Source Water Monitoring

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Algae Blooms Source to Tap

- Monitoring
- Source Control
- Plant Operations
- Treatment Processes
- Distribution System

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Monitoring for Algal Blooms & Toxins – Field Analysis

Parameter	Sampling Location	Sampling Frequency			Testing Needs
		Routine Summer Monitoring	Transitional Season Monitoring	Event Monitoring	
Visual (water transparency, visible cyanobacteria)	Source water	2x per week @ high risk plants 1x per week @ moderate risk plants	1x per week @ all plants	Daily @ affected plant	Staff training
(Optional) Photosynthetic pigment for cyanotoxin identification and quantification (chlorophyll-α, phycocyanin)	Source water	1x per week @ all plants	1x per week @ high risk plants	2x per week @ affected plant	Portable fluorometer
Cyanotoxin screening (presence/absence)	Source water	1x per week @ all plants 2x per week triggered by visual observation	1x per week @ high risk plants 2x per week triggered by visual observation	None (conduct quantitative testing)	Strip test kits

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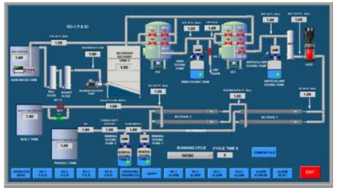
Monitoring for Algal Blooms & Toxins - Laboratory

Parameter	Sampling Location	Sampling Frequency			Testing Needs
		Routine Summer Monitoring	Transitional Season Monitoring	Event Monitoring	
Microscopic cyanobacterial identification	Source water			2x per week @ affected plant; triggered by visual observation	Microscope or digital imaging
Total microcystins and microcystin-LR quantification	Source water	1x per week with ELISA @ all plants Confirmation sample with ELISA upon detection in source	Confirmation sample with ELISA upon detection in source	Confirmation sample at laboratory to measure microcystin-LR upon detection ≥1 µg/L in source 2x per week with ELISA @ affected plant	ELISA kits; laboratory
	Treated water	Upon detection in the source water, 1x per week with ELISA @ all plants Confirmation sample with ELISA upon detection in source	Confirmation sample with ELISA upon detection in source	Confirmation sample at laboratory to measure microcystin-LR upon detection ≥1 µg/L in source or treated water 2x per week @ affected plant until microcystin-LR in source water returns to <1 µg/L; use also to monitor treatment effectiveness	ELISA kits; laboratory
Taste and odor compounds (geosmin and MIB)	Source and treated water	1x per week @ all plants	1x per week @ high risk plants (source water only)	2x per week @ affected plant or as needed	Laboratory
Nutrients (nitrate, ammonia, total phosphorus)	Source water	1x per week @ all plants	1x per month @ all plants	1x per week @ all plants	Laboratory

Monitoring for Algal Blooms & Toxins – Plant Operations



Parameter	Sampling Location	Sampling Frequency			Testing Needs
		Routine Summer Monitoring	Transitional Season Monitoring	Event Monitoring	
Sniff test by operators	Raw water	(General)			Operator training
Changes in raw water measured at the intake (temperature, turbidity, pH)	Raw water		Continuous via SCADA		SCADA (flags/alarms)
Increasing prechlorine demand (at intake for zebra mussel control or as part of pretreatment process if used)	Raw water		Continuous via SCADA		SCADA (flags/alarms)
Deteriorating pretreatment performance (increasing settled water turbidity, or increasing coagulant dose to control turbidity)	Pretreated water		Continuous via SCADA		SCADA (flags/alarms)
Deteriorating filter performance (decreasing filter run time, increasing individual filter effluent turbidity, decreased backwash interval)	Filtered water		Continuous via SCADA		SCADA (flags/alarms)

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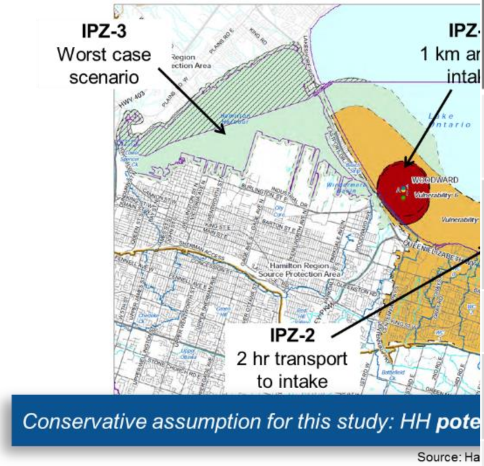
Monitoring for Algal Blooms & Toxins – Communications

Parameter	Sampling Location	Sampling Frequency			Testing Needs
		Routine Summer Monitoring	Transitional Season Monitoring	Event Monitoring	
Internal – between departments	N/A	1x per week or event driven	1x per week or event driven	Daily	N/A
External – with other area users	N/A	1x per week or event driven	1x per week or event driven	As needed; appropriate frequency to be determined for each individual event depending on circumstances. At minimum upon detection in source water ≥1 µg/L.	N/A
External – with customers	N/A	Rely on previously identified sensitive customers to call Region	Rely on previously identified sensitive customers to call Region	N/A	Response plan from call center

