Regional Water Quality Issues: Algae and Associated Drinking Water Challenges

Workshop – September 2007

A Cooperative Research and Implementation Program
Arizona State University (Tempe, AZ)
Paul Westerhoff, Milton Sommerfeld, Susanne Neuer
K.C. Kruger, Chao-An Chiu, and Marisa Masles

- Salt River Project
- Central Arizona Project
- City of Phoenix
- City of Tempe
- City of Glendale
- City of Chandler
- ASU NSF Water Quality Center

Quagga mussels attached to a plastic dock cart that had fallen into Lake Mead, and (below) quaggas to scale. Photos by David Britton, U.S. Fish and Wildlife Service, courtesy of 100thMeridian.org.

Agenda

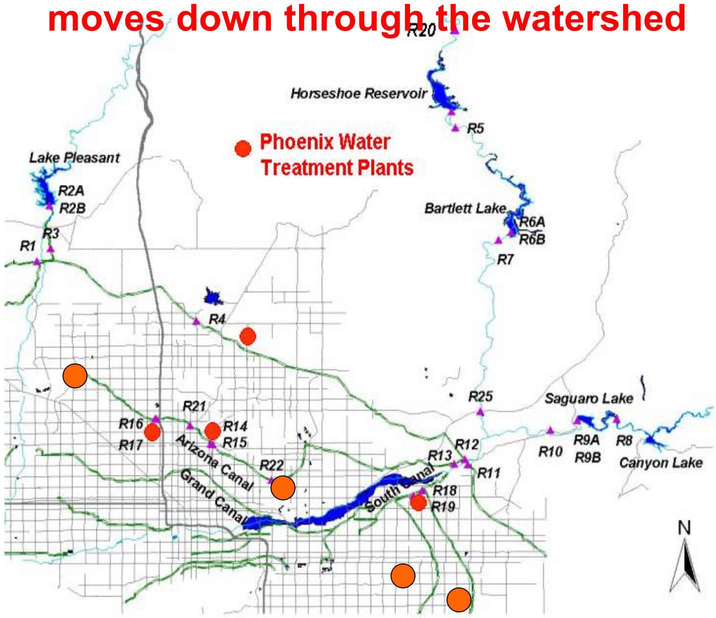
Purpose: Provide a forum to review and discuss on-going regional water quality issues, in particular algae-associated issues.

- 8:30 Refreshments
- 8:45 Introductions
- 9:00 Project overview, Past, Present, and Future
- 9:15 Satellite Imaging of Algae in Reservoirs
- 9:45 Break
- 10:00 In-plant algae identification
- 10:30 DBP Precursors & Modeling
- 11:00 Future directions & discussion

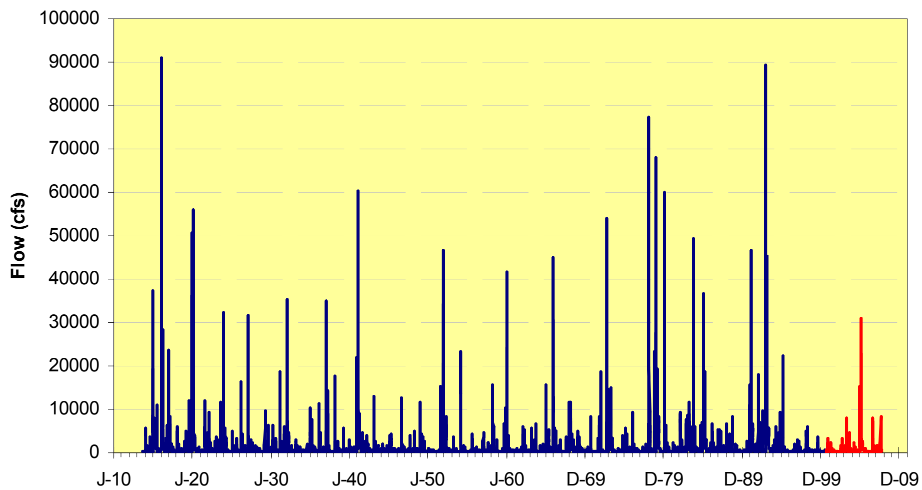
The "State" of Water Supplies in 2007

2007 was more about dissolved organic carbon (DOC) issues than about T&O levels

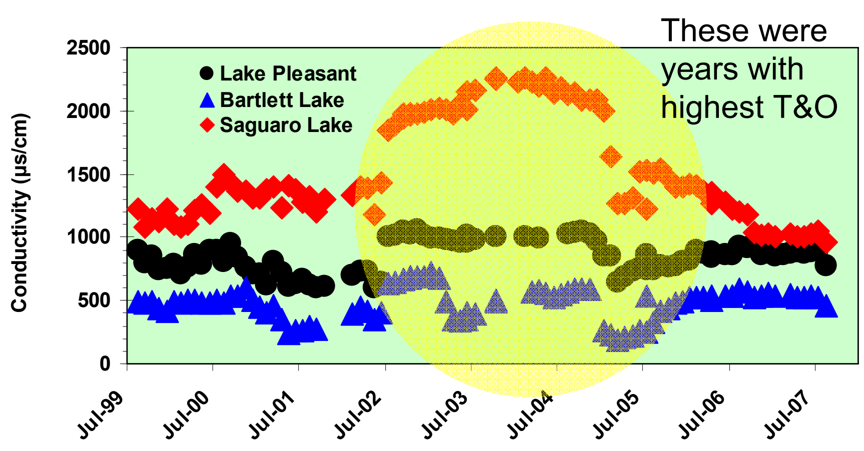
Workshop will present results as water moves down through the watershed



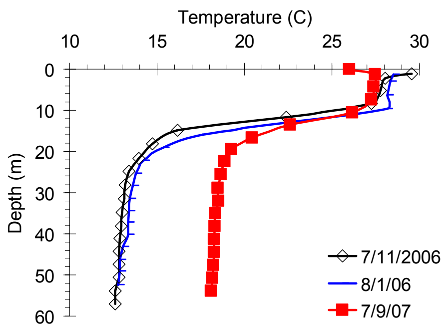
Salt River Above Roosevelt

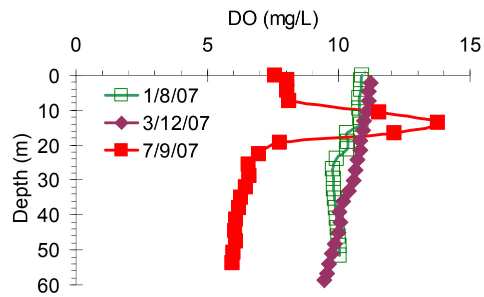


Hydrology Affects Water Quality (conductance can affect algal dominance)

