IWRA’s XVII
WORLD WATER CONGRESS
제 17차 IWRA 세계물총회
Prevention, Mitigation and Control of CyanoHABs

2021. 12. 01

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Special Session:
Freshwater Cyanobacteria Harmful Algal Blooms:
Human drivers and climate change
Prevention, Mitigation and Control of cyanoHABs

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Special Session
Freshwater Cyanobacteria Harmful Algal Blooms: Human drivers and climate change
Harmful Algal Blooms in Global Waters
Harmful Algal Blooms (HABs) in Korean Waters

The Nakdong River, Haman Weir 2021.08.09

The Nakdong River, Goryung Weir 2021.08.31

<table>
<thead>
<tr>
<th>Classes</th>
<th>Temperature</th>
<th>Season</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diatom</td>
<td>&lt;10 °C</td>
<td>Late fall - spring</td>
<td>Brown</td>
</tr>
<tr>
<td>Green Algae</td>
<td>10~20 °C</td>
<td>Spring - Early summer</td>
<td>Light Green</td>
</tr>
<tr>
<td>Cyanobacteria</td>
<td>20~30 °C</td>
<td>Early summer - Fall</td>
<td>Dark Green</td>
</tr>
</tbody>
</table>

4 Harmful Cyanobacteria Species

- Microcystis
- Anabaena
- Oscillatoria
- Aphanizomenon
## HABs Early Warning Standards in Korean Rivers

<table>
<thead>
<tr>
<th>Steps</th>
<th>Standard (~2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watch</td>
<td>Chl-a $&gt; 15$ mg/㎥ and Toxic Cyanobacteria $&gt; 500$ CELL/m</td>
</tr>
<tr>
<td>Warning</td>
<td>Chl-a $&gt; 25$ mg/㎥ and Toxic Cyanobacteria $&gt; 5,000$ CELL/m</td>
</tr>
<tr>
<td>Bloom</td>
<td>Chl-a $&gt; 100$ mg/㎥ and Toxic Cyanobacteria $&gt; 10^6$ CELL/m</td>
</tr>
<tr>
<td>Cancel</td>
<td>Chl-a $&lt; 15$ mg/㎥ or Toxic Cyanobacteria $&gt; 500$ CELL/m</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Steps</th>
<th>Standard (2016~)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watch</td>
<td>Toxic Cyanobacteria $&gt; 1,000$ CELL/mL</td>
</tr>
<tr>
<td>Warning</td>
<td><strong>Toxic Cyanobacteria $&gt; 10,000$ CELL/mL</strong></td>
</tr>
<tr>
<td>Bloom</td>
<td><strong>Toxic Cyanobacteria $&gt; 10^6$ CELL/mL</strong></td>
</tr>
<tr>
<td>Cancel</td>
<td>Toxic Cyanobacteria $&lt; 1,000$ CELL/mL</td>
</tr>
</tbody>
</table>
Toxic Cyanobacteria

<table>
<thead>
<tr>
<th>Cyanobacteria</th>
<th>Nitrogen Fixation*</th>
<th>Toxic**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcystis</td>
<td>No</td>
<td>Microcystin</td>
</tr>
<tr>
<td>Oscillatoria</td>
<td>Yes</td>
<td>Anatoxin(s), Microcystin</td>
</tr>
<tr>
<td>Anabaena</td>
<td>Yes</td>
<td>Anatoxin(s), Microcystin, Saxitoxin</td>
</tr>
<tr>
<td>Aphanizomenon</td>
<td>Yes</td>
<td>Anatoxin(s), Cylindrospermopsis Saxitoxin</td>
</tr>
</tbody>
</table>

* S. Chapra (2015), “Modeling and Managing the Eutrophication of Natural Waters”, Korea Environment Institute, Sejong, Korea
Factors affecting cyanobacterial growth

- HABs = Photosynthesis - Respiration - Death and Excretion – Settling
  - Photosynthesis = Growth = f(Nutrient, Light, Temperature)
    - Nutrients - N, P, Si and others, Leibig’s law of mimimum
      \[ \text{min} \left( \frac{NH_4+NO_3}{KHK_x+NH_4+NO_3}, \frac{PO_{4d}}{KHP_x+PO_{4d}}, \frac{SA_{ad}}{KHS+SA_{ad}} \right) \text{ vs min} \left[ 1 - \frac{q_{0Np}}{q_{Np}}, 1 - \frac{q_{0Pp}}{q_{Pp}}, \frac{[H_2CO_3^+]+[HCO_3^-]}{k_sCP+[H_2CO_3^+]+[HCO_3^-]} \right] \]
  - Light Effect = Solar Energy, Water Depth, Turbidity
  - Temperature Effect = Heat/Water Volume
  - Respiration, Death, Settling
  - Predator - zooplankton
HABs Control Methods