Testing Equipment

Manufacturer	Device	Description	Approx. Cost
Measurement of algal metabolites			
Abraxis	Microcystins Strip Test	Toxin test strip measuring microcystin and nodularin concentrations via immunochromatographic toxin assay. Kits also available for anatoxin-a and cylindrospermopsin.	$400 to 480 for 20 samples
Abraxis	ELISA Kits	Enzyme-linked immunoassay kits measuring microcystin, nodularin, cylindrospermopsin, or saxitoxin concentrations	$400 to 480 for 20 samples
Algae identification via digital imaging			
Fluid Imaging Technologies	FlowCAM	Digital imaging particle analyzer for monitoring and identifying algae and particulate matter	$50,000 to $100,000
bbe Moldaenke	DaphTox	Biomonitoring (*Daphnia* taximeter) via digital image analysis	N/A
Measurement of photosynthetic pigments			
YSI	EXP Total Algae Sensor	Fluorescence sensor measuring Chlorophyll and Blue-Green Algae Phycocyanin, along with Conductivity, Temperature, dissolved organic matter, pH, depth and turbidity	$15,000 to $20,000
Datalink Instruments	FL200 Online Chlorophyll A Fluorometer	Fluorometer measuring chlorophyll-□	$20,000
AWA Instruments	CX7000 Chlorophyll Online Analyser	Fluorometer measuring chlorophyll-□	N/AV
Turner Designs	AlgaeWatch Online Fluorometer	Fluorometer measuring chlorophyll-□	$7,500
Turner Designs	CyanoWatch Online Fluorometer	Fluorometer measuring phycocyanin	$7,500
ZAPS	LiquID Station 1000	Fluorometer measuring chlorophyll-□, Chlorophyll-b, and Phycobilin	$75,000
bbe Moldaenke	Algae Online Analyzer	Online chlorophyll fluorescence measurement with detection of chlorophyll concentration, algae classes, and photosynthetic activity	$25,000
bbe Moldaenke	Algae Torch	Portable LED fluorometer measuring total Chlorophyll and Cyanobacteria concentration	$11,000
bbe Moldaenke	Algae Guard	Continuous chlorophyll fluorescence measurement with algae	$20,000
Wet Labs	ECO FL	Fluorometer measures chlorophyll-□, CDOM, uranine, rhodamine, and phycocyanin and phycoerythrin	$200
bbe Moldaenke	Algae Lab Analyzer	Bench-top instrument for measurement of total chlorophyll a, quantification of algal classes and determination of photosynthetic activity	$36,500
Blue Water Satellite	Blue Water Satellite	Analyzes satellite images for cyanobacteria, chlorophyll a, total phosphorous in water bodies, data frequency variable (e.g., up to every 8 days)	$750/day for 250 hectares $2,000/day for 3,000 hectares

Raw Water Monitoring – Intake Protection Zones



Group	Potential Impacts		Monitoring (Probability based on Observation)		WTP Risk Score (based on limited data available)	
	Health & Aesthetics	WTP Performance	Hamilton Harbour (IPZ-3)	WTP Intake (IPZ-1)	Category	Response
Cyanobacteria	•T&O •Toxins	•Filter clogging	•Dominate •T&O producers often dominate •Toxin producers often dominate	Present (also in lake)	**Serious**	**Avoid or Transfer**
Chlorophytes	•T&O	•Filter clogging •Increased organic load •Nuisance mats	•Dominate •T&O producers may be present	Present	**Important**	**Accept Risk and Manage**
Diatoms	•T&O •Toxins	•Filter clogging •Thick biofilms	•T&O producers dominate •Toxin producers absent	Present	**Important**	**Accept Risk and Manage**
Chrysophytes	•T&O •Toxins (suspected)		•Dominate •T&O producers absent •Toxin producers absent	Not monitored	**Uncertain**	**Accept Risk and Manage**
Cryptophytes	•T&O •Toxins (suspected)		•T&O producers dominate •Toxin producers present	Not monitored	**Important**	**Accept Risk and Manage**
Dinoflagellates	•T&O •Toxins (only one species)	•Filter clogging	•T&O producers dominate •Toxin producers dominate	Present	**Serious**	**Avoid or Transfer**

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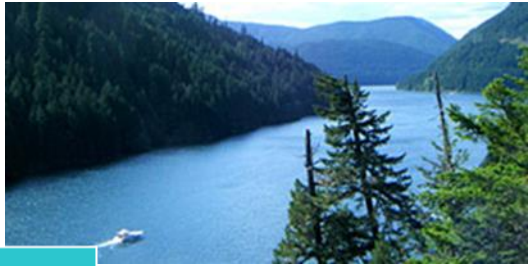
Source Modifications



Potential Action	Benefits	Drawbacks	Relative Cost
Move Inlet Location	Avoid algae intake at new location	• Large reservoirs only	Medium
Alter Inlet Depth	Avoid algae intake at specific depths	• Deep reservoirs only	Low
Riverbank Filtration	Removes algae without a waste stream	• Rivers only • Depends on soil conditions	Medium
News Source(s)	Avoid algae at new source	• May require other treatment barriers • New pipelines and right-of-ways • Water rights	High

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Source Controls

Potential Action	Benefits	Challenges	Relative Cost
Block sunlight (Floating Covers)	Limits occurrence of algae and byproducts at the source	• Loss of recreation • Service life	Medium
Reduce nutrient load (Point-source and non)		• Difficult implementation • Long timeframes	Low
Mixing and aeration		• May not work on large or deep sources • Operating cost unless solar powered	Medium
Chemical Phosphorus Precipitation		• Recreational use • Fish/wildlife side effects	High
Algicides		• Recreational use • Kills algae - release of toxins	High
Bio-manipulation		• Fish/wildlife side effects	Low
Dredging		• Permitting, disposal	High

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Hypolimnetic Oxygenation

- Limits nutrients, especially phosphate
- Disrupts Cyanobacteria Cycle

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Exploiting cyanobacteria ecology

- Nutrient denial:
  - To form blooms need deep water luxury nutrient uptake
  - Suppress deep water nutrients
- Buoyancy disruption:
  - Too little time in light
  - Not enough time taking up nutrients in deep

Follow simple rules into complexity

- **Harmful algae blooms**: mostly cyanobacteria, sometimes diatoms, occasionally another type
- **Cyanobacteria**:
  - Grow slow
  - All bloom formers control buoyancy
  - Freshwater blooms usually limited by P and Fe
- **Diatoms**:
  - Grow fast
  - Sink out of the light
  - Freshwater blooms limited by P, Si, sometimes N (if P low)

