Management of Bioavailable Phosphorus in Municipal Wastewaters for Control of Cladophora in the Great Lakes

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2016 MWEA 91st Annual Conference
GLWQA 1978

- Reduction in P loads
- Trophic state goal met

Lake Ontario Loading History

Target Load 7000 MTA

Lake Ontario Trophic Index

Goal Oligomesotrophic

Trophic Index

Oligotrophic
Mesotrophic
Europhic

Data credit: David Dolan
Adapted from: EPA.gov
GLWQP 2012

- Nearshore water quality
- P Bioavailability

Photo by Scott Higgins
A little background

- **Particulate Phosphorus (PP)**
- **Soluble Reactive Phosphorus (SRP)**
- **Dissolved Organic Phosphorus (DOP)**

\[ DOP = TDP - SRP \]

0.45 μm filter
Managing *Cladophora* *(Nearshore attached Algae)*

Despite over 50 years of nuisance growth, there is ...

- no criterion defining acceptable conditions
- no criterion defining nuisance conditions
- no quantitative linkage between P and algae
- no phosphorus concentration objective
- no phosphorus loading target

And regulatory officials continue to manage based on the total phosphorus analyte, ignoring the key role of soluble reactive P, the bioavailability of dissolved organic P.
With Oligotrophy Offshore...
(attention turns to the nearshore)

Cladophora growth 1 μgP/L
The Golden Horseshoe
(a.k.a. the fertile crescent)

The Fertile Crescent is ringed by point source discharges and much, if not all, colonizable substrate supports *Cladophora*.
Outfall Design

Optimization of -

• offshore distance of outfall and
• degree of treatment.

Constrained by -

• outfall cost and logistics
• available treatment technologies
Syracuse Metropolitan Treatment Plant

- Serves a population of 270,000
- Average flow of 84 MGD (318 MLD, 4 m³/s)
- Discharges to Onondaga Lake
- Eventually to Lake Ontario via the Oswego River

![Graph showing load (kgP/d) from 1970 to 2010](image)
Total Phosphorus (µgP/L)

- Average: 86±32 µgP/L

Soluble Reactive Phosphorus (µgP/L)

- Average: 3±8 µgP/L
Ballasted Flocculation - Actiflo®

- A high rate coagulation – flocculation – sedimentation process
- Either ferric chloride or alum may be used as the coagulant
- Dissolved phosphorus strongly bonds with the coagulant.
- Micro-sand ballast serves as a seed for floc formation.
- Sludge is separated from the ballast in a hydrocyclone.

Objective -

- assess efficacy in reducing levels of bioavailable dissolved and particulate P in the effluent
# Ballasted Flocculation Manufactures

<table>
<thead>
<tr>
<th>Manufacturer/Distributor</th>
<th>Number of WWTP Installations *</th>
<th>Range in Operating Flows (MGD)</th>
<th>Flagship Installation (including flow)</th>
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<tbody>
<tr>
<td>Infilco Degremont, Inc.</td>
<td>11 (12)</td>
<td>0.3 - 20</td>
<td>West Basin WWTP California 20 MGD</td>
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<td>Technology: DensaDeg®</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Krüger, Inc.</td>
<td>17 (25)</td>
<td>1.3 - 126</td>
<td>Syracuse, New York, 126 MGD</td>
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<td>Technology: Actiflo®</td>
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<td></td>
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</tr>
<tr>
<td>Evoqua Water Technologies LLC</td>
<td>6 (All USA)</td>
<td>0.5- 14</td>
<td>Billerica, Massachusetts, USA 14 MGD</td>
</tr>
<tr>
<td>Co-Mag®</td>
<td></td>
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</table>

*First number US and Canada, in parentheses international installations.
Phosphorus Fractions

- Soluble Reactive Phosphorus (SRP)
- Dissolved Organic Phosphorus (DOP)
- Particulate Phosphorus (PP)

DOP = TDP - SRP

0.45 μm filter
Methods – Particulate Phase

- Dual Culture Diffusion Apparatus (DCDA; DePinto 1981)
Methods – Soluble Phase

- Bottle Test (Miller et al. 1978)

![Image of bottle test with P-starved algae and sample filtrate]

![Graph showing P concentration over incubation time with bioavailable P indicated]

P-starved algae + sample filtrate
METRO Final Effluent 1996
Conventional treatment with ferric chloride

