Hypolimnetic Oxygenation for Indian Creek Reservoir Restoration

Bill Faisst
CA/NV
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Indian Creek Reservoir

- High desert lake
- Little runoff
- ~1500 acre foot volume
- Regulatory requirements (TMDL approved July 2003)

TMDL = Total Maximum Daily Limit
South Tahoe Public Utilities District
Indian Creek Reservoir

- Constructed in mid-1960’s
- Received South Tahoe effluent for 20 plus years, to avoid harming Lake Tahoe but transferred lots of nutrients to ICR
- Converted to recreation only in ~1990
- Sustained with water from Carson River
- Showed water quality problems in 1980’s (blue green algae blooms, low transparency and DO)
- Need to control Total P, DO and algae
Indian Creek Reservoir Location

Lake Tahoe

Nevada

California
STPUD Project Goals

- Improve water quality and meet regulations (comply with TMDL)
- Preserve/enhance fishery
- Minimize visual impacts
- Control costs
- Carbon neutral?
Water Quality Indicator Parameters and Target Values (TMDL)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Interim Target</th>
<th>Final Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Phosphorus (TP)</td>
<td>≤0.04 mg/L, annual mean</td>
<td>≤0.02 mg/L, annual mean</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>30-day mean – 6.5 mg/L</td>
<td>Whichever is most restrictive:</td>
</tr>
<tr>
<td></td>
<td>7-day mean min. – 5.0 mg/L</td>
<td>i) DO depressed not more than 10%;</td>
</tr>
<tr>
<td></td>
<td>1-day min. – 4.0 mg/L</td>
<td>ii) DO % Saturation ≥ 80%; or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii) DO ≥ 7.0 mg/L</td>
</tr>
<tr>
<td>Secchi Depth (SD)</td>
<td>Summer mean ≥ 2 meters</td>
<td></td>
</tr>
<tr>
<td>Chlorophyll a (Chl-a)</td>
<td>Summer mean ≤ 10 mg/cu meter</td>
<td></td>
</tr>
<tr>
<td>Trophic State Index (TSI)</td>
<td>Composite index ≤ 45 units</td>
<td></td>
</tr>
</tbody>
</table>
Facts about Water and Oxygen

- Highest water density is at 4°C
- Saturation dissolved oxygen varies with temperature
- Higher DO at lower temperature
- Higher DO at higher pressure

Density/Temperature Relationship for Distilled Water. Shaded areas show relative difference in density for 5°C temperature changes.
Oxygen in Water

Light in Water

Influence on Dissolved Oxygen Capacity

Light versus depth profiles for a clear lake ($k=0.2 \text{ m}^{-1}$) and a turbid lake ($k=0.9 \text{ m}^{-1}$).
What the heck is a hypolimnion?

Lake Cross-Section
What happens in a lake or reservoir and why is DO important?

Rain and atmospheric fallout
(dust, mercury, NO\textsubscript{x})

Stream runoff
sediment
nutrients, trace constituents
(metals, organics)

Organics
P & N
methylmercury sulfide

Anoxic sediment
What happens at Indian Creek Reservoir?

Annual Cycle of Thermal Stratification in a Dimictic Lake

- Early Summer
- Late Summer
- Early Fall
- Spring Turnover
- Winter
- Fall Turnover
ICR TMDL Monitoring Sites
ICR February 2007 Profiles

Isothermal, Cold Water at Maximum Density
ICR April 2005 Profiles

Stratification Starts, DO Drops at Depth
ICR June 2005 Profile

Water Warms, DO Falls
ICR July 2005 Profiles

ICR-1
Temperature

ICR-1
Dissolved Oxygen

Strongly Stratified

Decreasing DO
ICR August 2005 Profiles

ICR-1
Temperature
0 5 10 15 20 25
Temperature, C
Depth, ft

ICR-1
Dissolved Oxygen
0 2 4 6 8 10 12
mg/L D.O.
Depth, ft

Strong Thermocline

No DO!
ICR September 2005 Profiles (after Fall Turnover)

**Temperature**

- Depth, ft
- Temperature, C
- Completely Mixed

**Dissolved Oxygen**

- Depth, ft
- mg/L D.O.
- DO to Bottom

Completely Mixed
ICR December 2005 Profiles

ICR-1
Temperature

ICR-1
Dissolved Oxygen

Temperature, C

Depth, ft

mg/L D.O.

Depth, ft
If hypolimnion becomes anoxic, what do you do?

- Mechanically mix the lake—lots of energy, uniform temperature
- Aerate the lake—lots of energy, uniform temperature
- Oxygenate the lake—lots of oxygen, possibly uniform temperature
- Oxygenate the hypolimnion-focused oxygen, preserve stratification and colder bottom water
Oxygenate the hypolimnion?

- Soaker hoses
- Bubble plumes
- Speece cone
ICR HOS Project Requirements

- Needed about 1,000 lb/day of oxygen
- Had limited electrical service
- Reached by poor quality roads
- Couldn’t interfere with recreation/fishery
- Needed low visual impacts
- Should be highly reliable and easy to operate
What is a good solution for ICR?