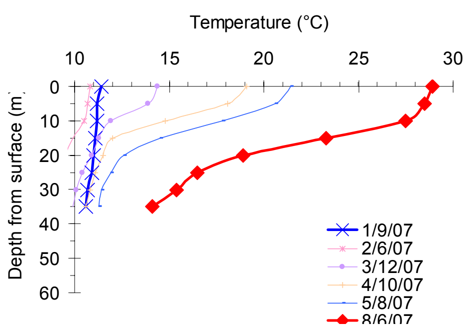


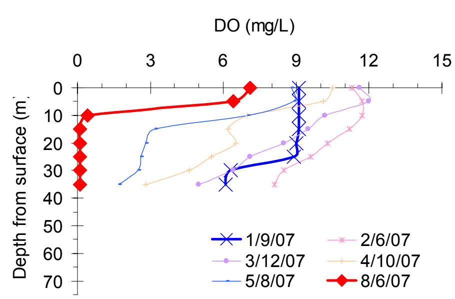
Lake Pleasant



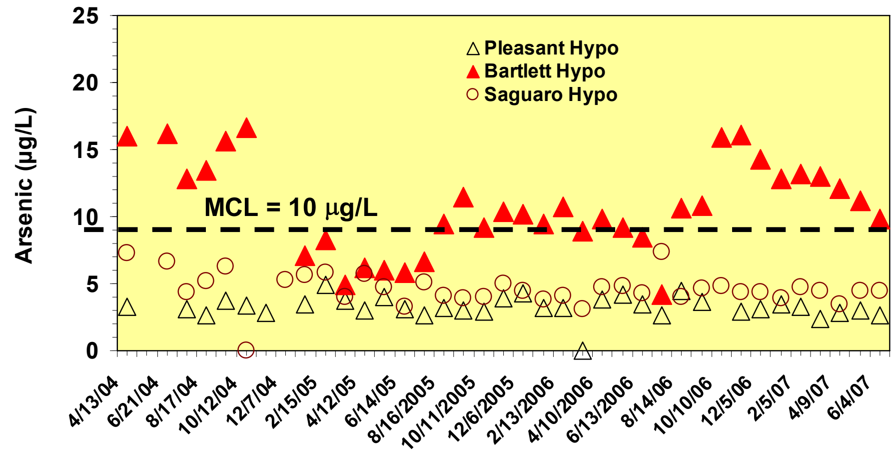


Bartlett Lake

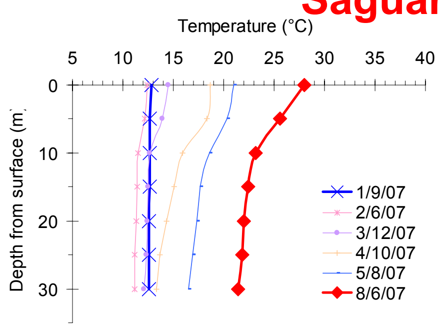




Arsenic is highest in Bartlett Reservoir

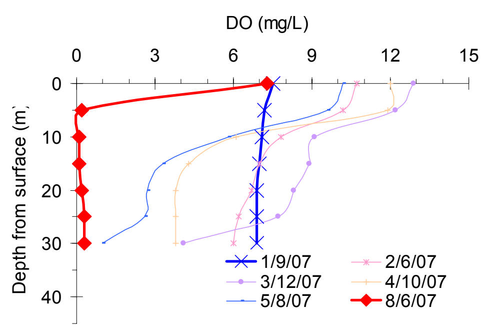


Saguaro Lake

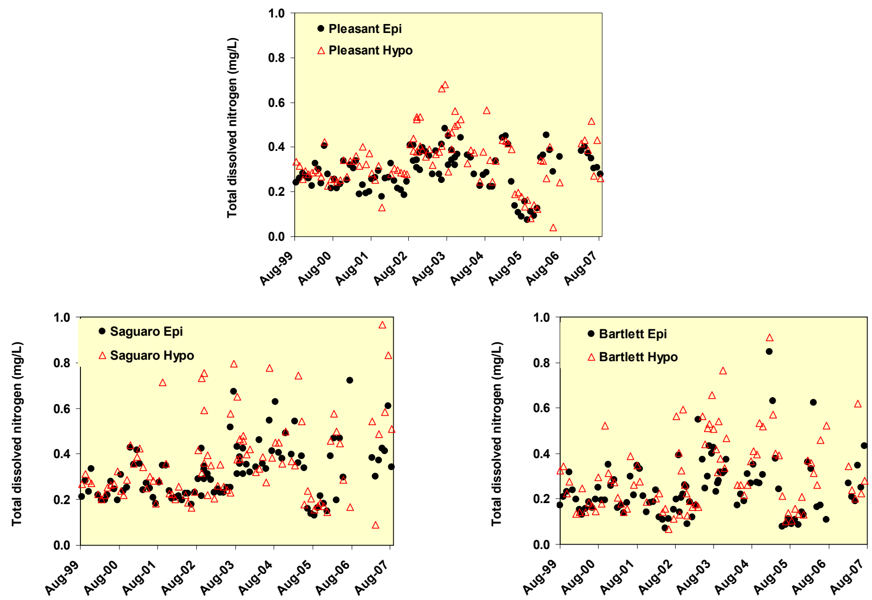


2008 Operation: Draw down Canyon Lake from Oct 07-Jan 08

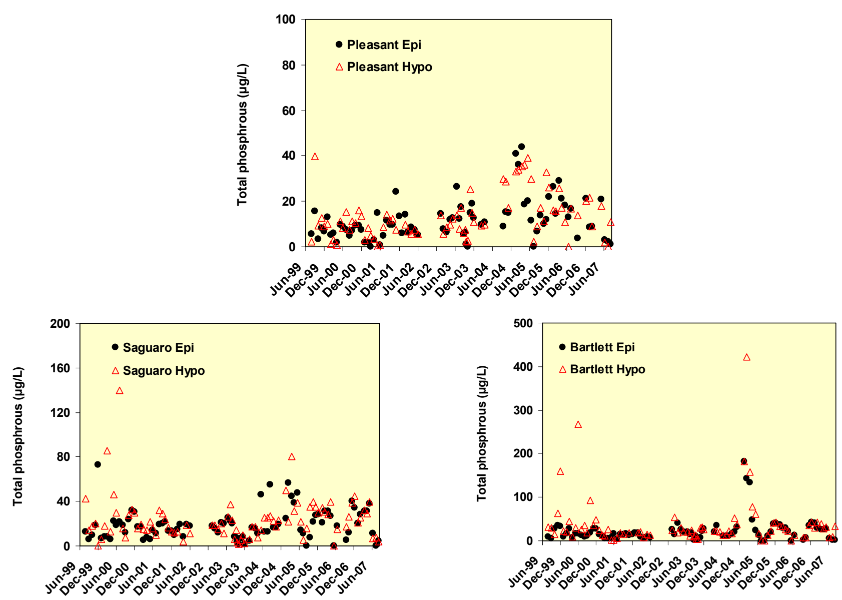
2007 Operation: Apache Lake was drawn down during same periods



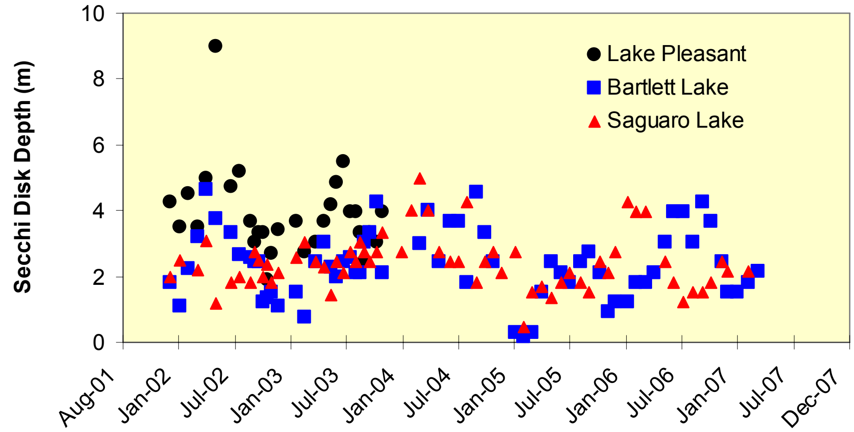
Dissolved Nitrogen Trends in Reservoirs



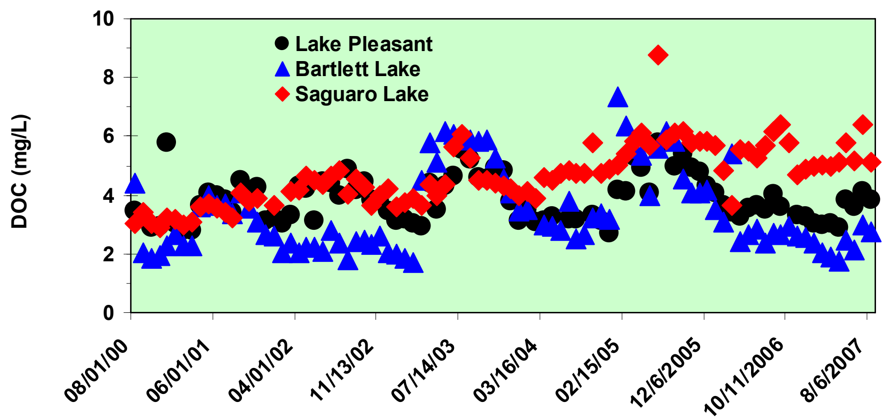
Total Phosphorous

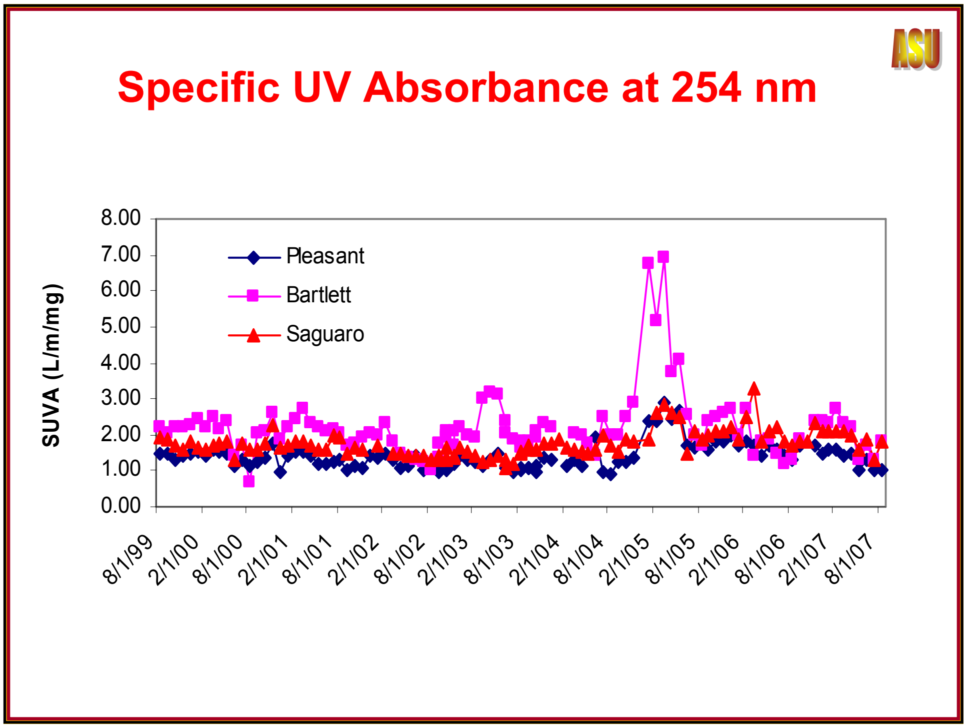


Secchi Disk Depth Influenced by Inorganic Suspended Sediment and/or Organic Biomass