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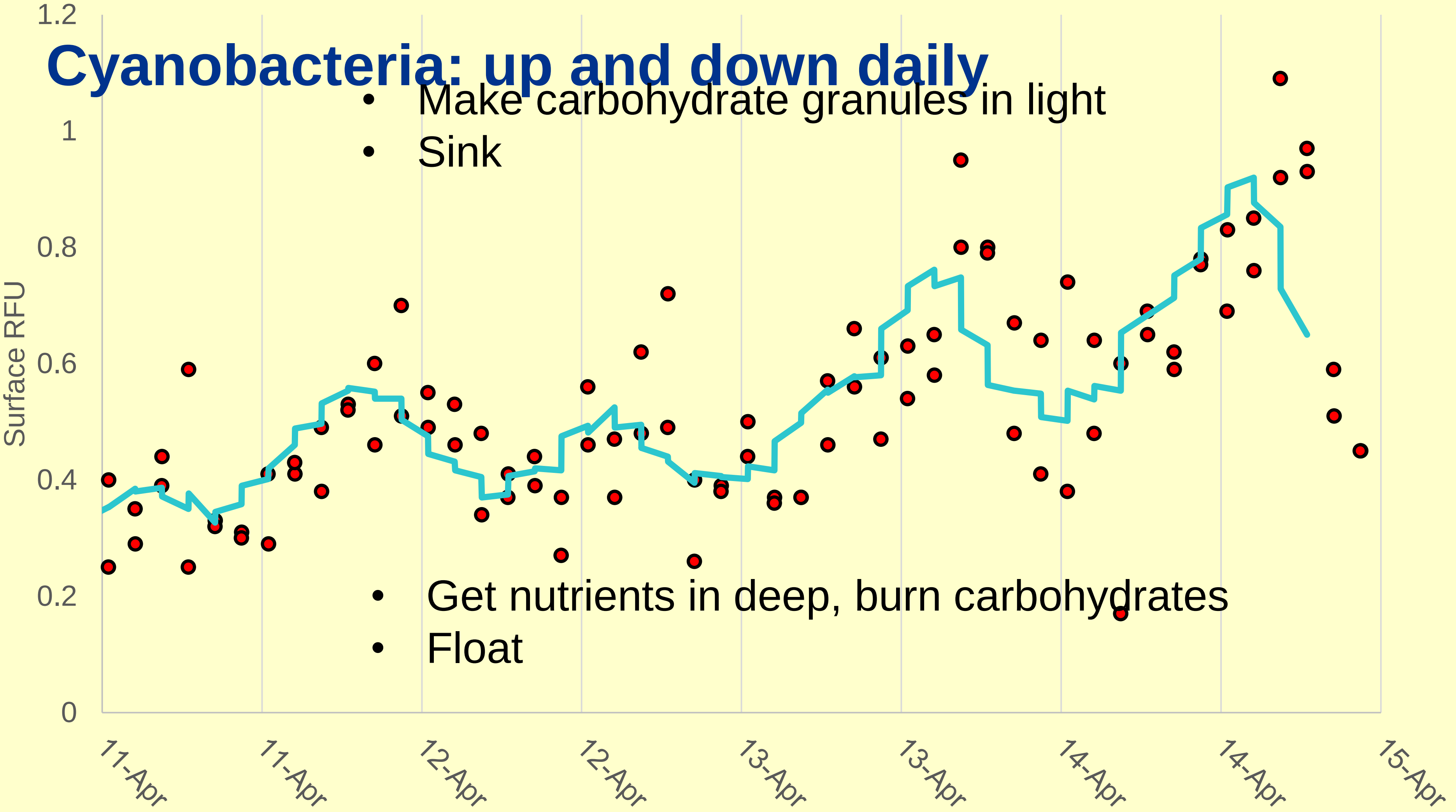
Cyanobacteria: up and down daily

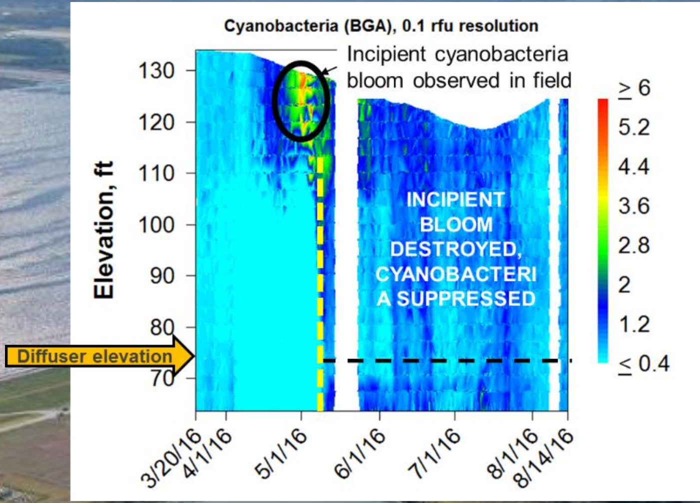
- Make carbohydrate granules in light
- Sink



- Get nutrients in deep, burn carbohydrates
- Float

- Destroy anoxia
- Sequester nutrients
- Limit cyanobacteria growth

Buoyancy disruption



Cyanobacteria physical ecology and control theory

- Mix cyanobacteria out of the light = no bloom
- Must be reservoir-wide (dam front alone not good enough)
- Function of
  - **Depth** (too shallow will not work)
  - **Turbulent diffusivity** (wind mixing intensity)

Huisman et al. 2004. Changes in turbulent mixing shift competition for light between phytoplankton species. Ecology. 85(11):2960-2970.