- Colder water for fish
- DO at depth for fish
- Summer stratification maintained
- DO control of nutrient cycling

→ HOS with Speece Cone
ICR Bathymetry
Speece cone fabrication at STPUD shop
Speece cone and diffuser during field assembly
Pipe installation in lake and across beach
Oxygen equipment (PSA system) and electrical service

(PSA = Pressure Swing Absorption)
Did HOS help at ICR?
February and September 2012 Data

ICR-1 Temperature

ICR-1 Dissolved Oxygen

ICR-1 Dissolved Oxygen

Feb.

Feb.

Sept.
February and September 2013

July 2013 ICR-1
Temperature

July ICR-1
Dissolved Oxygen

September 2013 ICR-1
Temperature

September ICR-1
Dissolved Oxygen
New Data—July 2014

- **Temperature**
  - July 2014 ICR-1
  - Depth vs. Temperature

- **Dissolved Oxygen**
  - July 2014 ICR-1
  - Depth vs. Dissolved Oxygen (mg/L D.O.)
Did HOS help at ICR?

**INDIAN CREEK RESERVOIR**

- ICR-1
- ICR-3
- ICR-5

**Dissolved Oxygen (in mg/L)**

- Interim Target ($\geq 4.0$ mg/L)

**Dates**
- 1-Jan-13
- 2-Apr-13
- 2-Jul-13
- 1-Oct-13
- 1-Jan-14
Did HOS help at ICR?

**INDIAN CREEK RESERVOIR**

- **TOTAL PHOSPHORUS**

<table>
<thead>
<tr>
<th>ANNUAL MEAN (mg/L)</th>
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<tbody>
<tr>
<td>0.02</td>
</tr>
<tr>
<td>0.03</td>
</tr>
<tr>
<td>0.04 (Interim Target)</td>
</tr>
<tr>
<td>0.05</td>
</tr>
<tr>
<td>0.06</td>
</tr>
<tr>
<td>0.07</td>
</tr>
<tr>
<td>0.08</td>
</tr>
</tbody>
</table>

Year:
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
Secchi Disk—Used to measure water clarity
Did HOS help at ICR?
Did HOS help at ICR?

INDIAN CREEK RESERVOIR

CHLOROPHYLL - a (mg/m³)

SUMMER MEAN

TMDL Target (≤ 10.0 mg/m³)
## Carlson Trophic State Index

<table>
<thead>
<tr>
<th>TI</th>
<th>Chl</th>
<th>P</th>
<th>SD</th>
<th>Trophic Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30—40</td>
<td>0—2.6</td>
<td>0—12</td>
<td>&gt;8—4</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td>40—50</td>
<td>2.6—20</td>
<td>12—24</td>
<td>4—2</td>
<td>Mesotrophic</td>
</tr>
<tr>
<td>50—70</td>
<td>20—56</td>
<td>24—96</td>
<td>2—0.5</td>
<td>Eutrophic</td>
</tr>
<tr>
<td>70—100+</td>
<td>56—155+</td>
<td>96—384+</td>
<td>0.5—&lt;0.25</td>
<td>Hypereutrophic</td>
</tr>
</tbody>
</table>
Did HOS help at ICR—Trophic State Index?

![Graph](image-url)
Conclusions

- TP decreased—0.07 to 0.03 mg/L
- DO increased—> 6.0 mg/L
- Secchi disk depth improved~1.5 to ~4 m
- Chlorophyll a decreased > 10 fold
- HOS operation addressed TMDL requirements
Is HOS important beyond algae?

Control Program for Mercury in California’s Reservoirs
Speece Cone for ICR

NOTES:
1. FOR 8-IN DIA OUTLET PIPE, SUPPORT AT ENDS. PROVIDE EVENLY SPACED OUTLET SLOTS IN LOWER HALF OF PIPE WITH A TOTAL OPEN AREA OF AT LEAST 1 SQ FT.
2. ALL FASTENERS SHALL BE TYPE 316 STAINLESS STEEL. FOR SS NUTS ON SS BOLTS, COAT ALL THREADS WITH ANTI-SEIZE COMPOUND BEFORE ASSEMBLY OR USE BRONZE NUTS ON SS BOLTS.
3. DIFFUSER PORTS SHALL BE ORIENTED 5 DEGREES BELOW HORIZONTAL.
4. ACCESS PORT SHALL 24-INCH DIA WITH HINGED COVER.
5. PROVIDE 1/2" MESH SS SCREEN ON INTAKE.
6. PROVIDE 3.4 CU. FT. CONCRETE WEIGHTS STRAPPED TO 8" HOPE 15" O.C. WI/ (2) SS STRAPS AND BOLTS. PROVIDE 1/8" NEOPRENE PADDING BETWEEN PIPES, WEIGHTS AND STRAPS.
7. PROVIDE 3/4" ELL VENT AT TOP OF TEE.
HOS Schematic
What happens to a bubble in water?

- Buoyancy
- Drag

- Smaller bubbles rise more slowly = more time

- $O_2$ dissolves in water

- Bubble shrinks

- More time = more $O_2$ transfer
- Smaller bubbles = more surface area/unit volume
Problem solution integrates multiple disciplines under the lead of a civil/environmental engineer or geologist

- Limnologist
- Oceanographer
- Geotechnical engineer/diver
- Civil engineer
- Structural engineer
- Electrical engineer
- Instrumentation engineer
- Environmental specialist
- Green energy specialist