Up-stream reservoirs attenuate DOC




Specific UV Absorbance at 254 nm
SUVA (L/m/mg)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Pleasant
Bartlett
Saguaro
8/1/99
2/1/00
8/1/00
2/1/01
8/1/01
2/1/02
8/1/02
2/1/03
8/1/03
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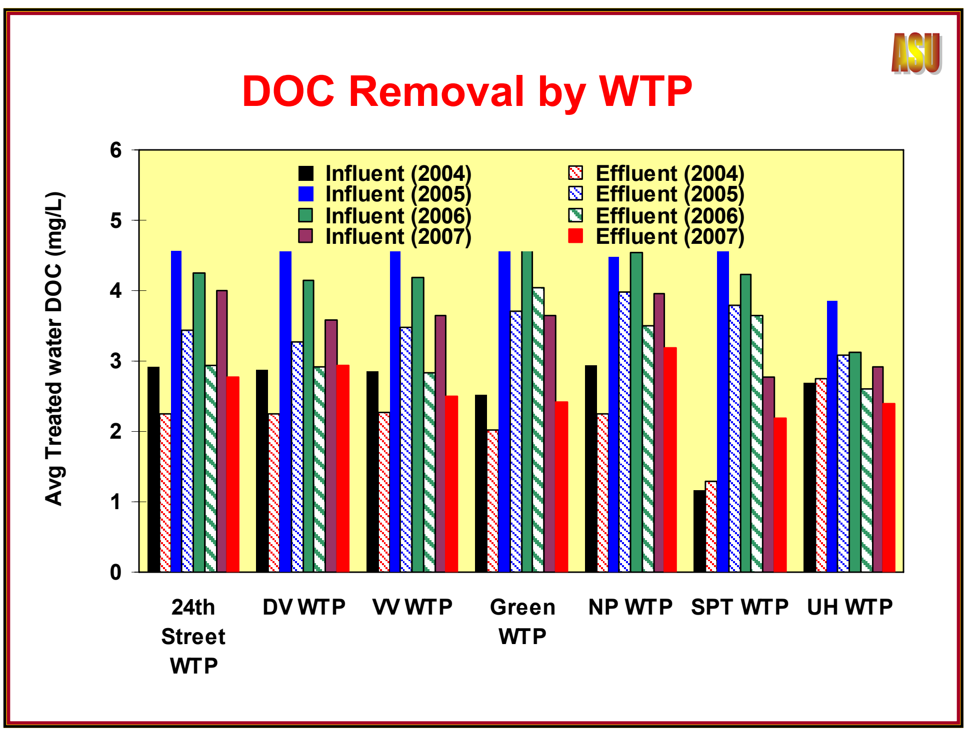
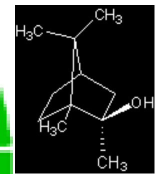
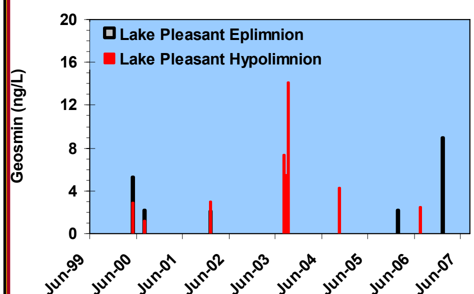
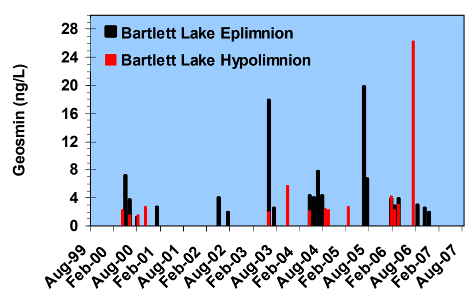
2/1/07
8/1/07

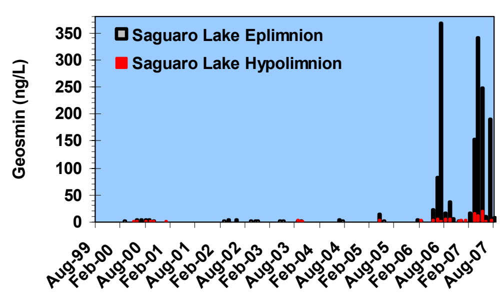

DOC Removal by WTP
Avg Treated water DOC (mg/L)
6
5
4
3
2
1
0
Influent (2004)
Influent (2005)
Influent (2006)
Influent (2007)
Effluent (2004)
Effluent (2005)
Effluent (2006)
Effluent (2007)
24th Street WTP
DV WTP
VV WTP
Green WTP
NP WTP
SPT WTP
UH WTP



