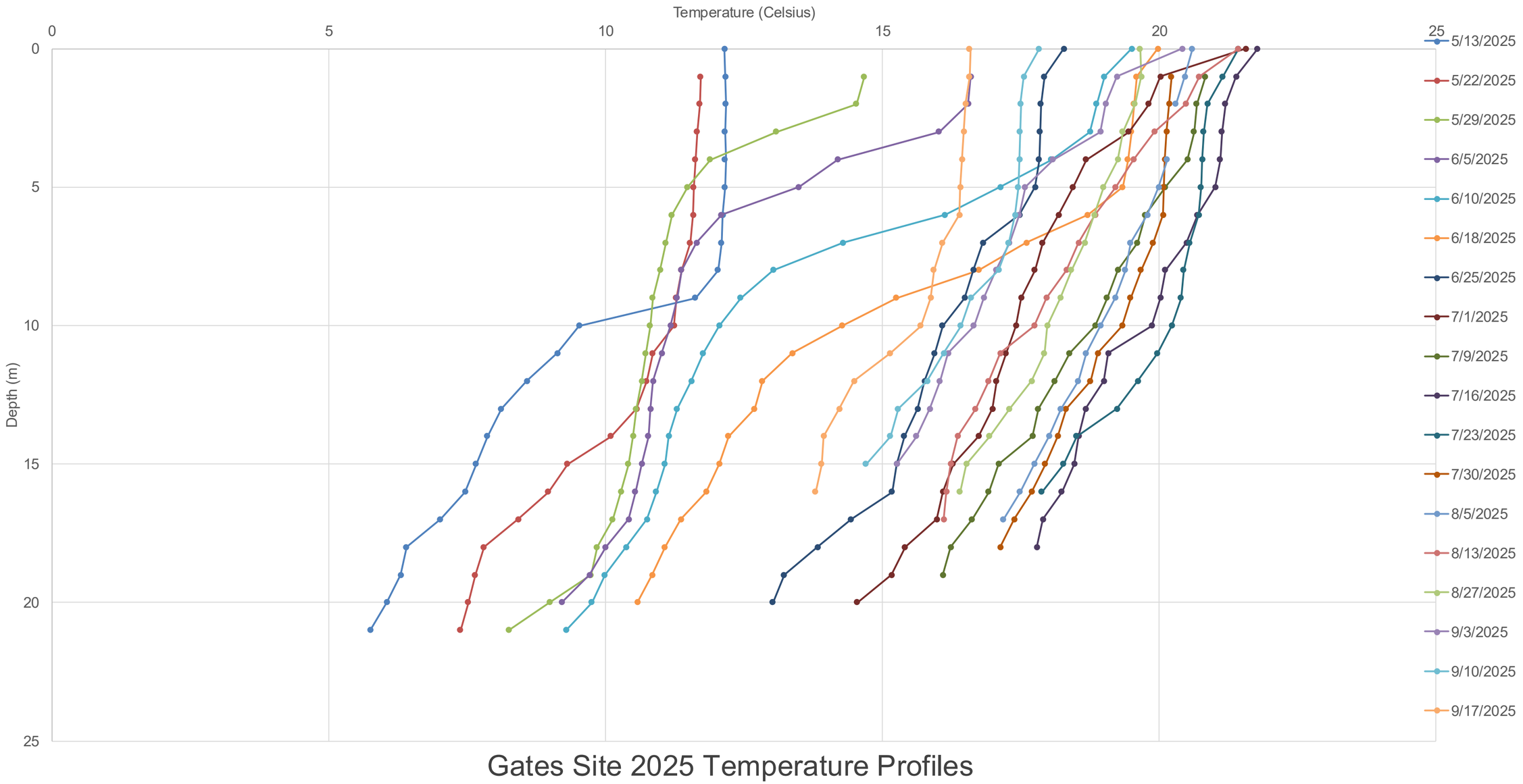
In-Reservoir Data

Weekly Sampling

- Water Quality Profiles
  - **Dissolved Oxygen**
  - **Temperature**
  - **Chl-*a* and Phycocyanin**
  - **Conductivity**
  - **pH**
  - **Turbidity**
- Algal Enumerations
- Cyanotoxin Test Strips
- Nutrients
  - **Top and Bottom**

