Development of Nutrient Criteria to Support Recreational Uses of Texas Reservoirs

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Sampling Design Workshop
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Topics

- Conceptual Model
- Case Studies
- Historical Data from Study Reservoirs
- Design of User Surveys
- Analysis of User Survey Data
Causal Pathways Linking P Loads to Water Uses

Lake Inputs

Nutrients

Algal Growth

Water Quality

Water Uses

Watershed P Load → Lake Mean Phosphorus → Mean Chlorophyll-a → Algal Blooms

Sediments

Transparency

DO Depletion

Ammonia

Turbidity

Taste & Odor

Toxic Organics

Aesthetics

Recreation

Fisheries

Water Supply

Other Controlling Factors
Conceptual Model for Lake Phosphorus TMDLs

Lake Inputs
- Watershed P Load

Nutrients
- Lake Mean Phosphorus
- Mean Chlorophyll-a
- Sediments

Algal Growth

Water Quality
- Algal Blooms
- Transparency
- DO Depletion
- pH
- Ammonia
- Turbidity
- Taste & Odor
- Toxic Organics

Water Uses
- Aesthetics
- Recreation
- Fisheries
- Water Supply

Source

TMDL

Modeled

Surrogate Goal

Ultimate Goal Support Use

Assumed or Empirically Calibrated
### Chlorophyll-a Nuisance Values for South African Impoundments

<table>
<thead>
<tr>
<th>Instantaneous Chl-a (ppb)</th>
<th>Nuisance Value (Use Impact)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>No Problems Encountered</td>
</tr>
<tr>
<td>10-20</td>
<td>Algal Scums Evident</td>
</tr>
<tr>
<td>20-30</td>
<td>Nuisance Conditions</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>Severe Nuisance Conditions</td>
</tr>
</tbody>
</table>

Based upon simultaneous water quality sampling & user surveys

Statistical Basis for Mean Chlorophyll-a Criteria
Frequency of Severe Nuisance Blooms vs. Mean Chl-a

Based upon Log-Normal Frequency Distribution Models Calibrated to Various Datasets
Walker, W., "Statistical Bases for Mean Chlorophyll-a Criteria", Lake & Reservoir Mgt, 1985
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Algal Bloom Frequencies vs. Mean Chlorophyll-a
Cherry Creek Reservoir, Colorado

Y Axis: Percent of Days in July - September with Chl-a Exceeding 10, 20, or 30 ppb
Near-Shore Bloom Frequencies vs. Pelagic Mean TP
Lake Okeechobee, Florida

Havens & Walker, Lake & Reservoir Mgt, 2002
Derivation of P Target for Compliance with pH Standard
Upper Klamath Lake, Oregon

Yearly Means by Lake Region, April-October
Frequency = % of Measurements (All Stations & Depths) Exceeding pH 9
Total P Standard Based upon Transparency
Platte Lake, Michigan

Y-Axis = Frequency of Secchi Depths < 10 feet
Algal Bloom Frequency vs. Total Phosphorus
St. Paul Water Supply

Goal = 25 ppb
Development of a Chlorophyll-a Goal for Lake Pepin, Minnesota

Algal Bloom Frequencies vs. Mean Chl-a in Different Years

Heiskary & Walker, "Establishing a Chlorophyll-a Goal for a Run-of-the River Reservoir" Lake & Reservoir Management, 1995
Topics