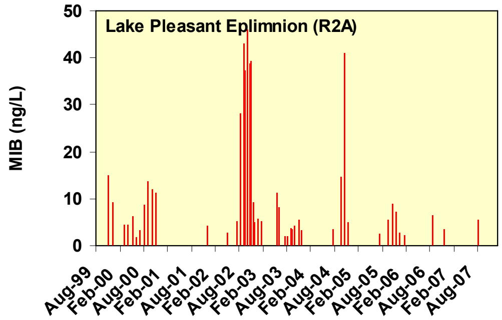
Geosmin Data

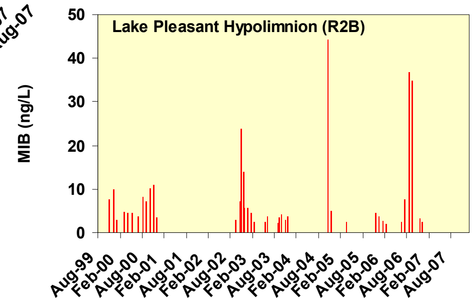




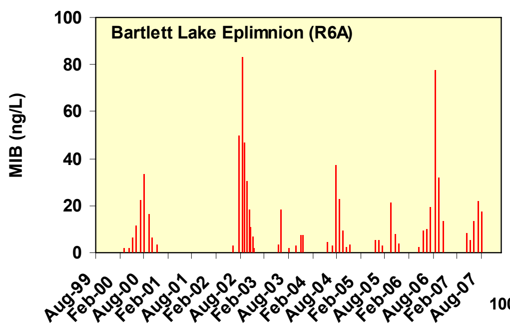


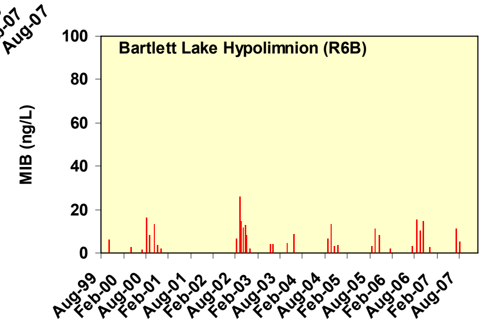
MIB Data – Lake Pleasant



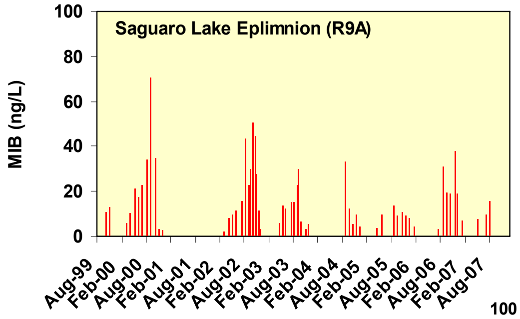


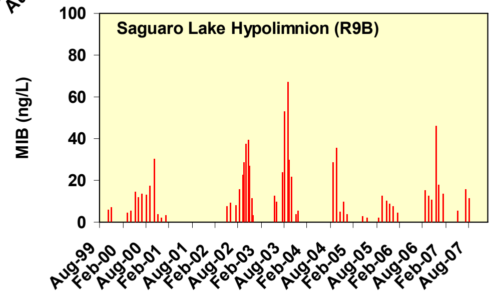
MIB Data – Bartlett Lake



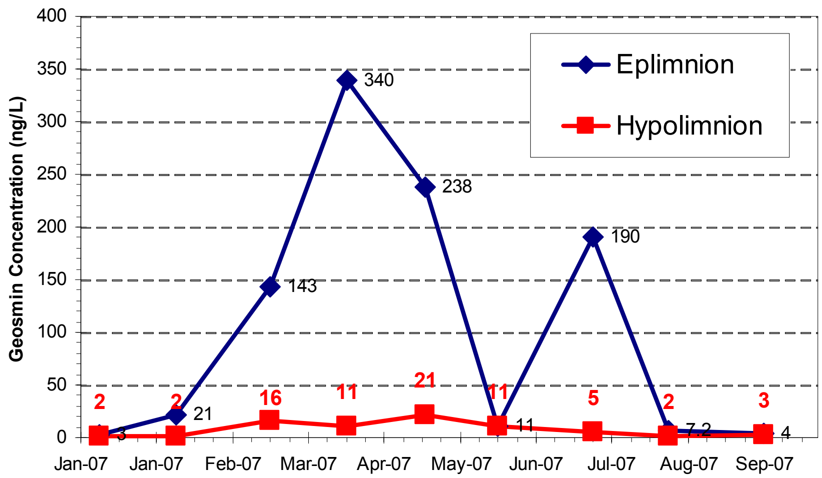


MIB Data – Saguaro Lake



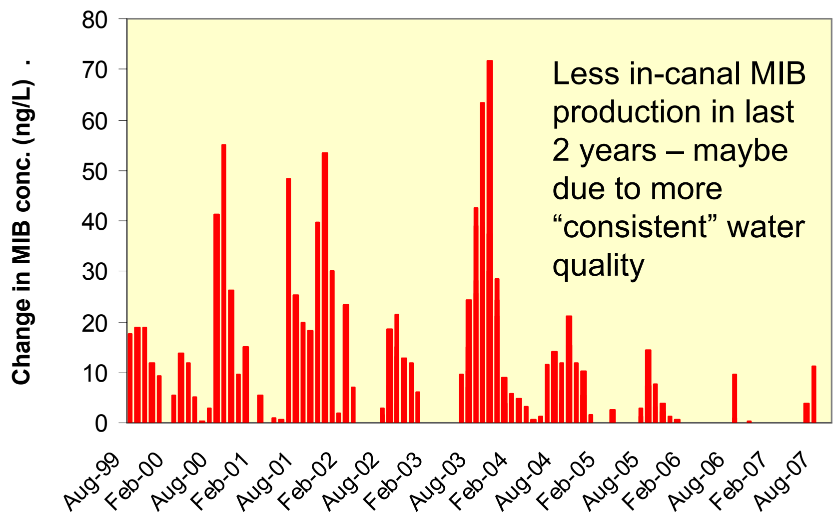


Saguaro Lake had highly variable geomsin levels in 2007

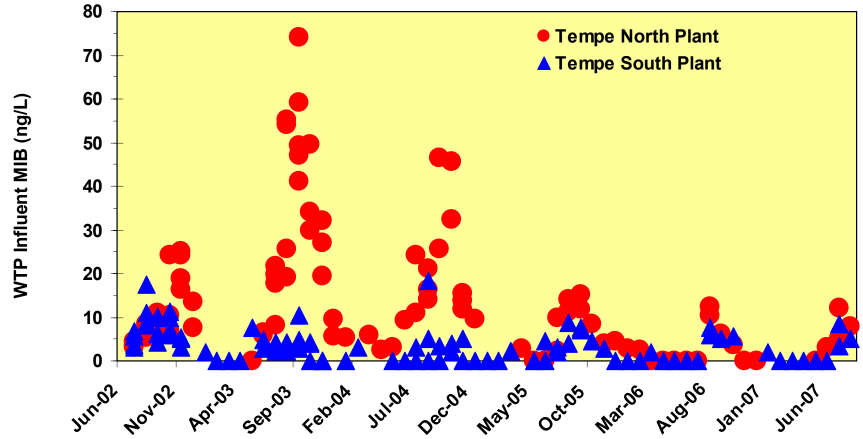


In-Canal Production of T&O is seasonal

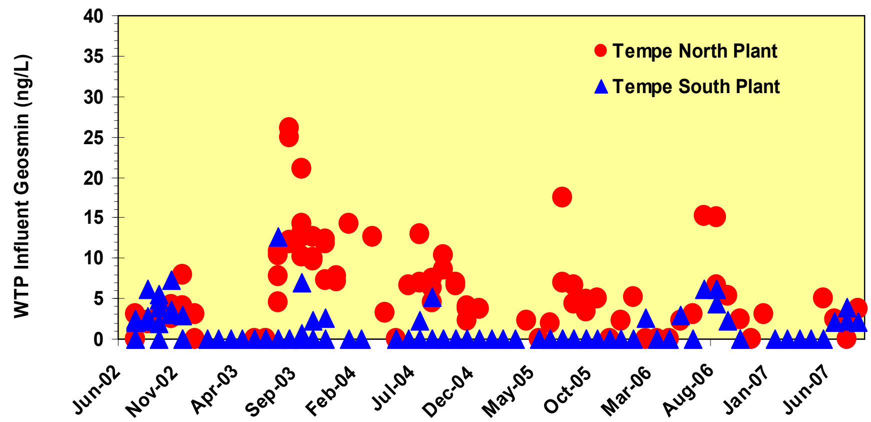
MIB Growth in AZ canal from below X-Con to DV Inlet



MIB levels higher in AZ Canal system compared against South Canal system 2005-2007 have lower MIB levels

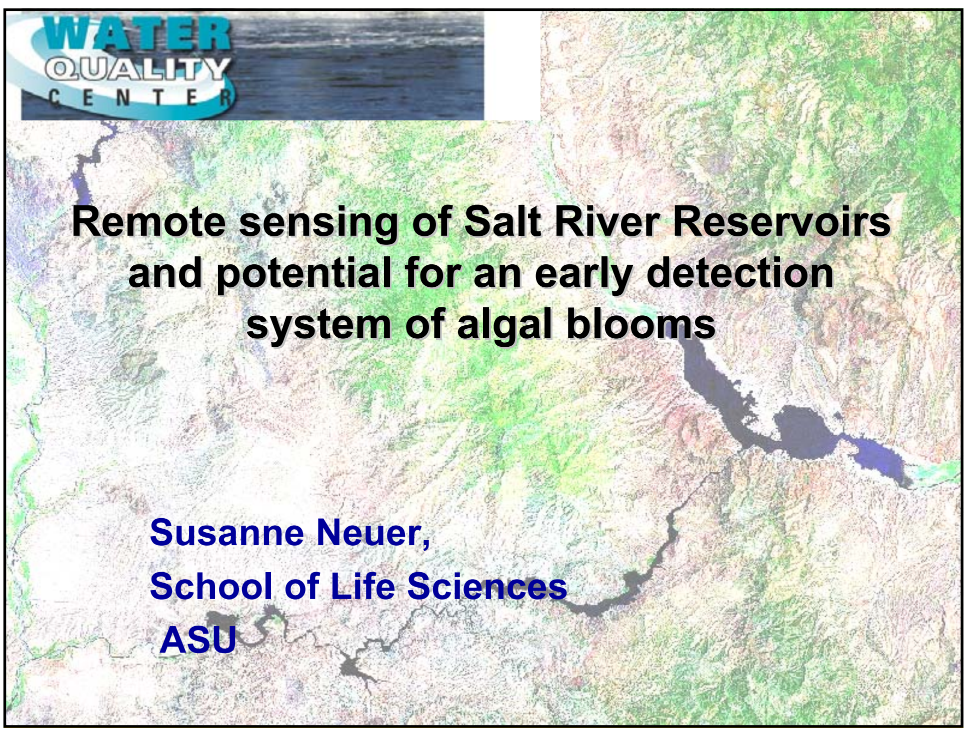


Geosmin is more prevalent in AZ Canal



Summary

- Since heavy rains in winter 2005:
  - Conductance has decreased
  - MIB concentrations are lower in reservoirs
  - MIB production in canal is minimal, presumably due to less blending of water sources
  - DOC is higher
  - Tradeoff between T&O and DOC
- According to SRP we remain in the 13th year of a drought, this may lead to higher conductance levels again
- Rainfall impacts the availability of water and water quality



Break

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In-Plant Algae Identification, Characterization and Control

Arizona State University
Milton Sommerfeld
Thomas Dempster
Paul Westerhoff

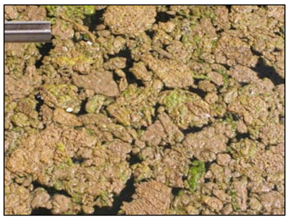
&

Malcolm Pirnie Inc.

Strategies for Controlling and Mitigating Algal Growth Within Water Treatment Plants

AWWARF Project (RFP 3111)

Malcolm Pirnie, Inc.
Sunil Kommeneni
Shahnawaz Sinha
Kristen Amante



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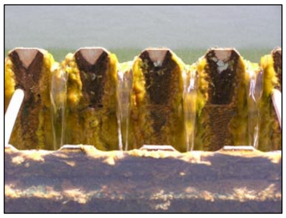


Goal

Identify and recommend strategies for controlling algae growth within water treatment plants

Project Objectives

- Gather Background Information (literature review)
- Utility Survey (e-mail surveys)
- Case Study of Selected Plants (on-site visits)
- Identify/Document Dominant Algae Types
- Identify Optimal Algae Control Strategies
- Develop Guidance Document for Utilities

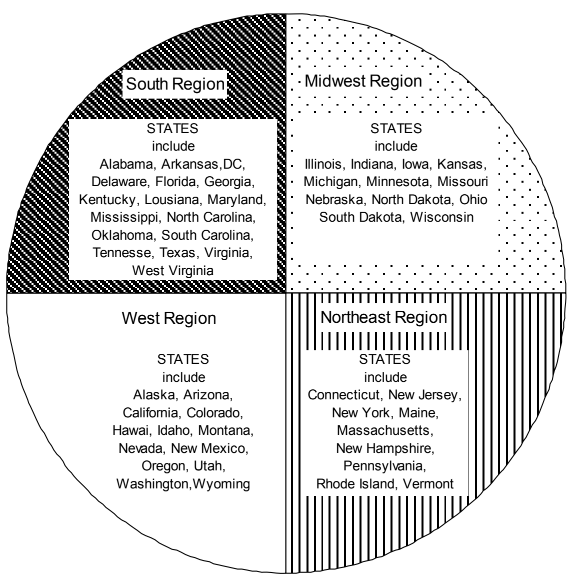
Participating Utilities

- Ca. 200 utilities were solicitated to participate in survey
- 76 utilities completed website survey
- Survey contained questions about demographics, algae occurrence and characterization, algae control strategies

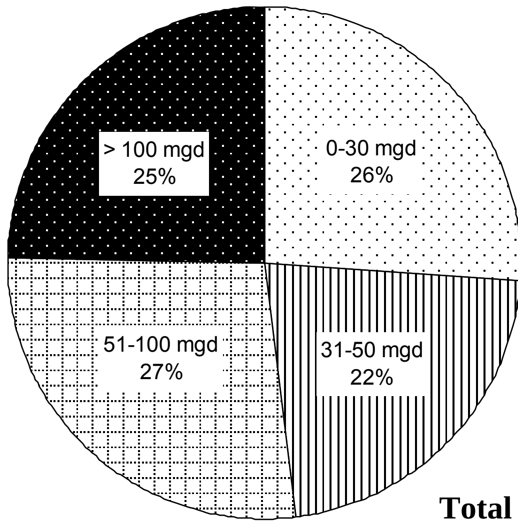
Example Survey Questions

- Do you have in-plant algae problems?
- Where do you have algae growth?
- Do you analyze algae samples?
- What kind of algae occur at your plant?
- When do you have algae problems?
- What are some of the issues caused by algae growth?
- What operational practices are used to control algae growth?