TP = 436 μg·L⁻¹
BAP = 294 μg·L⁻¹

<table>
<thead>
<tr>
<th>Fraction</th>
<th>$f_{bio}$</th>
</tr>
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<tbody>
<tr>
<td>SRP</td>
<td>1.00</td>
</tr>
<tr>
<td>DOP</td>
<td>0.62</td>
</tr>
<tr>
<td>PP</td>
<td>0.58</td>
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<tr>
<td>TP</td>
<td>0.67</td>
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METRO 2° Effluent 2012
Pre – Actiflo

TP = 679 μg·L⁻¹
BAP = 314 μg·L⁻¹

<table>
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<tr>
<td>SRP</td>
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<tr>
<td>DOP</td>
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<tr>
<td>PP</td>
<td>0.14</td>
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<tr>
<td>TP</td>
<td>0.46</td>
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METRO Final Effluent 2012
Actiflo (Ferric Chloride)

TP = 97 μg·L⁻¹

<table>
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<th>Fraction</th>
<th>( f_{bio} )</th>
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<tbody>
<tr>
<td>SRP</td>
<td>1.00</td>
</tr>
<tr>
<td>DOP</td>
<td>0.15</td>
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<tr>
<td>PP</td>
<td>0.02</td>
</tr>
<tr>
<td>TP</td>
<td>0.07</td>
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BAP = 7 μg·L⁻¹
METRO Final Effluent 2012
Actiflo (Alum)

TP = 83 μg·L⁻¹

BAP = 9 μg·L⁻¹

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<td>SRP</td>
<td>1.00</td>
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<td>DOP</td>
<td>0.15</td>
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<tr>
<td>PP</td>
<td>0.02</td>
</tr>
<tr>
<td>TP</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Application to the Fertile Crescent (Lake Ontario)

Data credit: Dolan and Chapra 2012

Photo Credit: Atkinson et al. 1994
Lake Ontario Point Source Loads 
(Bioavailable phosphorus basis)

\[ f_{bio} = 0.67 \]
Lake Ontario Point Source Loads
(Total phosphorus basis)

86% Removal
Lake Ontario Point Source Loads

- Industrial removal: $f_{bio} = 0.67$
- Municipal removal: $f_{bio} = 0.09$
- 86% Removal
Lake Ontario Point Source Loads
(Bioavailable phosphorus basis)

A 98% reduction in the bioavailable load!
Cladophora – managed?
Conclusion

The application of best available technology for phosphorus removal holds exceptional promise for addressing the nearshore water quality degradation identified for action under the GLWQP of 2012.
Onondaga to Ontario: Management of bioavailable phosphorus in municipal wastewaters for control of Cladophora

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Article Info

Article history:
Received 4 February 2015
Accepted 20 September 2015
Communicated by John Janssen

Index words:
Ballasted flocculation
Bioavailability
Cladophora
Great Lakes
Lake Ontario
Phosphorus

Abstract

Phosphorus (P) concentrations in the open waters of Lake Ontario have been reduced markedly through load management. Yet, nuisance growth of Cladophora persists in the nearshore where urban P inputs are received. Elimination of nuisance conditions will require application of more effective phosphorus treatment technologies with particular attention to phosphorus bioavailability. One such technology, ballasted flocculation, was implemented in 2005 at the Metropolitan Syracuse Wastewater Treatment Plant (Metro) in Syracuse, NY which discharges 68 MGD (257 MLD, million liters per day) to Lake Ontario via the Seneca–Oneida–Oswego River system. Wet chemistry measurements and soluble- and particulate-phase bioassays of phosphorus bioavailability are used here in assessing the efficacy of the technology. Effluent total (TP) and soluble reactive (SRP) phosphorus concentrations using ballasted flocculation technology over the period 2005–2012 averaged 86 and 3 μg P/L, respectively, and the effluent BAP (bioavailable phosphorus) concentration was 10 μg P/L. In operation now for a decade, Metro has reduced its effluent total phosphorus by 86%, soluble reactive phosphorus by 99% and bioavailable phosphorus by 97% compared with the conventional chemical treatment used previously (iron salts and gravity clarification). The reduction in BAP was accomplished through direct removal of the SRP, dissolved organic (DOP) and particulate (PP) phosphorus fractions, but also by reducing the bioavailability of DOP and PP. Retrofit implementation of ballasted flocculation at Metro is described and the effectiveness of load reductions in altering the trophic state of the immediate receiving water, Onondaga Lake, is examined. The role of ballasted flocculation in an integrated phosphorus management program for the Lake Ontario nearshore is considered.
Actiflo in Michigan

- City of South Lyon (2.5 MGD) implemented ballasted flocculation to meet phosphorus limitations
- Reduced from 0.3 mg/L to between 0.03 to 0.10 mg/L
- First application for this technology in Michigan

Questions