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## Summary of Historical Monitoring Data from Study Reservoirs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Ref</th>
<th>First</th>
<th>Last</th>
<th>Count</th>
<th>Chlorophyll-a Samples</th>
<th>TP</th>
<th>Chl-a</th>
<th>Phaeo</th>
<th>Secchi</th>
</tr>
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<tbody>
<tr>
<td>LAKE FORK</td>
<td>R</td>
<td>1990</td>
<td>2001</td>
<td>38</td>
<td>41</td>
<td>12.4</td>
<td>4.0</td>
<td>1.5</td>
<td></td>
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<tr>
<td>LIVINGSTON</td>
<td></td>
<td>1990</td>
<td>2000</td>
<td>39</td>
<td>151</td>
<td>21.9</td>
<td>3.6</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>BRIDGEPORT</td>
<td>R</td>
<td>1990</td>
<td>2001</td>
<td>24</td>
<td>31</td>
<td>5.8</td>
<td>0.1</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>CEDAR</td>
<td></td>
<td>1990</td>
<td>1994</td>
<td>6</td>
<td>74</td>
<td>15.1</td>
<td>5.6</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>HOUSTON</td>
<td></td>
<td>1990</td>
<td>2001</td>
<td>14</td>
<td>243</td>
<td>10.1</td>
<td>6.7</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>GRANGER</td>
<td></td>
<td>1990</td>
<td>1999</td>
<td>11</td>
<td>30</td>
<td>2.7</td>
<td>5.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>GEORGETOWN</td>
<td>R</td>
<td>1990</td>
<td>1998</td>
<td>12</td>
<td>20</td>
<td>1.8</td>
<td>1.3</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>TRAVIS</td>
<td>R</td>
<td>1990</td>
<td>2001</td>
<td>28</td>
<td>53</td>
<td>3.5</td>
<td>1.6</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>CANYON</td>
<td>R</td>
<td>1992</td>
<td>2001</td>
<td>27</td>
<td>45</td>
<td>2.3</td>
<td>2.0</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

Ref = Reference Lake (State/USGS Study)

Samples <= 5 meters, May-September, 1990-2001
2-Dimensional Trophic State Classification System (Walker, 1985) Applied to U.S. Army Corps & Texas Reservoirs

- Corps Reserv Chl-a < 5 ppb
- Chl-a 5-20 ppb
- Chl-a > 20 ppb
- Texas Reserv Chl-a < 5 ppb
- Chl-a 5-20 ppb
- Chl-a > 20 ppb

Chl-a x Secchi (mg/m²)

Total Phosphorus (ppb)

- Algae-Dominated
- Light-Limited
- Turbidity-Dominated

Nutrient-Poor

Nutrient-Limited Biomass

Nutrient-Rich
2-Dimensional Trophic State Classification System (Walker, 1985) Applied to Texas Reservoirs (Long-Term Means)

- **Texas Reserv Chl-a < 5 ppb**
- **Chl-a 5-20 ppb**
- **Chl-a > 20 ppb**

- **High Chl-a**
- **Low Chl-a**

- **Nutrient-Poor**
- **Nutrient-Rich**

- **Light-Limited Biomass**
- **Turbidity-Dominated**

- **Total Phosphorus (ppb)**
- **Chl-a x Secchi (mg/m²)**
Algal Bloom Frequencies in Study Reservoirs

Walmsley (1983) Classifications based upon Instantaneous Chlorophyll-a (ppb)

- >10  Algae Visible
- >20  Nuisance
- >30  Severe Nuisance
- >60  [ Even Worse ]

1990-2001, May-September
Bloom Frequency vs. Mean Chl-a in Study Reservoirs

Symbols = Observed Values for Study Reservoirs  
1990-2001, May-September

Lines = Predicted from Log-Normal Distribution  
CV = 0.67 (Walker, 1985)
Bloom Frequency vs. Mean Total P in Study Reservoirs

- >10 Algae Visible
- >20 Nuisance
- >30 Severe Nuisance
Topics

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- Analysis of User Survey Data
Minnesota & Vermont User Survey Form

A. Please circle the one number that best describes the physical condition of the water today:
   1. Crystal clear water.
   2. Not quite crystal clear, a little algae present/visible
   3. Definite algal green, yellow, or brown color apparent.
   4. High algal levels with limited clarity and/or mild odor apparent.
   5. Severely high algal levels with one or more of the following: massive floating scums on surface or washed up on shore, strong foul odor, or fish kill

B. Please circle the one number that best describes your opinion on how suitable the water is for recreation and aesthetic enjoyment today:
   1. Beautiful, could not be any nicer.
   2. Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
   3. Swimming and aesthetic enjoyment slightly impaired because of algal levels.
   4. Desire to swim and level of enjoyment of the water substantially reduced because of algal levels (would not swim, but boating is okay).
   5. Swimming and aesthetic enjoyment of the water nearly impossible because of algal levels.
Lower Charles River User Survey