US Census Regions Classification

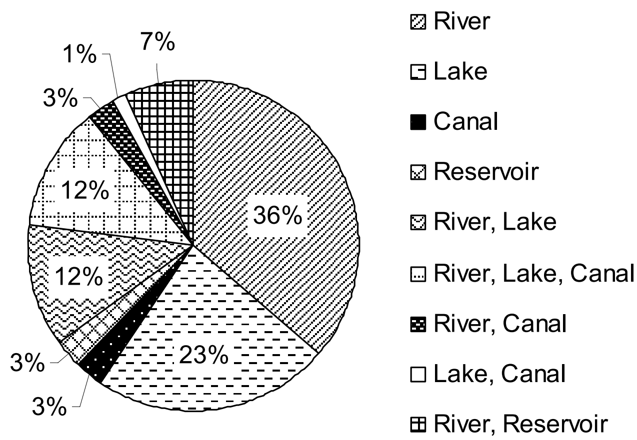


Plant capacities for the utilities taking the survey



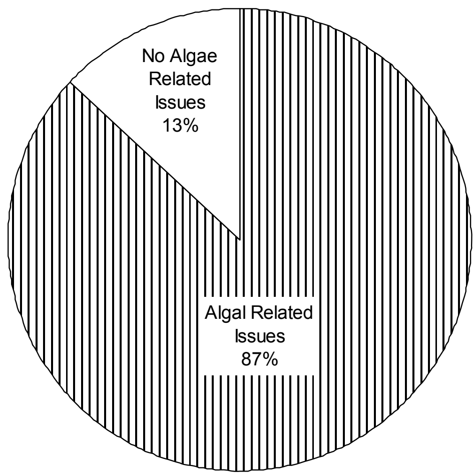
Total Responses: 73

Combinations of Surface Source Waters



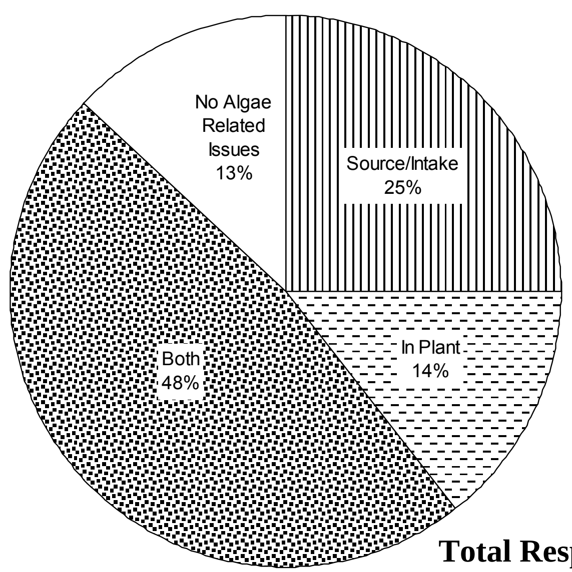
Total Responses: 74

Algae Related Issues



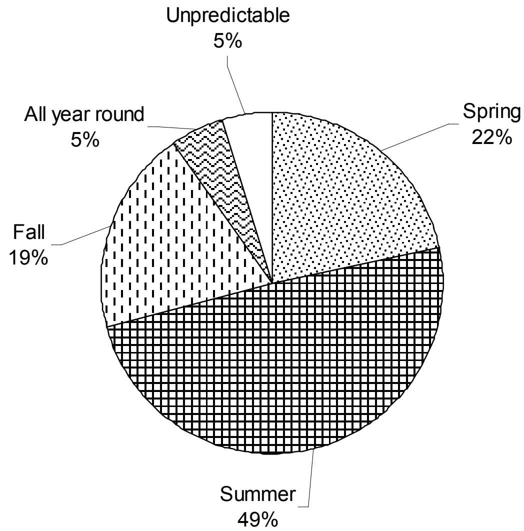
Total Responses: 76

Algae Related Issue by Location



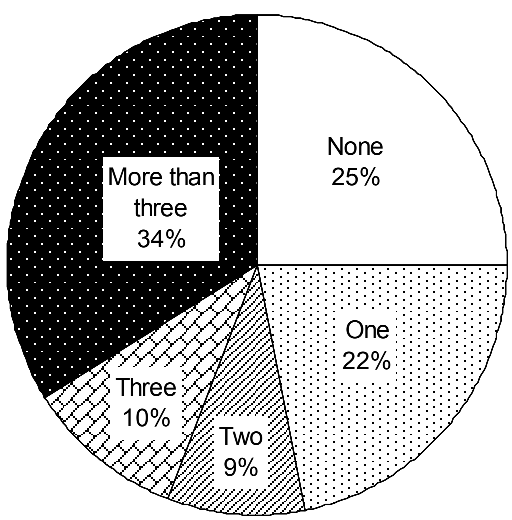
Total Responses: 76

Algae Growth by Season



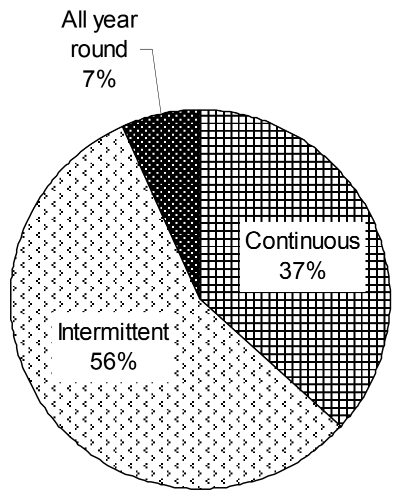
Total Responses: 64

Algae Events



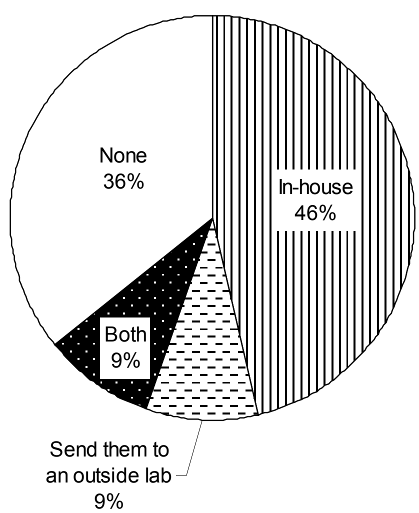
Total Responses: 68

Occurrence of Algae Events



Total Responses: 63

Algal Analysis



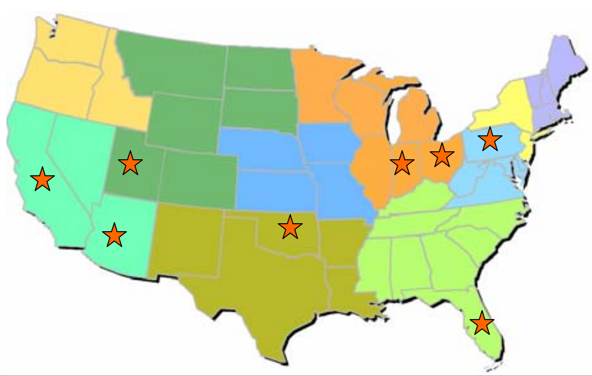
Total Responses: 67

Control Strategies for Algal Growth

No. of Responses	Summary of Responses
28	Operational practices to mitigate algae such as cleaning basins, and other mechanical equipment prone to algae
27	Chlorine use for algae mitigation (chlorinating for disinfection, and shock chlorination)
17	Copper sulfate use in source water or in treatment plant to mitigate algae and T&O
12	Potassium permanganate in source or in treatment plant to mitigate algae and T&O
9	PAC addition for algae mitigation and T&O.
8	Limit nutrients at source (i.e. use multiple sources, water shed protection).
6	Coagulant or polymer to restrict nutrient growth.
5	Cover portions of treatment train.
5	Aeration in source water
3	Algaecide use in source or within treatment train.
3	Ozonation for algae mitigation and T&O.
3	Chlorine dioxide in source water or within treatment train.
2	pH adjustment primarily used for softening, but is effective at mitigating algae.
1	Dissolved Air Flotation flocculation for algae mitigation.
1	Ultrasonic device for algae mitigation.
1	Minimize retention time.

Case Studies

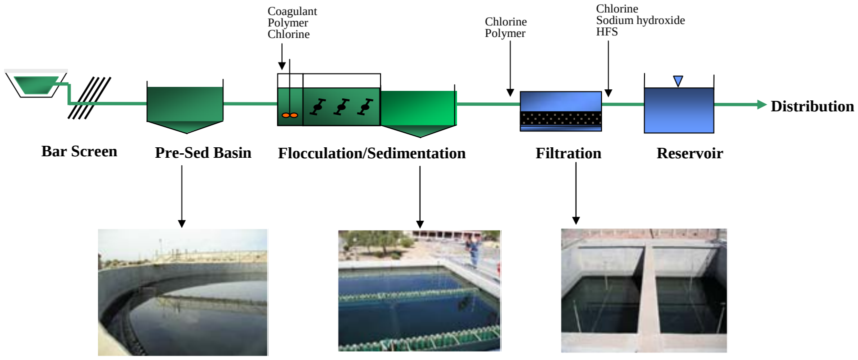
- WTPs Selected and Visited in Arizona, California, Oklahoma, Utah, Ohio, Indiana, Florida and Pennsylvania



Algae Sampling Methods

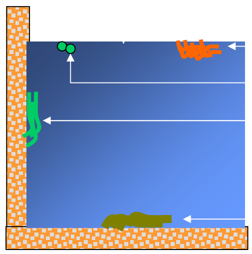
Sampling Locations in Treatment Plant

- Presedimentation Basins
- Sedimentation Basins
- Filtration Basins

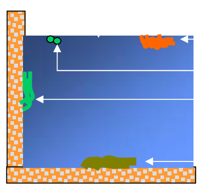


Types of Samples Collected

- Plankton or Suspended
- Floating (paddies or mats)
- Periphyton (attached to walls)
- Benthic (sediment from bottom surfaces)