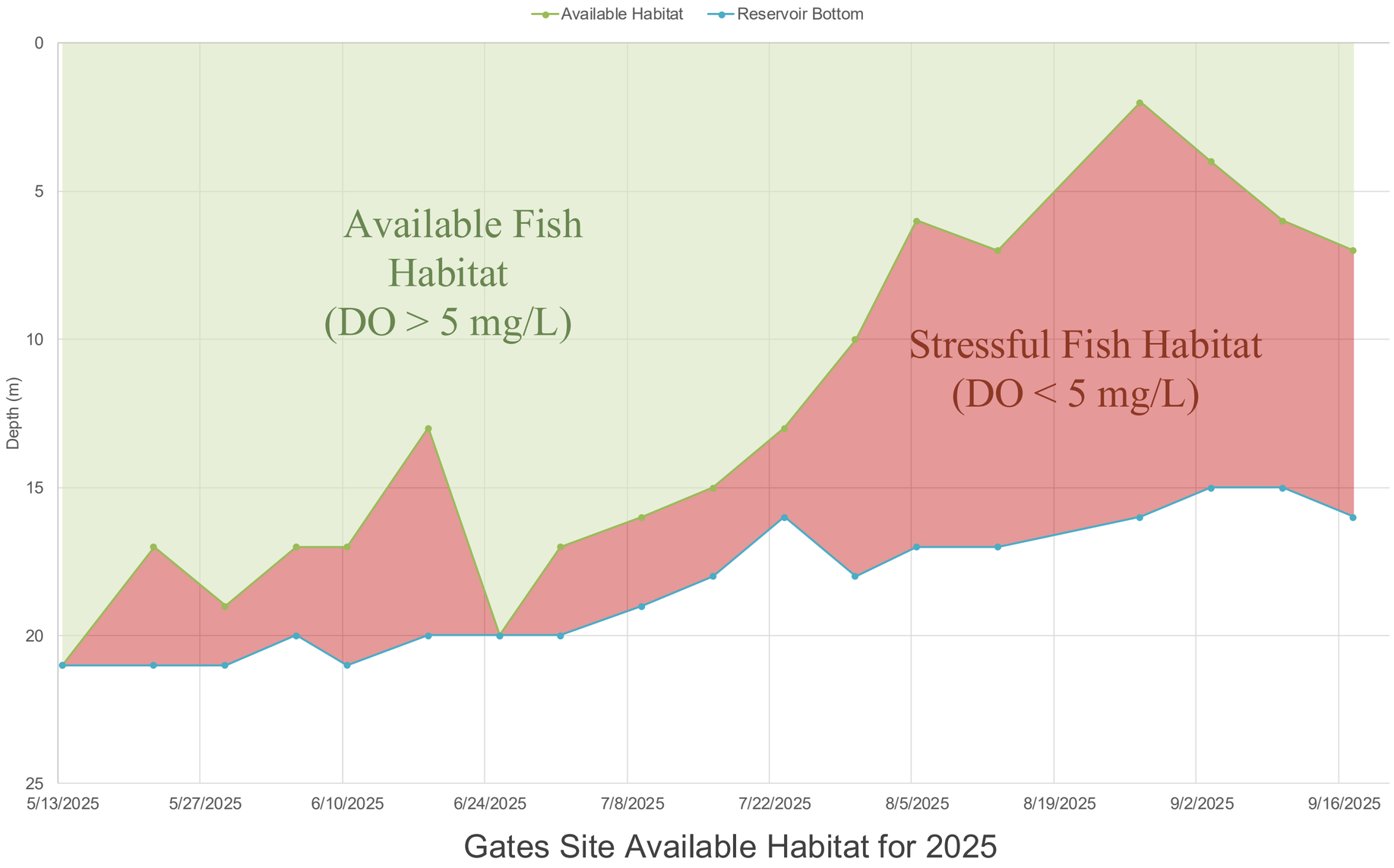


Profiles: Temperature



Gates Site 2025 Temperature Profiles

Profiles: Dissolved Oxygen



Gates Site Available Habitat for 2025

Oxygenation System: Alternatives Analysis

Overview of Alternatives Considered



Diffused Air / Destratification

- Aeration
- Uses high and low flux sections to provide direct and indirect DO infusion
- Destratifies



Speece Cone

- Oxygenation
- 2 options: submerged or on shore application
- Utilizes a chamber to produce oxygenated water that is then reintroduced to the lake
- Maintains stratification



Free Bubble Oxygenation

- Oxygenation
- Utilizes linear micropore hose diffuser to introduce DO into the hypolimnion
- Maintains stratification



Oxygen Saturation Technology

- Oxygenation
- New technology with limited field applications
- Modular submerged chambers that generate supersaturated water that is then reintroduced to the lake
- Maintains stratification

Basis of Design

- Hydrologic Flows dominate oxygen depletion in preliminary analysis
- Effect of DO concentration on maximum delivery is substantial
- Sediment Oxygen Demand was nearly negligible for this analysis
  - Further study is recommended

Parameter	Average Outflow (650 cfs)	Maximum Outflow (1,660 cfs)
Oxygen Depletion from SOD (kg/day)	439	439
Oxygen Depletion from Outflow (kg/day)	7,951	20,309
Total Oxygen Delivery Rate (kg/day)	**8,391**	**20,748**

Key Elements of Alternatives Considered

Key Elements

Oxygen Source

How is oxygen delivered to the system?

Diffuser Type

How is the delivered oxygen infused into the water? How is the enriched water introduced into the water column?

Combating Anoxia Requires the Infusion of Dissolved Oxygen

Key Elements

Oxygen Source

How is oxygen delivered to the system?