Location: ____________________
Surveyor: ____________________
Data Collector: ________________
Date: __________ Time: __________

Aesthetics

A. Please circle the one number that best describes the color of the water today:
   1. Clear or blue
   2. Yellow or brown
   3. More brown than green
   4. More green than brown
   5. Green

B. Please circle the one number that best describes the amount of particles or algae present in the water today:
   1. Very little or none
   2. Some present
   3. Substantial amount present
   4. Overwhelming amount present

C. Please circle the one number that best describes the odor of the water today:
   1. No odor
   2. Mild odor
   3. Strong odor
   
   Type of odor detected: sewage, fish, musty, sulfur, other: ________________
Lower Charles River
User Survey

Recreation Use

D. Based ONLY on the aesthetic condition of the water today, please circle the one number that best corresponds to your level of enjoyment for swimming today (ignoring any previous impressions and assuming that there are no health risks):

1. Excellent for swimming; very minor or no aesthetic problems
2. Swimming enjoyment slightly impaired due to aesthetic problems; would still swim
3. Swimming enjoyment substantially reduced due to aesthetic problems; would not swim
4. Swimming enjoyment nearly impossible due to aesthetic problems

E. Based ONLY on the aesthetic condition of the water today, please circle the one number that best corresponds your level of enjoyment for boating today (ignoring any previous impressions and assuming that there are no health risks):

1. Excellent for boating; very minor or no aesthetic problems
2. Boating enjoyment slightly impaired due to aesthetic problems
3. Boating enjoyment substantially reduced due to aesthetic problems
4. Boating enjoyment nearly impossible due to aesthetic problems
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Developing Phosphorus Criteria for Minnesota Lakes

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Road, St. Paul, Minnesota 55155

William W. Walker, Jr.
Environmental Engineer, Concord, Massachusetts
Table 1.—Aesthetic or use impairment classification systems based upon chlorophyll-a or transparency.

<table>
<thead>
<tr>
<th>AUTHOR/LOCATION</th>
<th>CHL-A(PPB)</th>
<th>SECCHI DEPTH</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walmsley (1984)</td>
<td>0—10</td>
<td></td>
<td>No Problems</td>
</tr>
<tr>
<td>South African</td>
<td>10—20</td>
<td></td>
<td>Scums Evident</td>
</tr>
<tr>
<td>Reservoir</td>
<td>20—30</td>
<td></td>
<td>Nuisance</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td></td>
<td>Severe Nuisance</td>
</tr>
<tr>
<td>Burden et al. (1985)</td>
<td>14 (a)</td>
<td>1.2</td>
<td>Excellent to Good</td>
</tr>
<tr>
<td>Louisiana</td>
<td>30 (a)</td>
<td>0.8</td>
<td>Good to Acceptable</td>
</tr>
<tr>
<td></td>
<td>32 (a)</td>
<td>0.7</td>
<td>Acceptable to Marginal</td>
</tr>
<tr>
<td>Barica (1975)</td>
<td>0—25</td>
<td>&gt; 1</td>
<td>Clear, No Blooms</td>
</tr>
<tr>
<td>Canadian Prairie Ponds</td>
<td>25—100</td>
<td>0.4—1</td>
<td>Moderate Blooms</td>
</tr>
<tr>
<td></td>
<td>100—200</td>
<td>&lt; 0.4</td>
<td>Dense Colonies &amp; Scums</td>
</tr>
<tr>
<td>McGhee (1983)</td>
<td>&gt; 15</td>
<td></td>
<td>Unsuitable for Trout</td>
</tr>
<tr>
<td>North Carolina</td>
<td>&gt; 40 (b)</td>
<td></td>
<td>Severe Nuisance</td>
</tr>
<tr>
<td>Lillie and Mason (1983)</td>
<td>&lt; 1</td>
<td>&gt; 6</td>
<td>Excellent</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1—5</td>
<td>3—6</td>
<td>Very Good</td>
</tr>
<tr>
<td></td>
<td>5—10</td>
<td>2—3</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>10—15</td>
<td>1.5—2</td>
<td>Fair</td>
</tr>
<tr>
<td></td>
<td>15—30</td>
<td>1—1.5</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td>&lt; 1</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Effler et al. (1984)</td>
<td></td>
<td>&gt; 1.2</td>
<td>State Standard</td>
</tr>
<tr>
<td>New York</td>
<td></td>
<td></td>
<td>for beaches</td>
</tr>
<tr>
<td>MDPH (1969)</td>
<td></td>
<td>&gt; 1.2</td>
<td>State Standard</td>
</tr>
<tr>
<td>Massachusetts</td>
<td></td>
<td></td>
<td>for beaches</td>
</tr>
</tbody>
</table>