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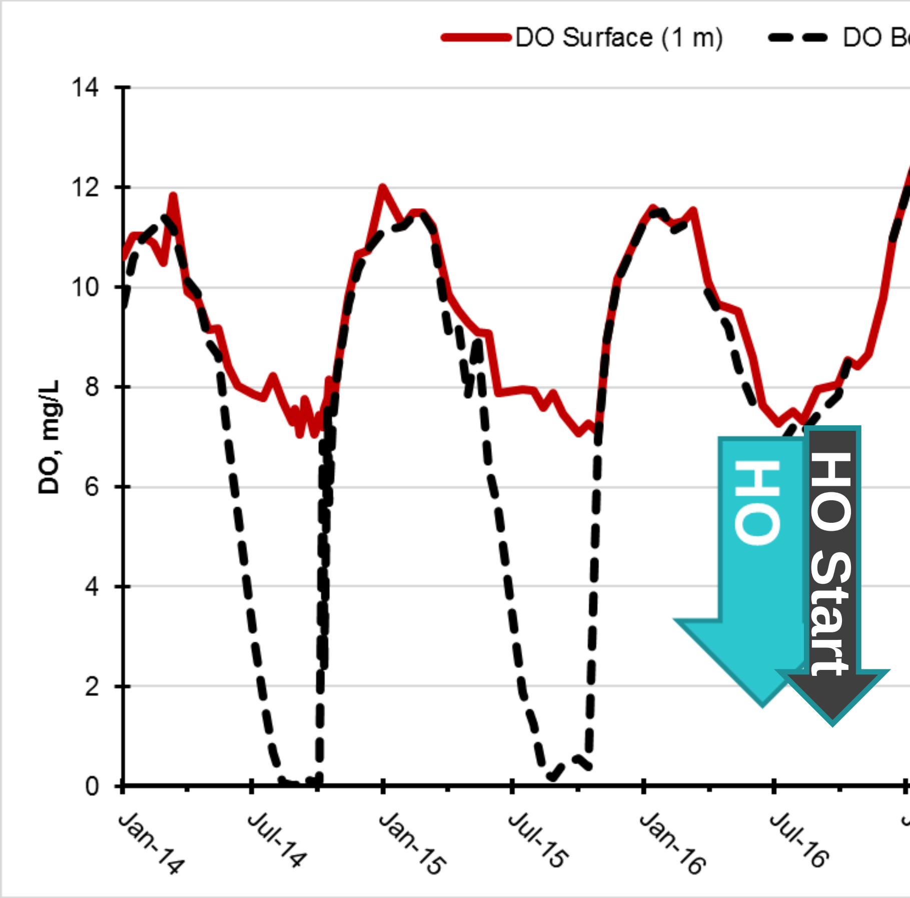
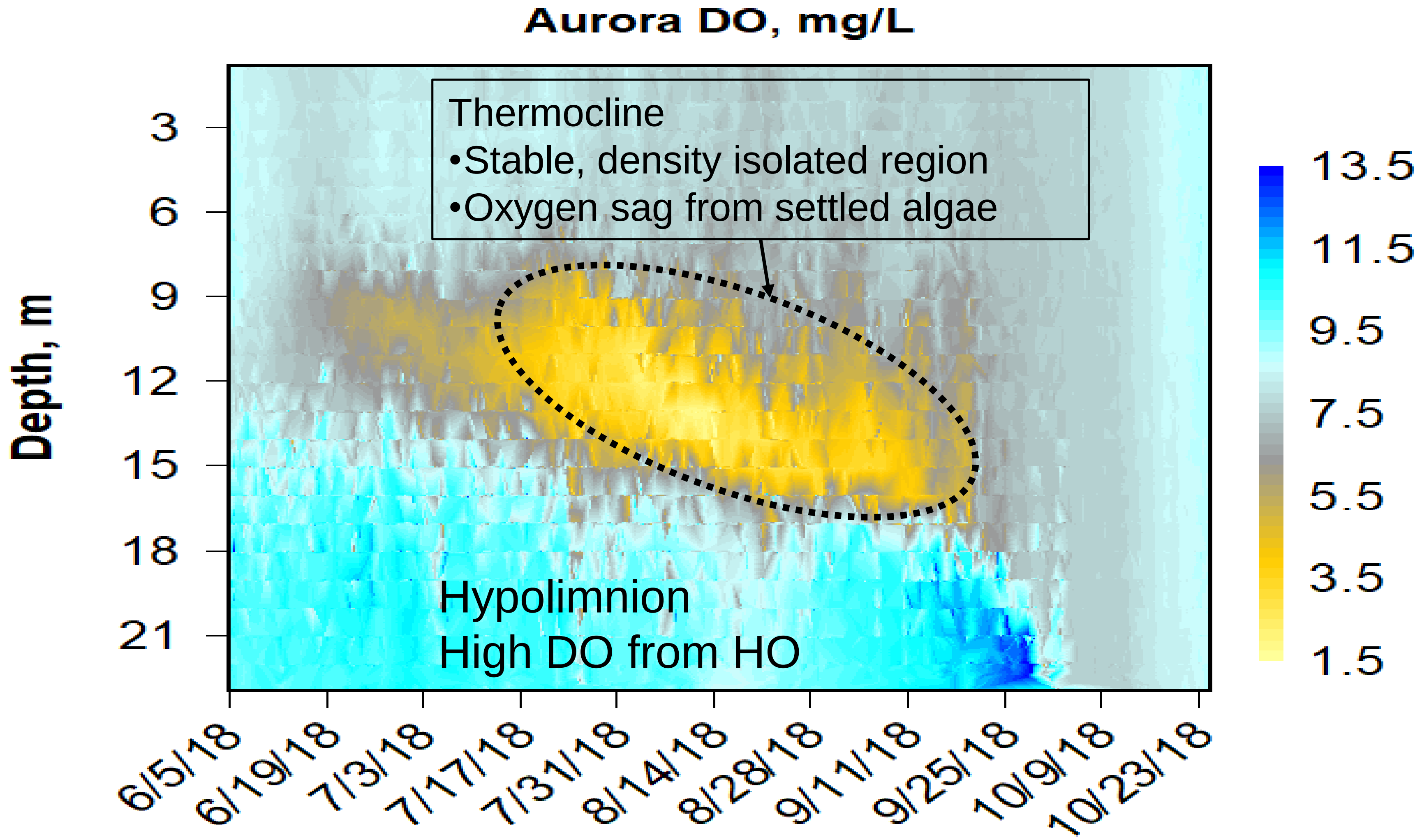
Aurora Reservoir, CO