Pure Oxygen

FBO
Speece Cone

Compressed Air



DA/D

Liquid Oxygen (LOX)



Lease

Own

Onsite Generation (PSA)



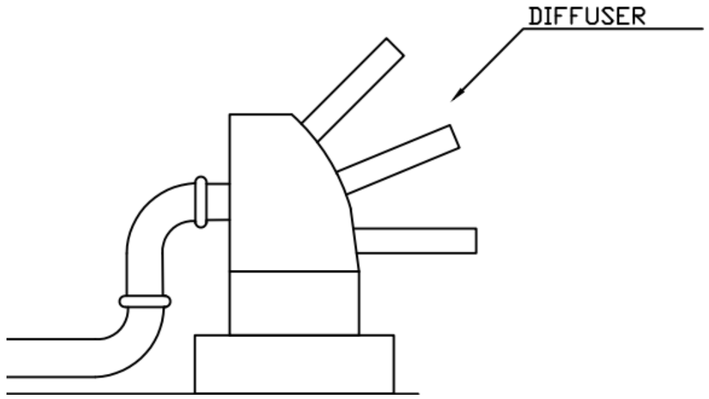
OST

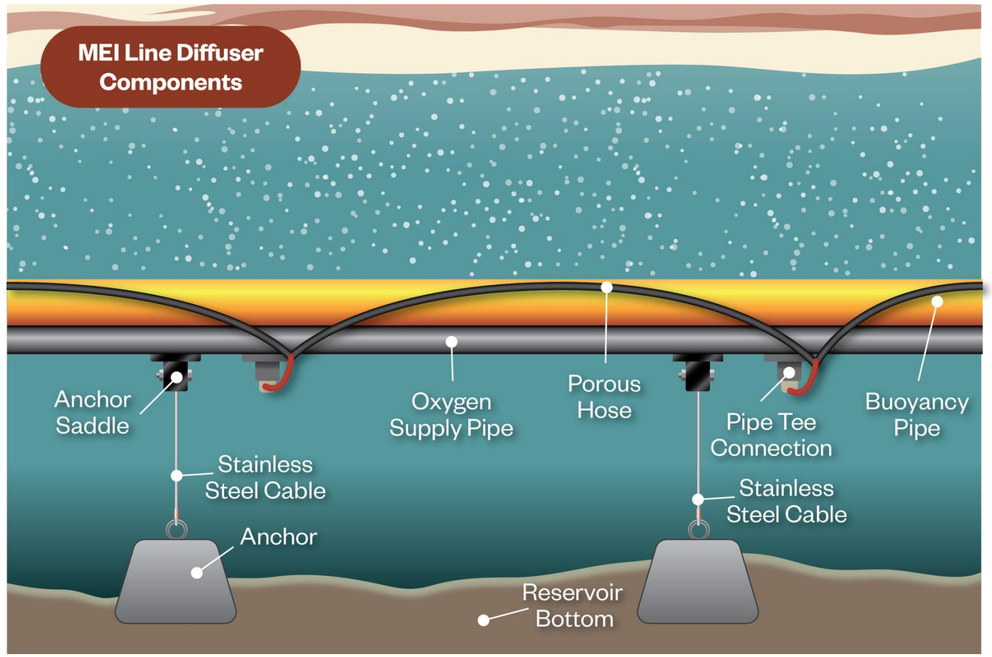
Combating Anoxia Requires the Infusion of Dissolved Oxygen

Key Elements:

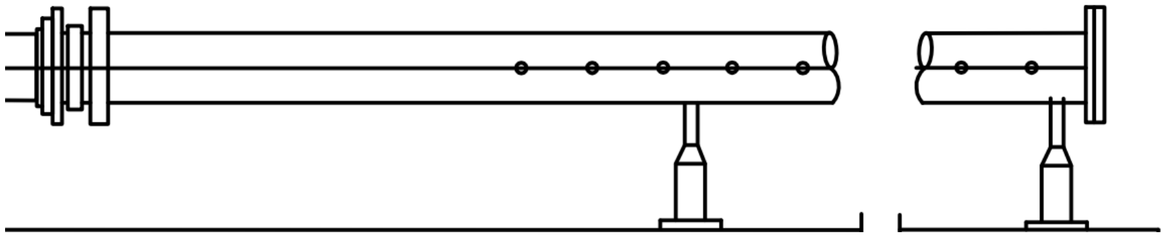
Diffuser Type

- **Linear hose diffuser line (micropore)**
  - *DA/D, FBO*
- **Effluent canon (multi-port diffuser)**
  - *SC*
- **Engineered slotted pipe (multi-port diffuser)**
  - *SC, OST*