Sample Collection Procedure



- Plankton or suspended
  - three 500 ml samples composited in 1,500 ml (X2)
- Floating (paddies or mats)
  - three mats composited in 1,500 ml basin water (X2)
- Periphyton
  - three wall scrapings composited in 1,500 ml basin water (X2)
- Benthic
  - three bottom sediment samples composited in 1,500 ml of basin water (X2)

Plankton Collection with Sludge Judge® II and 1 L Nalgene bottle in GAC filter beds

Benthic Sample Collected in GAC Filter with Sludge Judge® II

Periphyton Collected in GAC Filters with Telescopic Pole and Brush

Algae Characterization

Location in plant train (basin)

Habitat in basin
- **Plankton**
- **Floating**
- **Periphyton**
- **Benthic**

Form (unicellular, colonial or filamentous)
Size
Color

Relative abundance (dominant, abundant, frequent, common or rare)

Potential to produce off-flavors/odors and toxins

Scientific name

Algae Characterization at 9-CA on June 23, 2006

Location	Habitat	Organism	Growth Form	Color	Relative Abundance	Potential Problems
Flocculation Basin	phytoplankton	*Fragilaria sp.*	filamentous	golden-brown	abundant	filter-clogging
Flocculation Basin	phytoplankton	*Navicula sp.*	unicellular	golden-brown	frequent	none
Flocculation Basin	phytoplankton	*Synedra sp.*	unicellular	golden-brown	frequent	filter-clogging
Flocculation Basin	phytoplankton	*Chlorella sp.*	unicellular	green	frequent	none
Flocculation Basin	phytoplankton	*Scenedesmus sp.*	colonial	green	frequent	none
Flocculation Basin	phytoplankton	*Melosira varians*	filamentous	golden-brown	frequent	filter-clogging
Flocculation Basin	phytoplankton	*Planktothrix aghardhii*	filamentous	blue-green	common	MIB production
Flocculation Basin	phytoplankton	*Pseudanabaena sp.*	filamentous	blue-green	common	MIB/Geosmin production
Flocculation Basin	phytoplankton	*Amphora sp.*	unicellular	golden-brown	rare	none
Flocculation Basin	periphyton	*Oscillatoria spp.*	filamentous	blue-green	dominant	MIB/Geosmin production
Flocculation Basin	periphyton	*Anabaena sp.*	filamentous	blue-green	frequent	MIB/Geosmin production

Comprehensive List Of Algae Taxa Observed At Participating WTPs

	Water Treatment Plant							
CYANOPHYTA TAXA	Belmont	4-FL	5-IN	5-OH	6-OK	CUWCD	9-AZ	9-CA
Anabaena sp.		X					X	X
Aphanizomenon sp.			X					
Lyngbya sp.	X	X	X	X				
Microcystis sp.							X	
Planktothrix aghardhii						X		X
Oscillatoria sp.	X		X	X	X		X	
Oscillatoria splendida		X			X		X	
Oscillatoria spp.	X	X	X	X				X
Pseudanabaena sp.	X	X	X	X	X		X	X
Tolypothrix sp.			X					
Trichodesmium sp.			X	X				

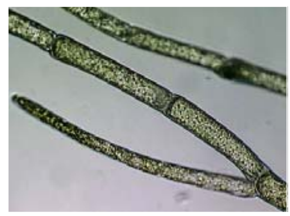
CHLOROPHYTA TAXA	Belmont	4-FL	5-IN	5-OH	6-OK	CUWCD	9-AZ	9-CA
Ankistrodesmus sp.		X						
Chlamydomonas sp.								X
Chlorella sp.						X		X
Cladophora sp.								X
Closterium sp.				X				
Cosmarium sp	X				X		X	X
Eudorina sp.								X
Microspora sp.								X
Mougeotia sp.	X		X					X
Oedogonium sp.			X		X			X
Oocystis sp.				X				
Ophiocytium sp.	X	X	X					
Pediastrum sp.					X			
Scenedesmus sp.	X	X	X		X		X	X
Spirogyra sp.			X					
Stigeoclonium sp.			X					X
Tetrahedron sp.								X
Ulothrix sp.			X					X

BACILLARIOPHYCEAE TAXA	Belmont	4-FL	5-IN	5-OH	6-OK	CUWCD	9-AZ	9-CA
Achnanthes minutissima	X	X	X		X	X	X	X
Achnanthes sp.				X				
Amphora sp.							X	X
Asterionella formosa						X		X
Aulacoseira sp.		X			X			
Cocconeis pediculus							X	
Cocconeis sp.	X	X	X			X		
Cyclotella sp.	X	X			X			X
Cymatopleura solea			X					
Cymbella sp				X		X	X	X
Diatoma sp.							X	X
Eunotia sp.								X
Fragilaria crotonensis						X		
Fragilaria leptostauron							X	
Fragilaria sp.							X	X
Gomphonema sp.	X	X	X					X
Gyrosigma sp.	X		X			X	X	
Mastogloia sp.								
Melosira varians	X	X	X		X		X	X
Navicula sp.	X	X	X	X		X	X	X
Nitzchia palea			X					
Nitzschia dissapata			X					
Nitzschia sigmoidea			X					
Nitzschia sp.	X		X	X	X	X	X	X
Pinnularia sp.	X		X				X	
Rhoicosphenia curvata						X		
Rhopalodia gibba							X	
Stephanodiscus sp.					X	X		
Surirella sp.							X	
Synedra affinis					X			
Synedra sp.		X	X	X	X	X	X	X
Synedra ulna					X			

Visual Characterization of Dominant Algae

- Field image of dominant algae in treatment plant
- Images of collected macroforms
- Microscopic images



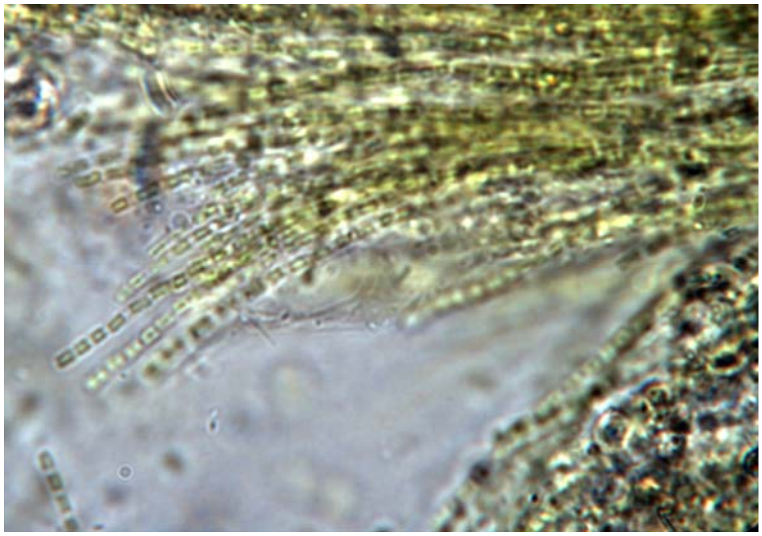


Floating Paddies In The Sedimentation Basin Contributed To High Algae Biomass At WTP 9-AZ

Photomicrograph of *Pseudanabaena* sp. from Sedimentation Basin Phytoplankton Sample at 4-FL

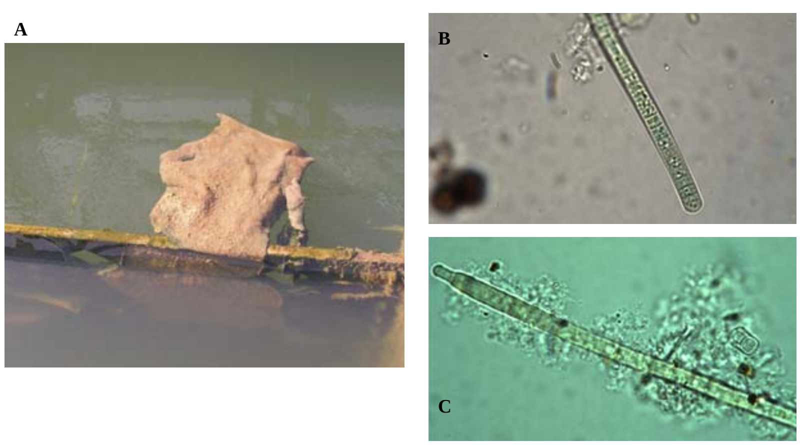
Sedimentation Basin Periphyton Contributed To High Algae Biomass At 9-AZ

Pseudanabaena sp. Was Prevalent Throughout WTP 9-AZ



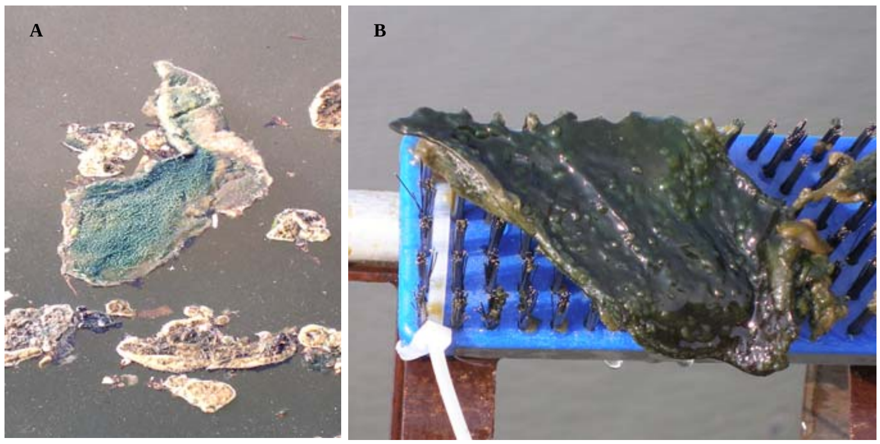
Flocculation Basin At WTP 9-CA.