- 90% reduction in T&O complaints
- 3 YR ROI on $1M cost from net chemical/GAC savings

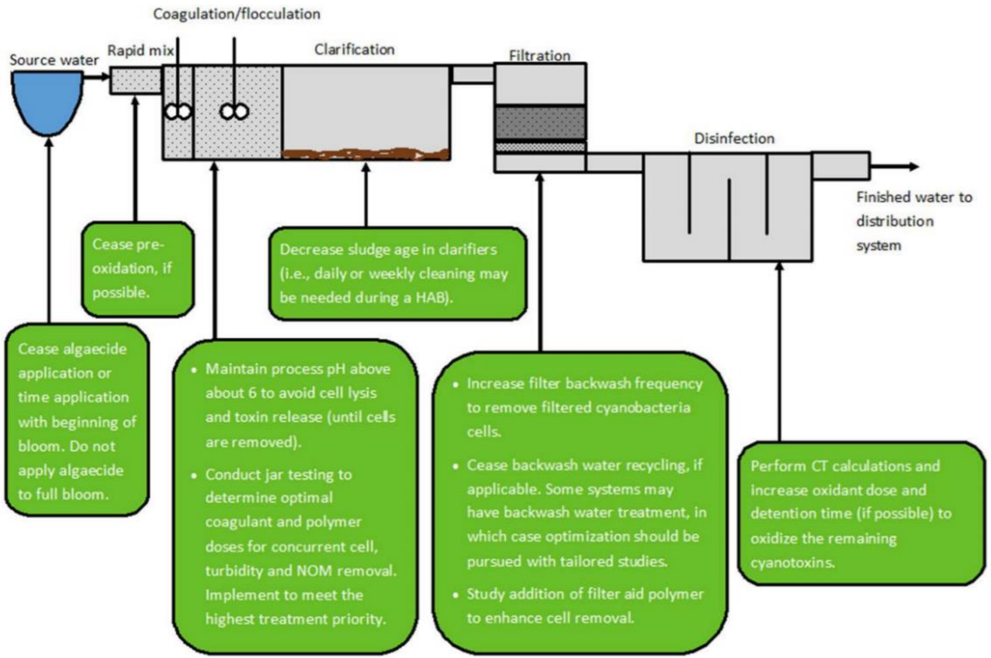


Aurora DO, mg/L
Thermocline
•Stable, density isolated region
•Oxygen sag from settled algae
Hypolimnion
High DO from HO
Depth, m
3
6
9
12
15
18
21
6/5/18
6/19/18
7/3/18
7/17/18
7/31/18
8/14/18
8/28/18
9/11/18
9/25/18
10/9/18
10/23/18
13.5
11.5
9.5
7.5
5.5
3.5
1.5

Algae Related Issues in Water Treatment Plants

- Clogging of Intake Screens
- Fouling Weirs/disruption of Settling
- Algal Mats
- Filter Clogging from Algae or Extracellular Organic Matter (EOM)
- Increased Coagulant Demand
- Increased Chlorine Demand
- Increased Disinfection By Products (DBPs)
- pH Fluctuations
- Tastes and Odors
- Release of Algal Toxins from Cell Lysing

EPA Guidance During a Bloom



- Don’t use algacide
- Don’t Preoxidize
- Keep Coagulation pH above 6
- Jar Testing
- Reduce Sludge Age
- Frequent Backwashing
- Don’t Recycle
- Optimize CT

Source: USEPAWater Treatment Optimization for Cyanotoxins, Version 1.0

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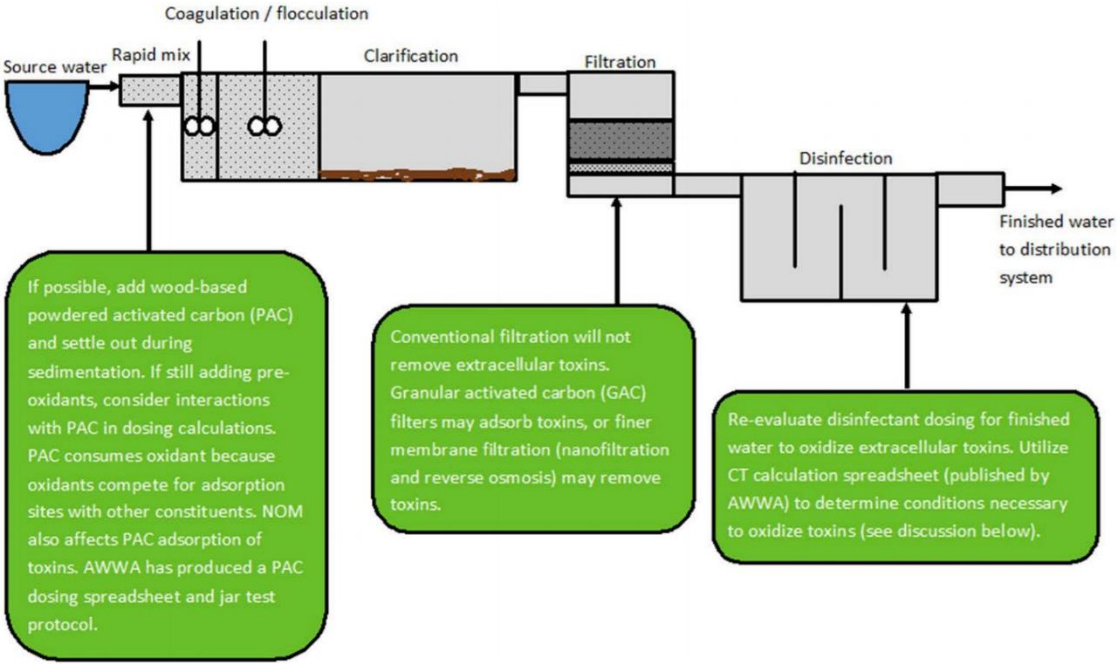
EPA Guidance During a Bloom