TYPICAL DIFFUSER PIPE LENGTH: 100 FT - 150 FT



Overview of Alternatives Considered: Oxygen Supply

Technology	Vendor	Type of System	Oxygen Supply	Diffuser Type
Diffused Air / Destratification (DA/D)	Mobley Engineering Inc. (MEI)	Aeration	Compressed Air	Linear hose diffuser line
Free Bubble Oxygenation (FBO)	Mobley Engineering Inc. (MEI)	Oxygenation	LOX*	Linear hose diffuser line
Speece Cone	ECO_2	Oxygenation	LOX*	Slotted Pipe or Effluent Canon
Oxygen Saturation Technology (OST)	Clarity Resources Group	Oxygenation	PSA	Slotted pipe

**Lease LOX equipment*

Recommended Alternative

Free Bubble Oxygenation (FBO)

- Designed for larger, deeper systems and hydropower facilitation
- Directly oxygenates target area (does not vertically mix)
- Use of LOX and buoyancy line reduced maintenance costs

Unselected Alternatives:

- Speece Cone: Potentially viable, but higher maintenance costs, lower delivery rate, and smaller spatial extent
- Oxygen Saturation Technology (OST): Less field-verified applications, not practical for large delivery rates
- Diffused Air/Destratification (DA/D): Not feasible for reservoir size and depth



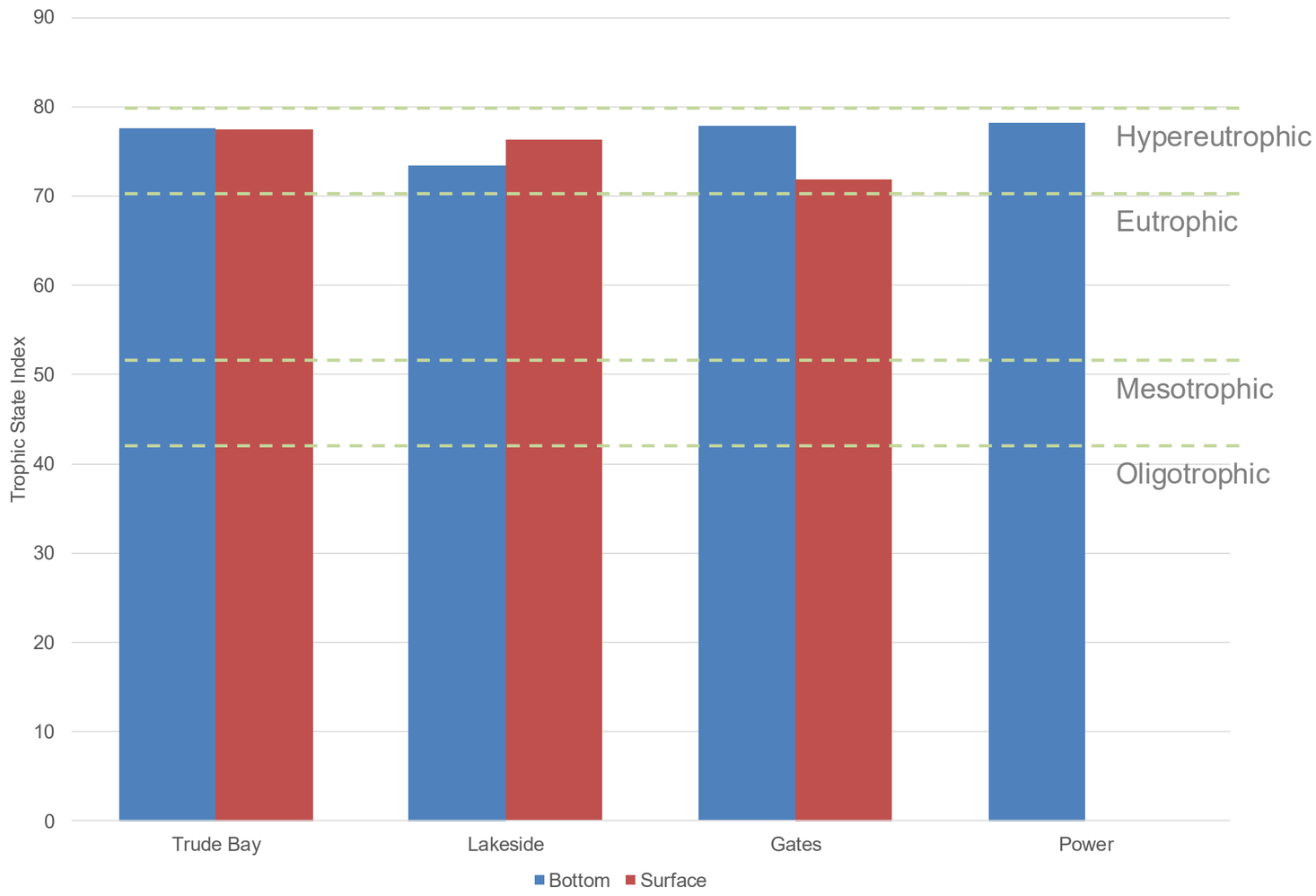
Addressing Eutrophication

In-Reservoir Data

Trophic State Index: TP

- TSI in Island Park Reservoir is ***hypereutrophic*** using total phosphorus
- High phytoplankton growth, likely causing oxygen depletion and other ecological impacts