A) *Oscillatoria* spp. Mat From Redwood Diffuser Wall,
B) Photomicrograph Of *Oscillatoria* sp., and
C) Photomicrograph Of *Planktothrix aghardhii*



A) *Oscillatoria* spp. Paddy Floating In Sedimentation Basin

B) *Oscillatoria* spp. Paddy Collected On Wire Brush



Oscillatoria splendida, a Known Geosmin Producer, Observed In Floating Paddies in Filter Basins At WTP 6-OK

Planktothrix aghardhii Collected From The Flocculation And Filter Basin Periphyton At UVWTP

Photomicrograph of _Pseudanabaena_ sp. from Sedimentation Basin Phytoplankton Sample at 4-FL

Summary

- **In-plant algae growth is common**
- **Most water treatment plants report algae in flocculation/sedimentation basins**
- **Most common algae mitigation measures were physical cleaning, chlorination, addition of copper sulfate and potassium permanganate**
- **Based on 8 case studies, 50 genera (61 sp.) of in-plant algae were identified and characterized**
- **Nine (9) genera identified were potentially producers of off-flavor compounds or toxins**

DBP Precursors & Modeling

- 2006-2007 SRP funded a project: Predicting Organic Carbon and Disinfection By Product Precursors in Metro-Phoenix Surface Water Reservoirs
- Conduct laboratory experiments on water from the three terminal reservoirs (Bartlett Lake, Saguaro Lake, Lake Pleasant)
- Use data to validate models for municipal users of water (DOC removal models, DBP formation models).
- Models will be useful in years to come for SRP to decide with the cities when certain reservoir water qualities are particular troublesome or desirable to assist cities in complying with DBP regulations.

Background

- THM formation is dependent on several water quality parameters

$$THM = 4.121 \cdot 10^{-2} (TOC)^{1.098} (Cl_2)^{0.152} (Br^-)^{0.068} (Temp)^{0.609} (pH)^{1.601} (time)^{0.263}$$

$$HOCl + Br^- \rightarrow HOBr$$

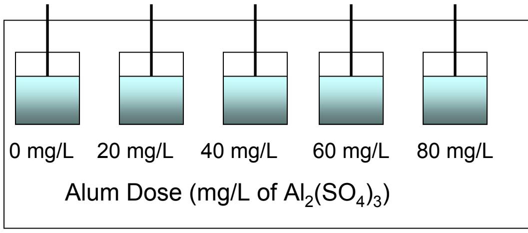
$$DOC + \begin{Bmatrix} HOCl \\ HOBr \end{Bmatrix} \rightarrow \begin{matrix} CHCl_3 \\ CHBrCl_2 \\ CHBr_2Cl \\ CHBr_3 \end{matrix}$$

Raw Water Quality Ranges During This Study

Parameter	Bartlett	Pleasant	Saguaro
DOC (mg/L)	1.93 - 3.07	3.07 – 3.72	4.84 – 6.20
TDN (mg/L)	0.16 – 0.22	0.28 – 0.39	0.23 – 0.40
UV_{254} (1/cm)	0.043 – 0.071	0.042 – 0.052	0.096 – 0.106
SUVA (L/mg-m)	1.4 – 3.7	1.1 – 1.5	1.5 – 2.1
pH	8.3 – 8.6	8.0 – 8.4	8.2 – 8.8
Alkalinity (mg/L as $CaCO_3$)	188 – 239	121 – 150	106 – 147
Br^- (mg/L)	0.070 – 0.098	0.105 – 0.113	0.091 – 0.150

Jar and SDS Tests

1



2

Filtration through GF/F filter with 0.7µm pore size

3

Measure DOC, TDN, UV_{254}, alkalinity, pH and Br^-

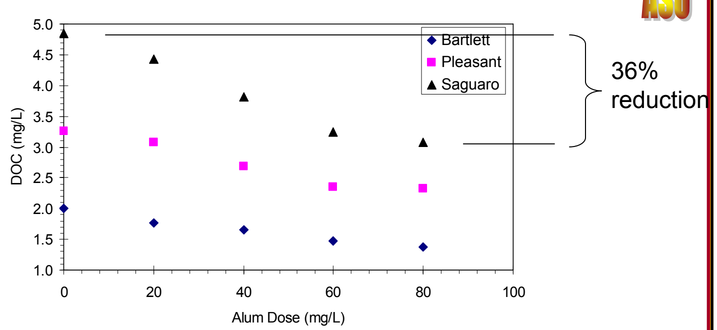
4

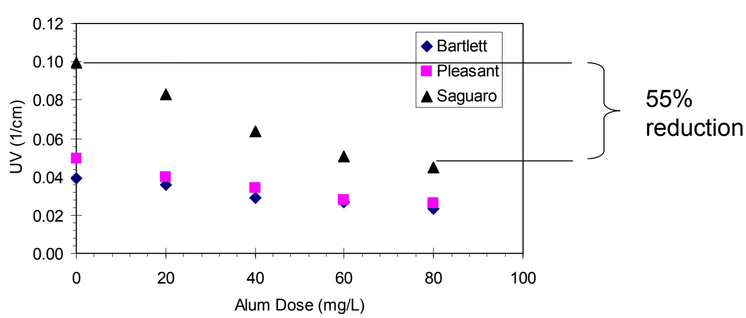
Chlorination such that free chlorine conc. after 24 hours is 1±0.2 mg/L

5

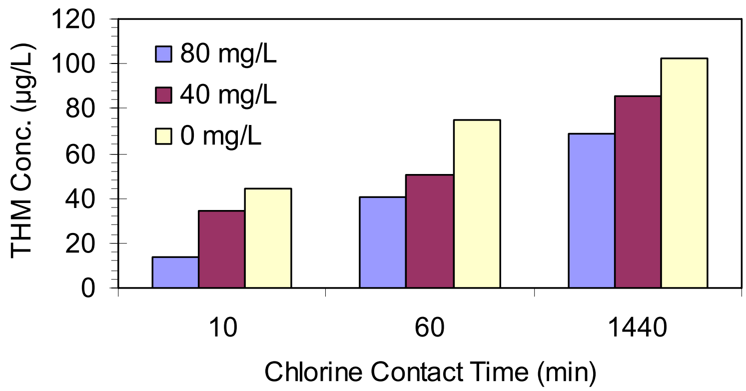
Measure THMs using EPA method 551.1

May 2007 Jar Tests

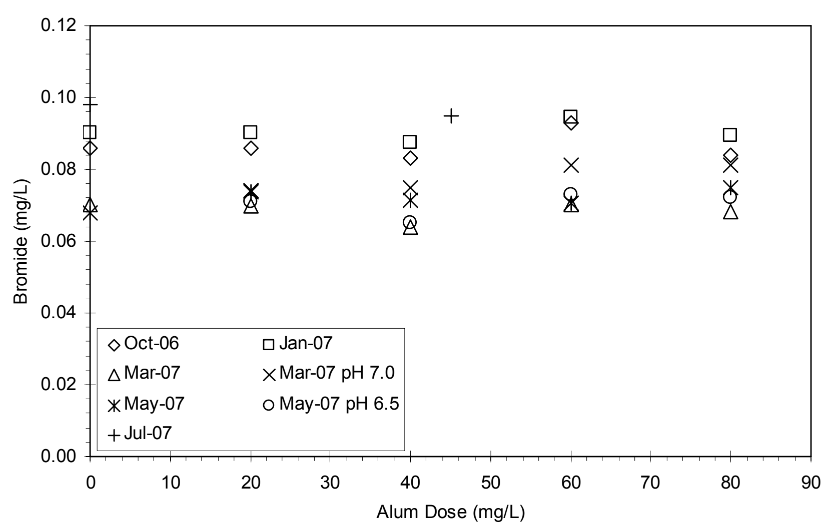




Kinetics of THM formation Saguaro Lake May 2007



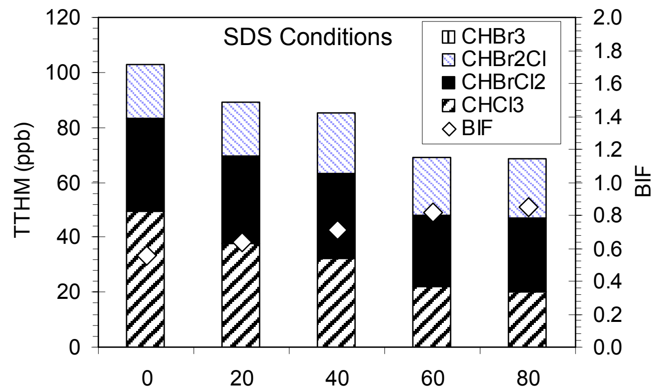
Coagulation does NOT remove Bromide



Saguaro Lake May 2007

$$BIF = \frac{\frac{\mu mole}{L} TTHMBr}{\frac{\mu mol}{L} TTHM}$$

$$THMBr = \sum_{i=1}^{3} i \times CHCl_{3-i}Br_i$$



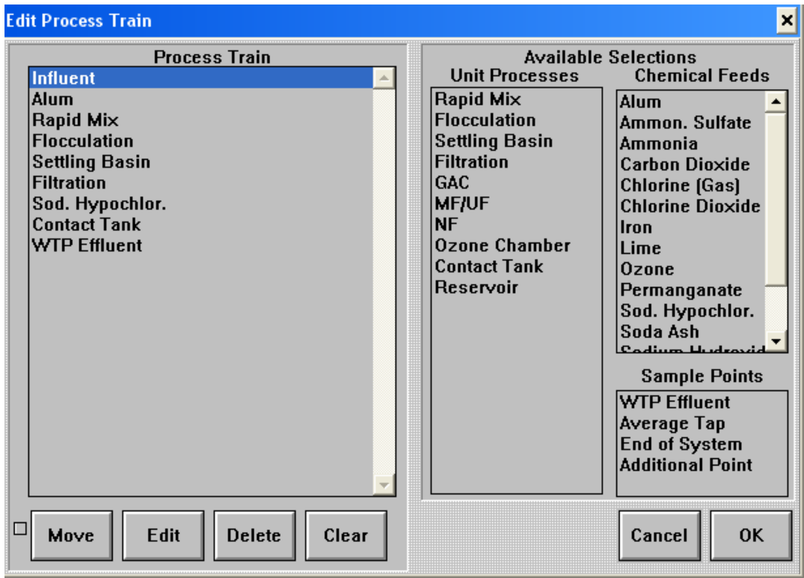
WTP model

•Originally developed for the USEPA in 1992 as an empirically based model to predict DBP formation, NOM removal, and disinfectant decay