- **Prevention**
  - Nutrient load source control
    - External – Basin Control, BMP, Soil Erosion Control, First Flush
    - Internal – Sediment Release Control

- **Mitigation**
  - Treatment methods of nutrients
    - Point – WWTPs
    - Nonpoint – Others (Space and Time)

- **Control**
  - In-situ (Field) treatments methods
  - Physical, Chemical, and Biological approaches
A typical natural and urban drainage system

Modified from SWMM User Manual
Prevention: Nutrient Source Control

External Sources

Urban Sources
- Urban Wastewater Treatment Plants
- Urban Rainfall Surface Wash-offs
- Industrial Wastewater

Agricultural Wastes, Fertilizers, Soils
Livestock Wastes

Atmospheric Fall out Wet and Dry

Internal Source (Sediment)

Internal Source (Sediment)

Nonurban Sources

Silviculture and Natural Sources

Agricultural Wastes, Fertilizers, Soils
Livestock Wastes

Fresh Water

Urban Sources

Urban Wastewater Treatment Plants

Atmospheric Fall out Wet and Dry

Nonurban Sources
Mitigation: Point Source Control

Typical Wastewater Treatment Processes
Mitigation: Nonpoint Source Control

- Mining Area
  - Timber strip
- Cattle Fields
  - Buffer strip
- Agricultural Area
  - Embankment
  - Retention pond or Constructed wetland
- Urban Area
  - Porous Pavement
  - Infiltration
Prevention: Green Infra Structure Tools

SOURCE: “Making the Invisible Visible: Seattle’s Green Stormwater Infrastructure”, Tracy Tackett, Green Stormwater Infrastructure Program Manager, Seattle Public Utilities

Reduce: Permeable Pavement Surfaces

Reduce: Green Roofs

Reduce: Trees+Compost+Amended Soils
Mitigation: Urban Nonpoint Source Control

- BioRetention Cells or Bioswales
- Vegetative Swales
- Rain Barrels Or Cisterns
- Infiltration Trench
- Rain Gardens
- Green Roofs
- Rooftop Disconnection
- Continuous Permeable Pavement
Control:
In situ CyanoHABs Control Methods

Biological
- Floating Island
- Macrophytes/Wetlands
  - Floating/submerged
  - Wetland
- Biomanipulation
  - Remove Small fish
  - Increase Daphnia
- Wetland

Chemical
- Cyanicide
- Alginicides
- Coagulants
- Alum or Lime
- Algae
- Cyanotoxins
- Release of Cyanotoxins
- Flocculation
- PO₄⁻

Physical
- Floating Boom Barriers
- Ultrasound
- Surface Mixer
- Air Floating
- Artificial Aeration
- Hypolimnetic Oxygenation

Sediment
- Sediment Capping
- Sediment P Release
- Air/O₂ From Outside
Types of Artificial Aerations

(a) Hydraulic Gun

(b) Double Layer Aeration

(c) Diffuser Aeration

(d) Porous Pipe
Types of Hypolimnetic Aerations

(a) Downflow Aeration

(b) Hypolimnion Aeration

(c) Side Stream Aeration

(d) Upflow Aeration
Physical Treatments

- Separation or Removal of CyanoHABS
  - Floating Boom and Barriers
  - Dissolved Air Floatation

- Ultrasound

- Artificial aeration
  - Destratification
  - Hypolimnetic aeration/oxygenation
  - Surface Mixers/Fountains

- Dredging
Chemical Treatments

- Herbicides; Algicides and Cyanocides
  - Diuron, Endothall, EMA, Potassium ions (K⁺), CuSO₄
  - Potential cyanotoxin release
- Hydrogen peroxide (H₂O₂)
  - Selective killing of cyanobacteria in freshwater lakes
  - MC-LR release potential; CuSO₄ > H₂O₂ > Diuron > EMA
- P inactivation or Sediment Capping
  - Alum (Al₂SO₄), Lime (Ca(OH)₂ or CaCO₃)
- Others
  - PAC (Poly aluminum chloride), CaO₂ (calcium peroxide)
  - LRS (local red soil) or lanthanum modified bentonite (LMB) clay
Biological Treatments

- **Biological approaches**
  - Biomanipulation of food web
    - Increase Daphnia, Remove Small Fish
  - Plant extracts
    - Barley Straw
  - Aquatic plants
    - Water hyacinth
  - Artificial Floating islands
    - Fish shelter
  - Wetlands Biomanipulation
Management Plan Development

Set up Goal(s) → Management and Governance

Monitoring and Identification → Modelling and Alternatives
The Way Forward