*a Class means.
*b North Carolina standard.
Bloom Frequency vs. Total P
Physical Appearance vs. Total P

![Graph showing the relationship between physical appearance and total phosphorus (PPB). The x-axis represents total phosphorus in PPB, ranging from 0 to 140. The y-axis represents frequency (%). The graph displays different shading levels corresponding to physical appearance: 1 = Crystal Clear, 2 = Some Algae, 3 = Definite Algae, 4 = High Algae, 5 = Severe Algae. The MPCA Staff Survey interval medians are indicated.]
Physical Appearance vs. TP, Chl-a, & Secchi

Figure 4.—Physical appearance ratings vs. lake water quality measurements.
Recreation Potential vs. TP, Chl-a, & Secchi

Figure 5.—Recreation potential ratings vs. lake water quality measurements.
Impairment Indices vs. TP

![Graph showing relationships between Total Phosphorus (PPB) and various impairment indices such as Chlorophyll-a, Transparency, Recreation, Appearance, Minor Aesthetic, Swimming Impaired, No Swimming, Definite Algae, and High Algae.](image)
User Perceptions vs. Total P & Chl-a

Inter-Quartile Ranges of Data in Each Rating Category
Analysis and Applications of Lake User Survey Data

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Vermont Department of Environmental Conservation
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Waterbury, Vermont 05676

Steven A. Heiskary
Minnesota Pollution Control Agency
520 Lafayette Road, St. Paul, Minnesota 55155
Regional Distribution of Study Lakes
Figure 2.—Geometric mean Secchi depth plotted vs. user survey response category for lake regions in Vermont and Minnesota. See Table 2 for region definitions.
Criteria for Support of Recreational Use Based upon User-Survey Results Minnesota Lakes

1. **Fully supporting**: Lakes fully supporting their uses should exhibit "impaired swimming" conditions (survey response B3) at less than a 10 percent frequency and should exhibit "high algal levels" (survey response A4) at less than a 10 percent frequency.

2. **Fully supporting—threatened**: These lakes may exhibit "impaired swimming" conditions at a frequency of 11-25 percent and "high algal levels" at a frequency of 11-25 percent.

3. **Partial support—impaired**: These lakes may exhibit "impaired swimming" at a 26-50 percent frequency and "no swimming" (survey response B4) at less than a 10 percent frequency. In terms of physical conditions, these lakes may exhibit "high algal levels" at a 26-50 percent frequency.

4. **Non-support—impaired**: These lakes will exhibit "no swimming" conditions with greater than 25 percent frequency and "no recreation possible" (survey response B5) on occasion. In terms of physical condition, these lakes will exhibit "high algal levels" with greater than 50 percent frequency.
Recreation Potential vs. Total P Vermont Lakes

![Bar chart showing frequency of response to user survey responses in relation to instantaneous total phosphorus concentration in Lake Champlain.](chart.png)

Figure 4.—Relationship between user survey response and total phosphorus concentration in Lake Champlain.
Recreation Potential vs. Chlorophyll-a Vermont Lakes

Figure 5.—Relationship between user survey response and chlorophyll a concentration in Lake Champlain.
Regional Variations in Transparency Criteria Based upon User Perception

Figure 3.—Median Secchi depths for four user survey response categories plotted vs. the median Secchi depths for each lake. Error bars represent interquartile ranges. See Table 2 for region definitions.