- Add wood based PAC
- You may get some metabolite removal on GAC media
- Optimize CTs if possible

Source: USEPAWater Treatment Optimization for Cyanotoxins, Version 1.0

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Oxidation

Table 3-1. General effectiveness of cyanotoxin oxidation with common water treatment oxidants[13]

Oxidant	Anatoxin-a	Cylindrospermopsin	Microcystins	Saxitoxin
Chlorine	Not effective	Effective (at low pH)	Effective*	Somewhat effective
Chloramine	Not effective	Not effective	Not effective at normal doses	Inadequate information
Chlorine dioxide	Not effective at normal doses	Not effective	Not effective at normal doses	Inadequate information
Potassium permanganate	Effective	Data ranges from not effective to possibly effective	Effective*	Not effective
Ozone	Effective	Effective	Very effective	Not effective
UV / advanced oxidation	Effective	Effective	Effective at high UV doses*	Inadequate information

* Dependent on initial cyanotoxin concentration, pH, temperature, and presence of NOM.

Source: USEPAWater Treatment Optimization for Cyanotoxins, Version 1.0

CT Tables

Mycrocystin-LR, Free Chlorine, Target 0.3 ug/L

pH	MC-LR conc [µg/L]	Effective CT [mg/L * min]				
		10°C	15°C	20°C	25°C	30°C
6	10	48.8	42.2	36.6	32.0	28.1
	25	61.5	53.2	46.2	40.4	35.4
	50	71.2	61.5	53.5	46.7	41.0
	100	80.8	69.9	60.7	53.0	46.5
7	10	56.9	50.1	44.3	39.5	35.5
	25	71.8	63.1	55.9	49.8	44.7
	50	83.1	73.0	64.7	57.6	51.7
	100	94.3	82.9	73.4	65.5	58.8
8	10	129.8	119.7	111.2	103.9	97.6
	25	163.7	151.0	140.2	131.0	123.1
	50	189.3	174.7	162.2	151.6	142.4
	100	215.0	198.3	184.2	172.1	161.7
9	10	466.6	421.7	382.0	346.8	315.3
	25	588.5	531.9	481.9	437.4	397.7
	50	680.7	615.3	557.4	505.9	460.0
	100	772.9	698.7	632.9	574.5	522.3

Cylindrospermopsin, Free Chlorine, Target 0.7 ug/L

pH	CYL conc [µg/L]	Effective CT [mg/L * min]				
		10°C	15°C	20°C	25°C	30°C
6	10	10.3	8.1	6.5	5.2	4.2
	25	13.9	10.9	8.7	7.0	5.6
	50	16.6	13.0	10.4	8.3	6.7
	100	19.3	15.2	12.0	9.7	7.8
7	10	4.1	3.3	2.6	2.2	1.8
	25	5.5	4.4	3.6	2.9	2.4
	50	6.5	5.2	4.2	3.5	2.9
	100	7.6	6.1	4.9	4.0	3.3
8	10	8.1	6.9	5.9	5.2	4.5
	25	10.8	9.2	8.0	6.9	6.1
	50	12.9	11.0	9.5	8.3	7.3
	100	15.0	12.8	11.0	9.6	8.5
9	10	55.2	48.5	43.1	38.6	34.8
	25	74.2	65.3	57.9	51.9	46.8
	50	88.6	77.9	69.2	61.9	55.9
	100	102.9	90.6	80.4	72.0	64.9

Source: USEPAWater Treatment Optimization for Cyanotoxins, Version 1.0

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Treatment Modifications

Option	Algae Removal	Taste & Odor	Algal Toxins	Details	Relative LCC
Dissolved Air Flotation (DAF)	✓			• Avoids lysing • Proven high removal rates • Piloting is key for best lifecycle cost	Low
Sedimentation or Plate Settling	✓			• May grow algae • Uncertain removal rates • Large footprint requirement	Moderate
Micro- strainers	✓			• Significant headloss • May lyse cells • Uncertain removal rates	Moderate
Ozone - BAC	✓	✓	✓	• CEC destruction is an additional benefit • Piloting is key	Moderate
Ozone		✓	✓	• Proven effectiveness • Potential for disinfection byproducts	Moderate
Advanced Oxidation		✓	✓	• Log removal credits and CEC destruction are additional benefits	High
Activated Carbon (GAC, PAC)		✓	✓	• High operating costs	High