$$TSI_{TP} = 14.42 \ln TP + 4.15$$



Overview of Nutrients

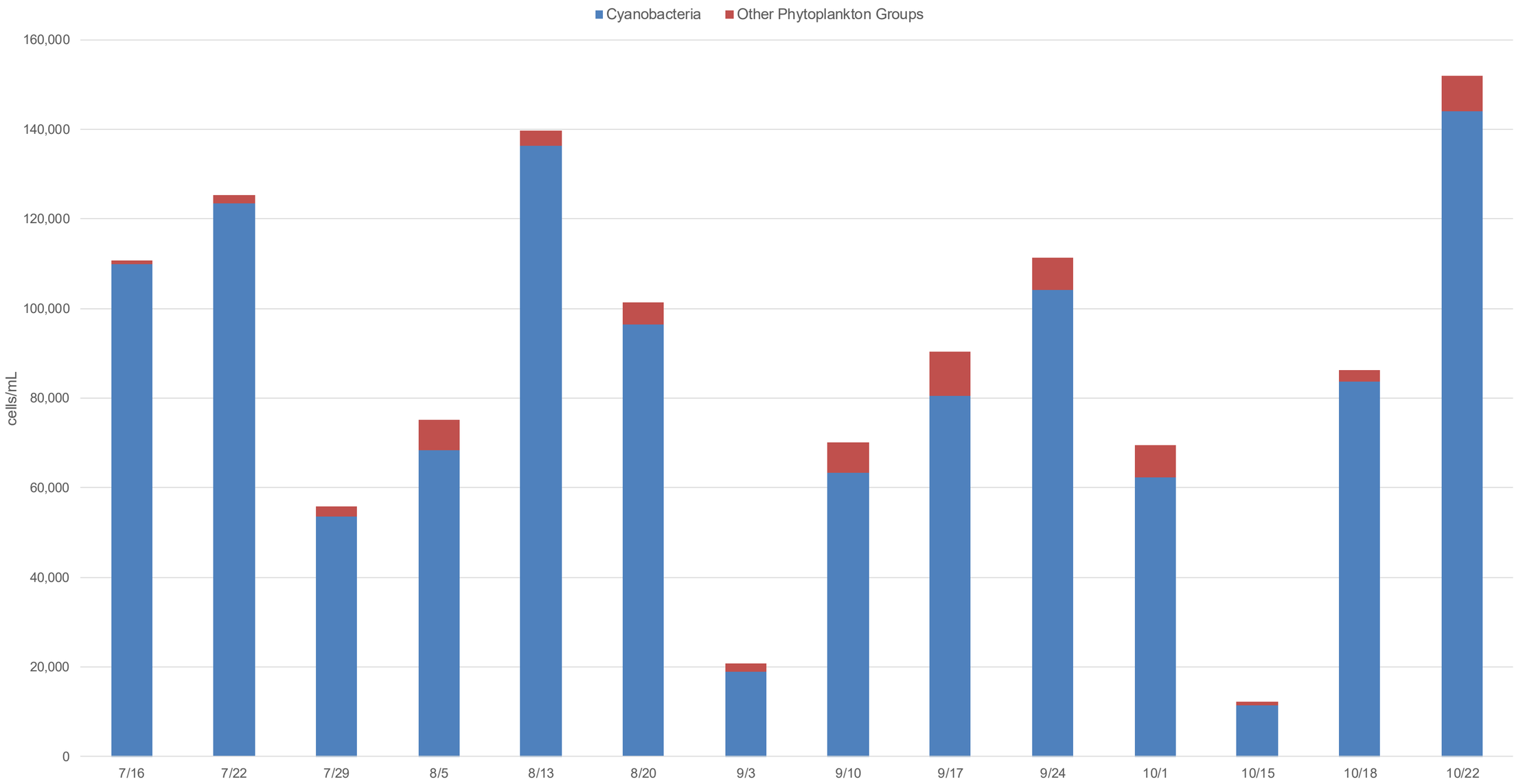
- TP very high throughout water column
  - Key macronutrient for phytoplankton growth
- TN:TP Ratio < 16
  - Indicates nitrogen-limited growth
  - Favors nitrogen-fixing cyanobacteria