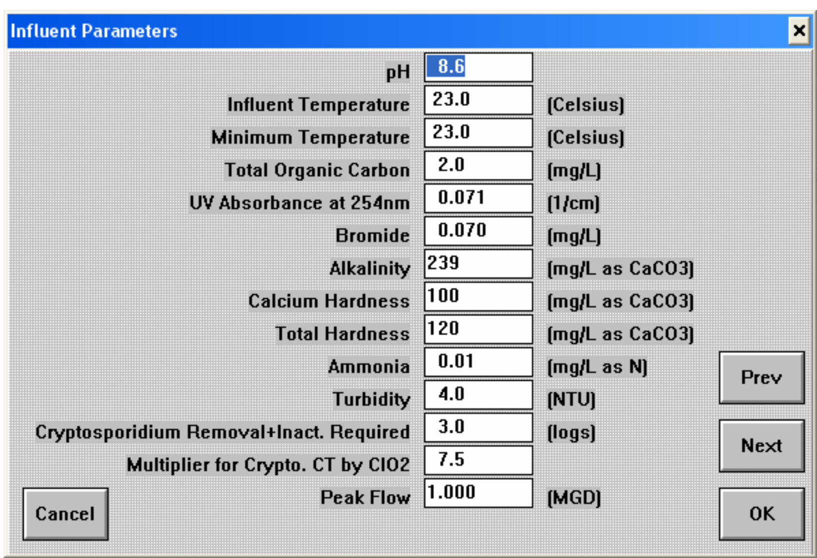
•Updated in 1999 to include increased data availability and knowledge of treatment processes and to include additional disinfectants

Treatment Process	Disinfectants
Coagulation / Flocculation. / Sedimentation	Chlorine
Precip. Softening / Clarification / Filtration	Chloramines
GAC Adsorption	Ozone
Membranes	Chlorine Dioxide
Biotreatment	

WTP.exe model



WTP.exe input parameters



Representative Model Outputs

Predicted Water Quality Profile
At Plant Flow (1.0 MGD) and Influent Temperature (23.0 C)

Location	pH (-)	TOC (mg/L)	UVA (1/cm)	(T)SUVA (L/mg-m)	Cl2 (mg/L)	NH2Cl (mg/L)	Residence Time Process (hrs)	Residence Time Cum. (hrs)
Influent	8.6	2.0	0.071	3.5	0.0	0.0	0.00	0.00
Alum	7.5	2.0	0.071	3.5	0.0	0.0	0.00	0.00
Rapid Mix	7.5	1.5	0.045	2.9	0.0	0.0	0.02	0.02
Flocculation	7.5	1.5	0.045	2.9	0.0	0.0	0.25	0.27
Settling Basin	7.5	1.5	0.045	2.9	0.0	0.0	0.75	1.02
Filtration	7.5	1.5	0.045	2.9	0.0	0.0	0.03	1.05
Sod. Hypochlor.	7.5	1.5	0.032	2.1	2.0	0.0	0.00	1.05
Contact Tank	7.5	1.5	0.032	2.1	0.9	0.0	24.00	25.05
WTP Effluent	7.5	1.5	0.032	2.1	0.9	0.0	0.00	25.05

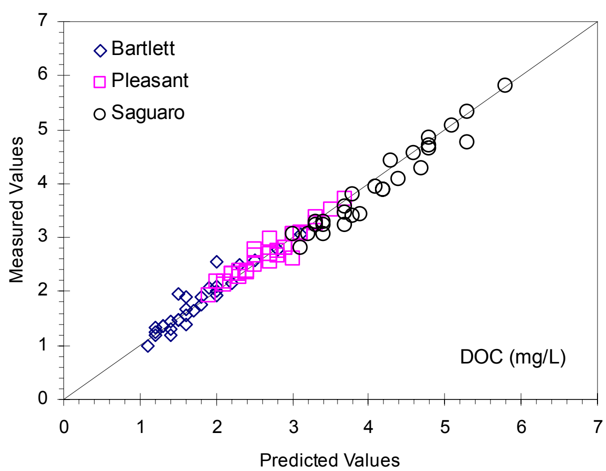
Predicted Water Quality Profile
At Plant Flow (1.0 MGD) and Influent Temperature (23.0 C)

Location	pH (-)	Alk (mg/L)	Calcium Hardness (mg/L)	Magnesium Hardness (mg/L)	Solids (mg/L)	NH3-N (mg/L)	Bromide (ug/L)
Influent	8.6	239	100	20	0.0	0.0	70
Alum	7.5	219	100	20	0.0	0.0	70
Rapid Mix	7.5	219	100	20	0.0	0.0	70
Flocculation	7.5	219	100	20	0.0	0.0	70
Settling Basin	7.5	219	100	20	23.7	0.0	70
Filtration	7.5	219	100	20	23.7		
Sod. Hypochlor.	7.5	221	100	20	23.7		
Contact Tank	7.5	221	100	20	23.7		
WTP Effluent	7.5	221	100	20	23.7		

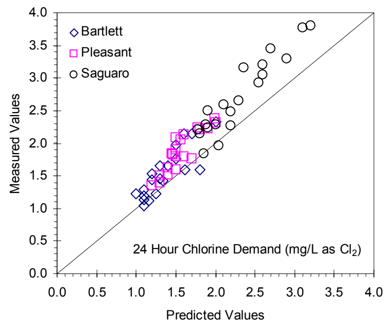
Predicted Trihalomethanes and other DBPs
At Average Flow (1.0 MGD) and Temperature (23.0 C)

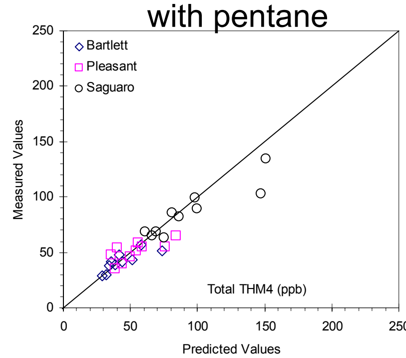
Location	BrO3- (ug/L)	ClO2- (mg/L)	TOX (ug/L)	CHCl3 (ug/L)	CHBrCl2 (ug/L)	CHBr2Cl (ug/L)	CHBr3 (ug/L)	TTHMs (ug/L)
Influent	0	0.0	0	0	0	0	0	0
Alum	0	0.0	0	0	0	0	0	0
Rapid Mix	0	0.0	0	0	0	0	0	0
Flocculation	0	0.0	0	0	0	0	0	0
Settling Basin	0	0.0	0	0	0	0	0	0
Filtration	0	0.0	0	0	0	0	0	0
Sod. Hypochlor.	0	0.0	0	0	0	0	0	0
Contact Tank	0	0.0	157	16	15	12	1	44
WTP Effluent	0	0.0	157	16	15	12	1	44

WTP Validation for DOC prediction



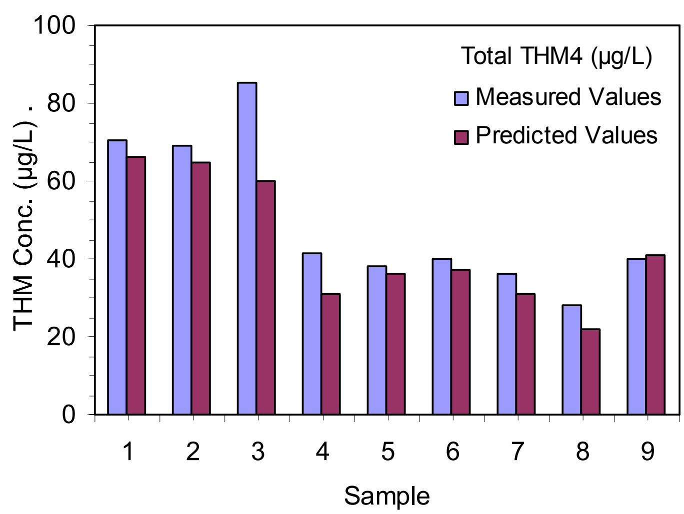
Model Predictions





Validate WTP model

Full Scale WTP



Summary

- WTP.exe model is appropriate for use with waters from Verde & Salt Rivers and Lake Pleasant to predict ability to remove DOC by coagulation.
- WTP.exe model accurately predicts THM formation
- With a minimal number of data inputs (TOC, pH, alkalinity, bromide, temperature) the model can be used to estimate the treatbility of different source waters before arriving at WTPs

Planning for the Future

- Continue baseline monitoring
- Apply WTP.exe model seasonally to predict "treatability" of organics in the three reservoirs
- 2007-08 will include sampling for trace organics (EDC/PPCPs) in the SRP watershed and maybe beyond
- Would like to use satellite imaging to evaluate past data and as a real-time monitoring tool on several lakes
- ASU/Carollo/Phoenix is conducting seasonal RSSCTs using Granular Activated Carbon to remove TOC and DBP precursors
- What would you like to see in the next year?