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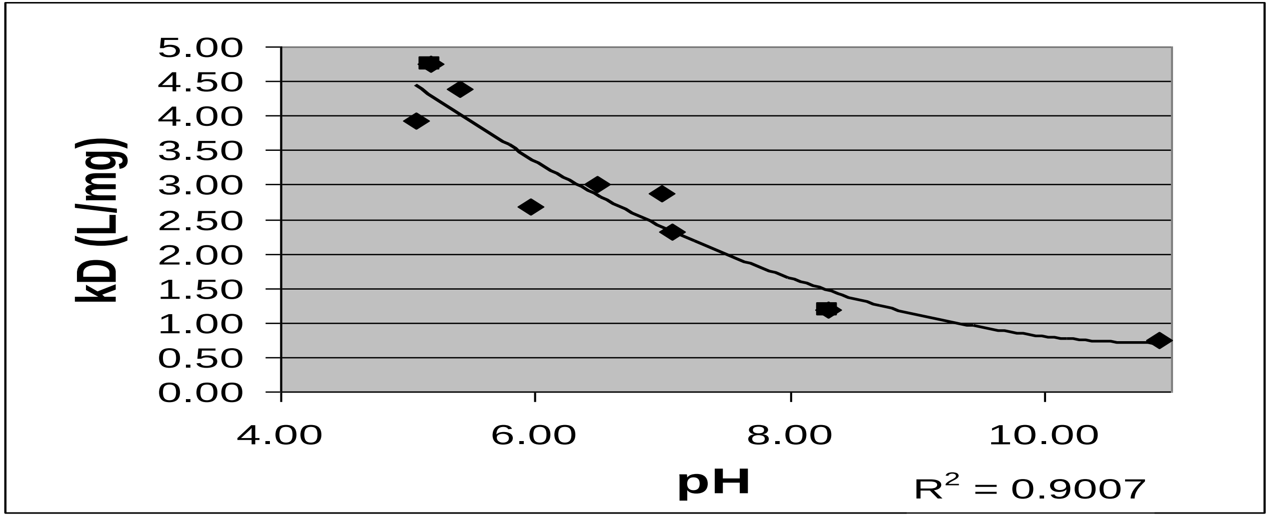
Using k_D to Determine Ozone dose



Co = 20 ug/L

C = 1 ug/L

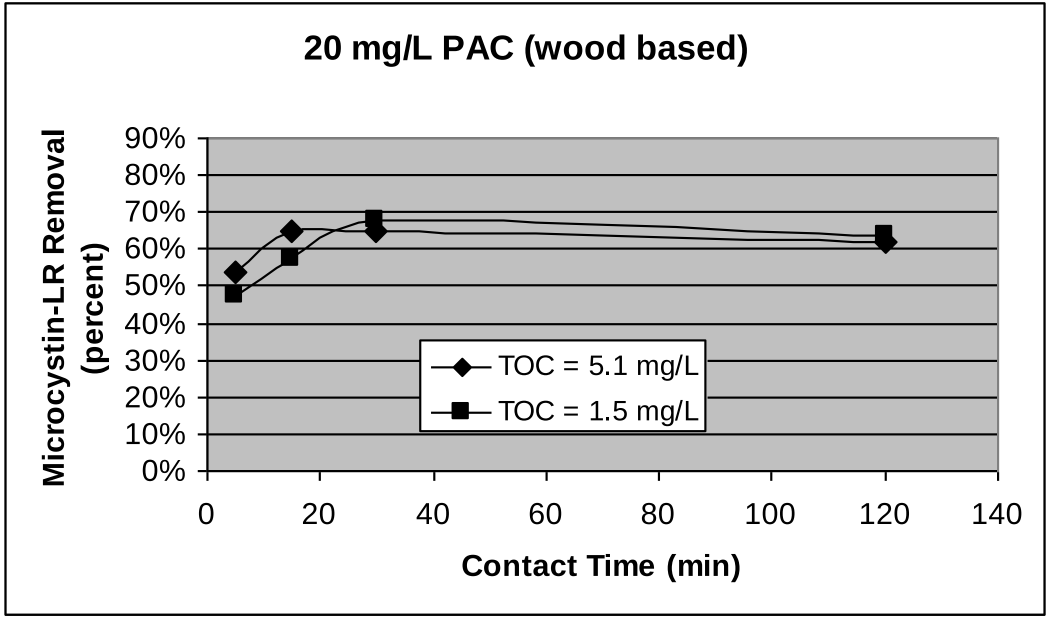
pH is 7

Calculate Ozone dose

$$O_3 = \frac{1}{-2.25} \times \ln\left(\frac{1}{20}\right)$$

$$O_3 = 1.3 mg / L$$

Wood-based Powdered Carbon Results



- Rapid uptake
- 60 to 70 percent removal
- TOC had little impact

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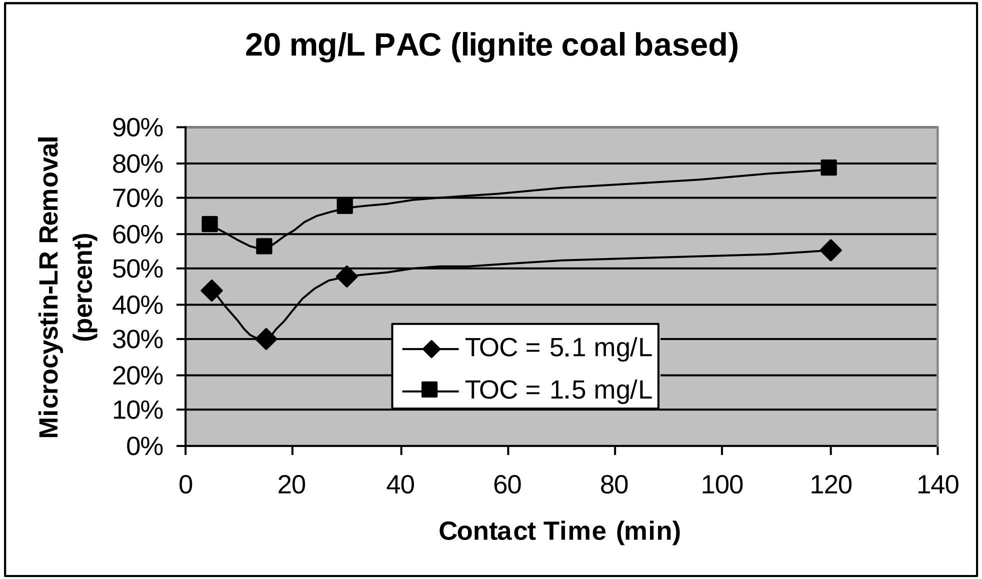
Lignite-based Powdered Carbon Results