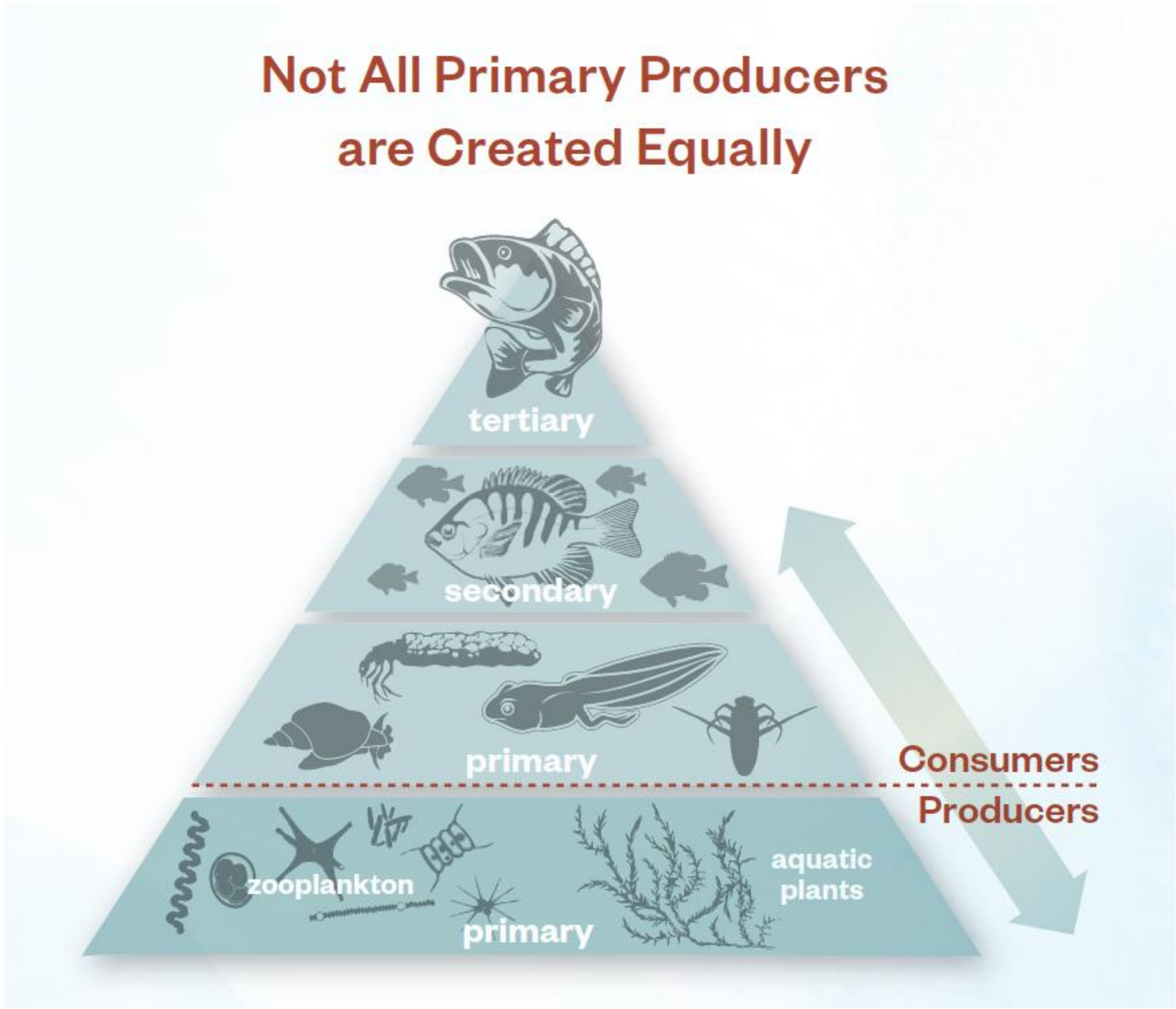
Parameter	2025 Seasonal Average
Total Phosphorus (mg/L)	0.171
Total Nitrogen (mg/L)	0.30
Ammonia (mg/L)	0.110
Nitrate & Nitrite (mg/L)	0.035
TKN (mg/L)	0.26
Orthophosphate (mg/L)	0.015

Phytoplankton Enumerations – Cyanobacteria Dominance



Impacts of Eutrophication

- Oxygen depletion via respiration
  - Diurnal cycle can cause fish kills
- Toxicity
  - Cyanotoxins exert a direct pressure on fish populations
- Disrupted food web
  - Reduced macrophytes, invertebrates, and fish populations
  - Turbidity reduced sunlight penetration
  - Altered nutrient cycling
- Risk to recreators