- Again Rapid uptake
- 30 to 60 percent removal in high TOC water
- 60 to 80 percent removal in low TOC water
- TOC had impact

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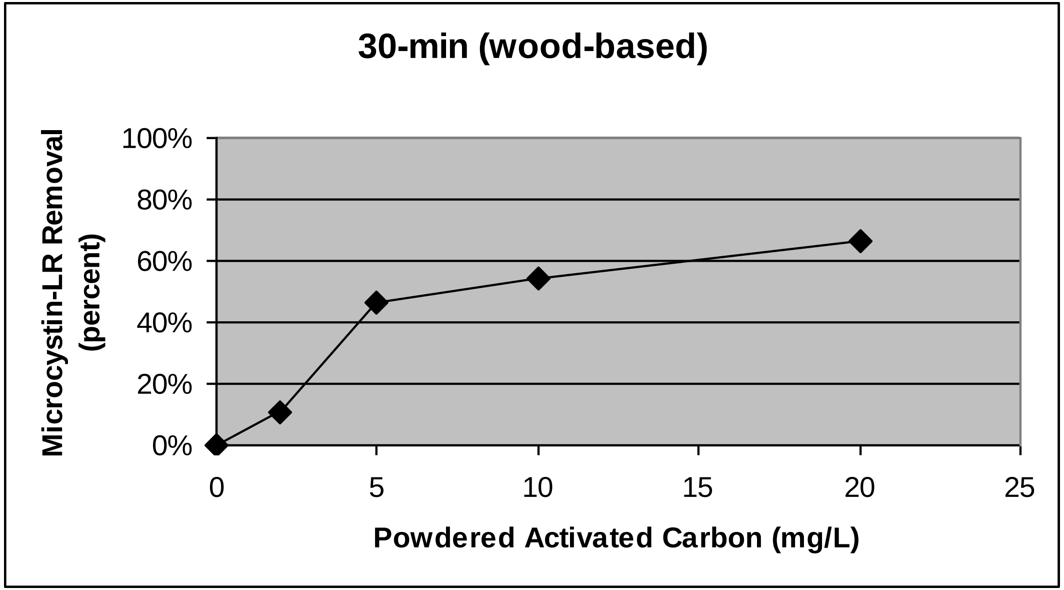
Powdered Activated Carbon Dose Response



Distribution System – Still Oxidizing

Mycrocystin-LR, Free Chlorine, Target 0.3 ug/L

pH	MC-LR conc [µg/L]	Effective CT [mg/L * min]				
		10°C	15°C	20°C	25°C	30°C
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	25	71.8	63.1	55.9	49.8	44.7
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	100	19.3	15.2	12.0	9.7	7.8
7	10	4.1	3.3	2.6	2.2	1.8
	25	5.5	4.4	3.6	2.9	2.4
	50	6.5	5.2	4.2	3.5	2.9
	100	7.6	6.1	4.9	4.0	3.3
8	10	8.1	6.9	5.9	5.2	4.5
	25	10.8	9.2	8.0	6.9	6.1
	50	12.9	11.0	9.5	8.3	7.3
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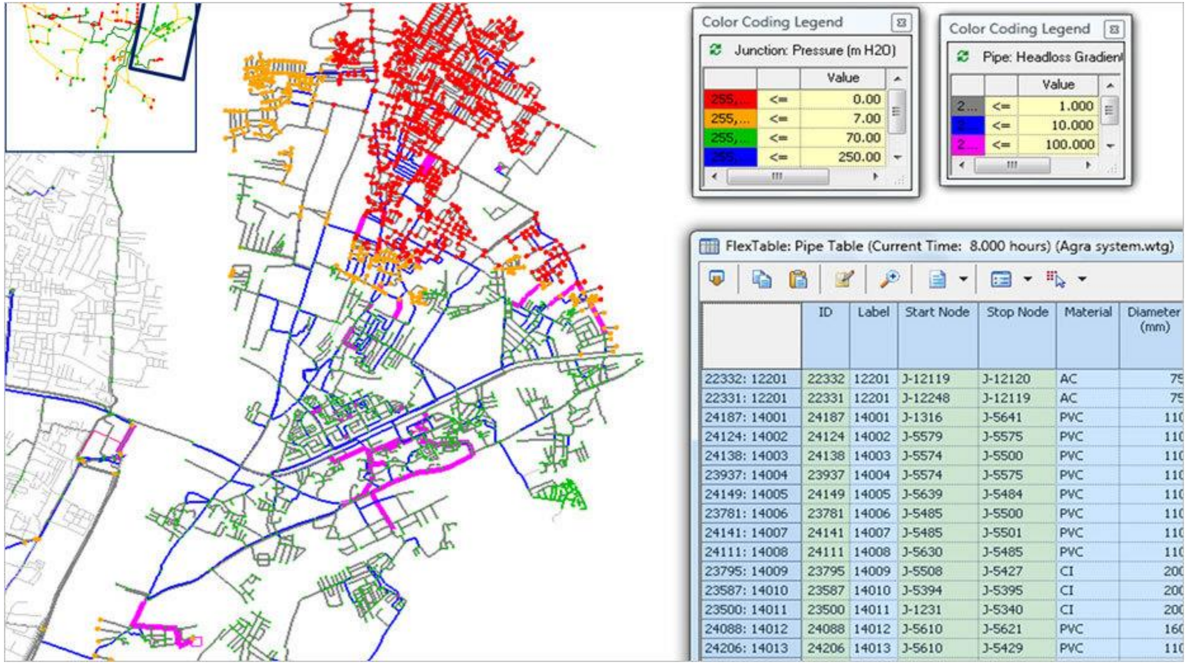
Distribution System



Questions?

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