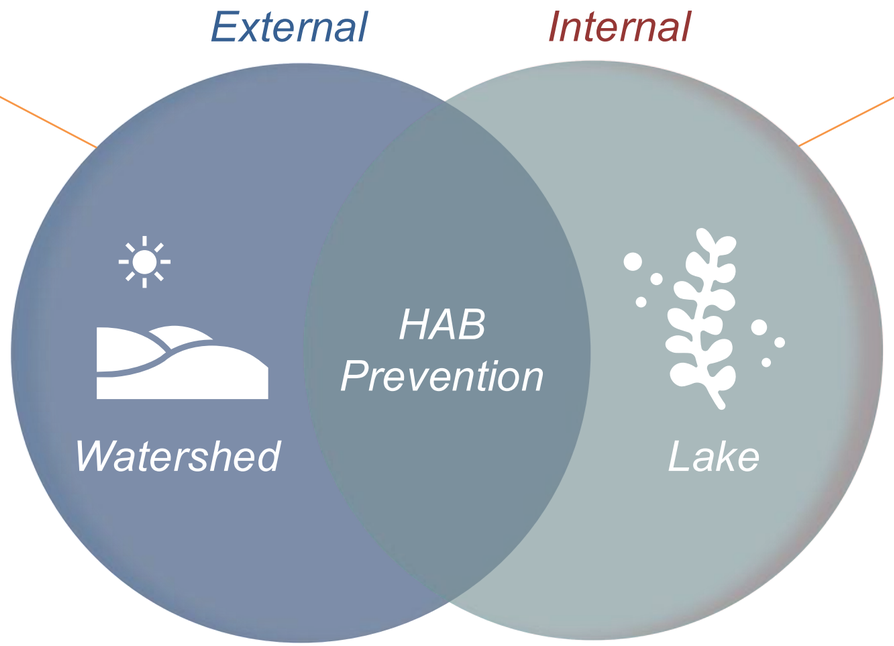
Management Strategies

Core Components of Source Water Protection and Management

No one “Silver Bullet” Solution

Source Water Protection

- Maintain quality of receiving waters
- Offset anthropogenic impact
- Watershed based



Protection ≠ Management

Source Water Management

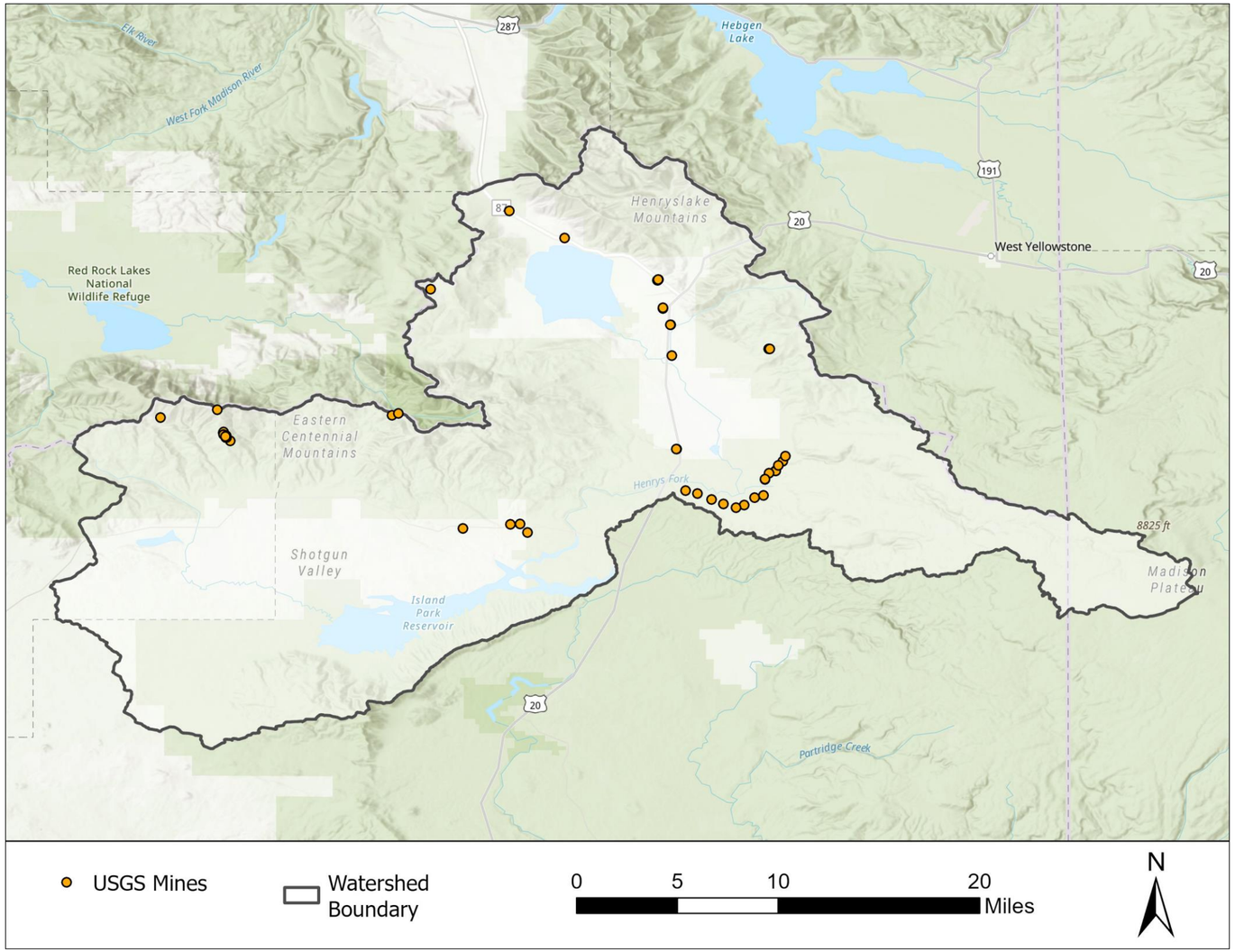
- Restore or maintain quality of source water
- Buffer impact of external influences
- In situ management

Source Water Protection: Watershed Nutrient Sources

Potential Sources

- Naturally occurring in surrounding geologic formations
- Septic systems
- Cattle ranching
- Phosphorus mines

Targeted watershed monitoring is recommended to determine sources



Watershed Phosphorus Mines (USGS)

Source Water Management: In-Reservoir Strategies

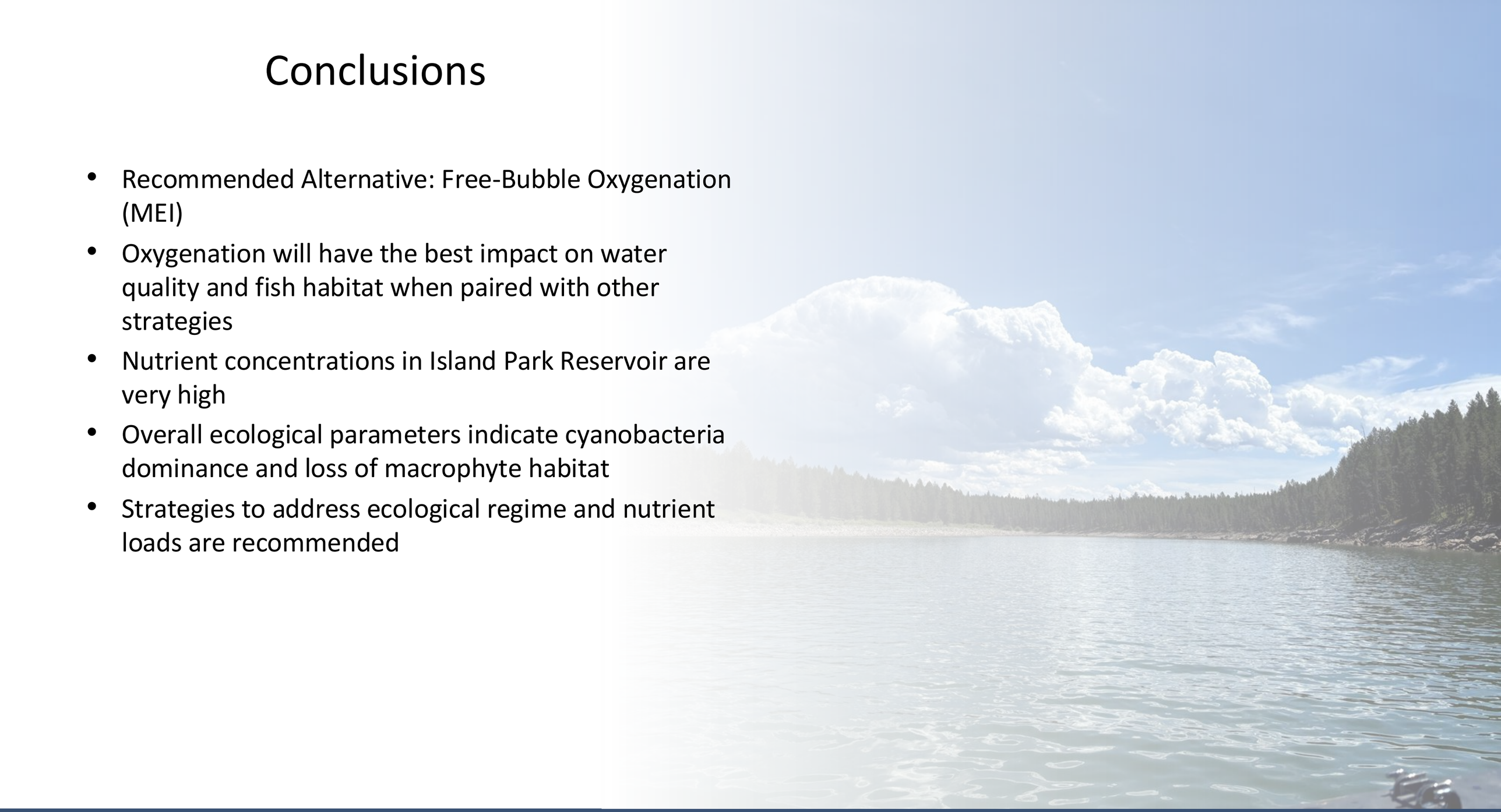
- Continued Routine Monitoring
  - Establishes the basis for long-term management
- Address impacts of motorized watercraft
- Algaecide
  - Hydrogen peroxide
- Littoral Zone Restoration



Conclusions

Conclusions

- Recommended Alternative: Free-Bubble Oxygenation (MEI)
- Oxygenation will have the best impact on water quality and fish habitat when paired with other strategies
- Nutrient concentrations in Island Park Reservoir are very high
- Overall ecological parameters indicate cyanobacteria dominance and loss of macrophyte habitat
- Strategies to address ecological regime and nutrient loads are recommended



Hazen