Reducing Taste and Odor and Other Algae-Related Problems for Surface Water Supplies in Arid Environments

Final Report

A Cooperative Research and Implementation Program

Arizona State University (Tempe, AZ)

Milton Sommerfeld, Paul Westerhoff, Larry Baker,

Qiang Hu, Thomas Dempster, Mario Esparza,

Mari Rodriquez, Samanth Dawson, Kirsten Hintze,

Michelle Cummings, My-linh Nguyen, and Marisa Marsles

Salt River Project

Central Arizona Project

and

the City of Phoenix

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Introduction and Overview

GOAL

Develop a comprehensive management strategy to reduce algae-related water quality problems for drinking water supplies in arid environments

Specific Objectives

- Develop a thorough understanding of conditions leading to T & O problems
- Conduct preliminary feasibility analysis for potential T & O control measures based on technical, economic and political considerations
- Conduct controlled lab and field-scale experiments to evaluate T & O control practices
- Integrate results for implementation of multiple-barrier approach to controlling T & O problems

Specific Objectives

- Develop a long term monitoring plan that will allow Phoenix and other municipalities to forecast the occurrence of T & O problems
- Quantify the extent to which reservoir algae produces DOC and the reactivity of the DOC in DBP formation
- Extrapolate applied research findings for Arizona to water treatment systems in other arid environments

Project Tasks

MONITORING

Task 1:	Monitoring Program – Algae and water quality parameters

MULTI-BARRIER TREATMENT OPTIONS

Task 2:	Experimental Evaluation of T&O control measures
Task 3:	Assessment of in-plant controls

FUNDAMENTAL INSIGHTS

Task 4:	Controlled Lab and field-scale T&O reduction experiments
Task 5:	Studies of DOC source, characterization, and treatability

IMPLEMENTATION

Task 6:	Midcourse feasibility analysis
Task 7:	Phased-in T&O implementation program

Task 8:	Guidance document and final report

Presentation Outline

Summary of Research Products

Summary of Monitoring Activities

Summary of Research Activities

Summary of Implementation Activities

Overview of Guidance Manual

Integration for Regional T&O Control

Recommendations & Future Needs

Summary of Research Products

- Presentations at local, regional, and national conferences (15)
- MS and PhD Theses completed or partially completed (6)
- Journal Articles published, in-press, or submitted (6)
- Related Project Funding:
  - AWWARF (3 Projects)
  - Salt River Project (2 Projects)
  - City of Tempe (2 Projects)
  - City of Chandler (1 Project)
- Final Report (PDF on Web)
- Guidance Manual (PDF on Web)
- Taxonomy Guide (available on Web)

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- Summary of Research Products
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- Summary of Implementation Activities
- Overview of Guidance Manual
- Integration for Regional T&O Control
- Recommendations & Future Needs

Summary of Monitoring-Related Activities

Baseline monitoring program (Task 1)

Purpose: To understand spatial and temporal patterns in water quality parameters that affect algae productivity and occurrence of T&O compounds

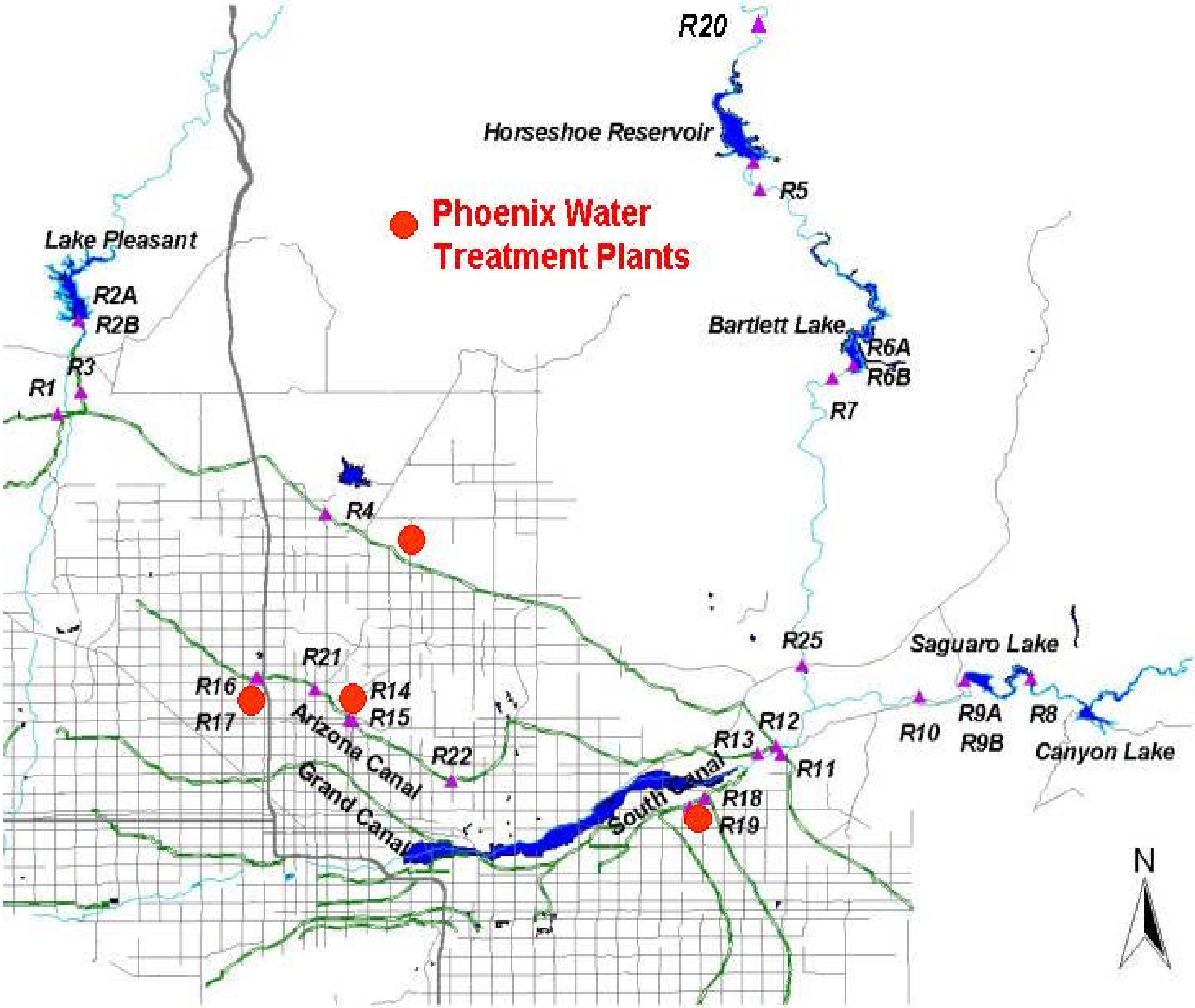
Studies of DOC sources and characterization (Task 5)

Purpose: To identify algae-sources of DOC and characterize DOC in the watershed

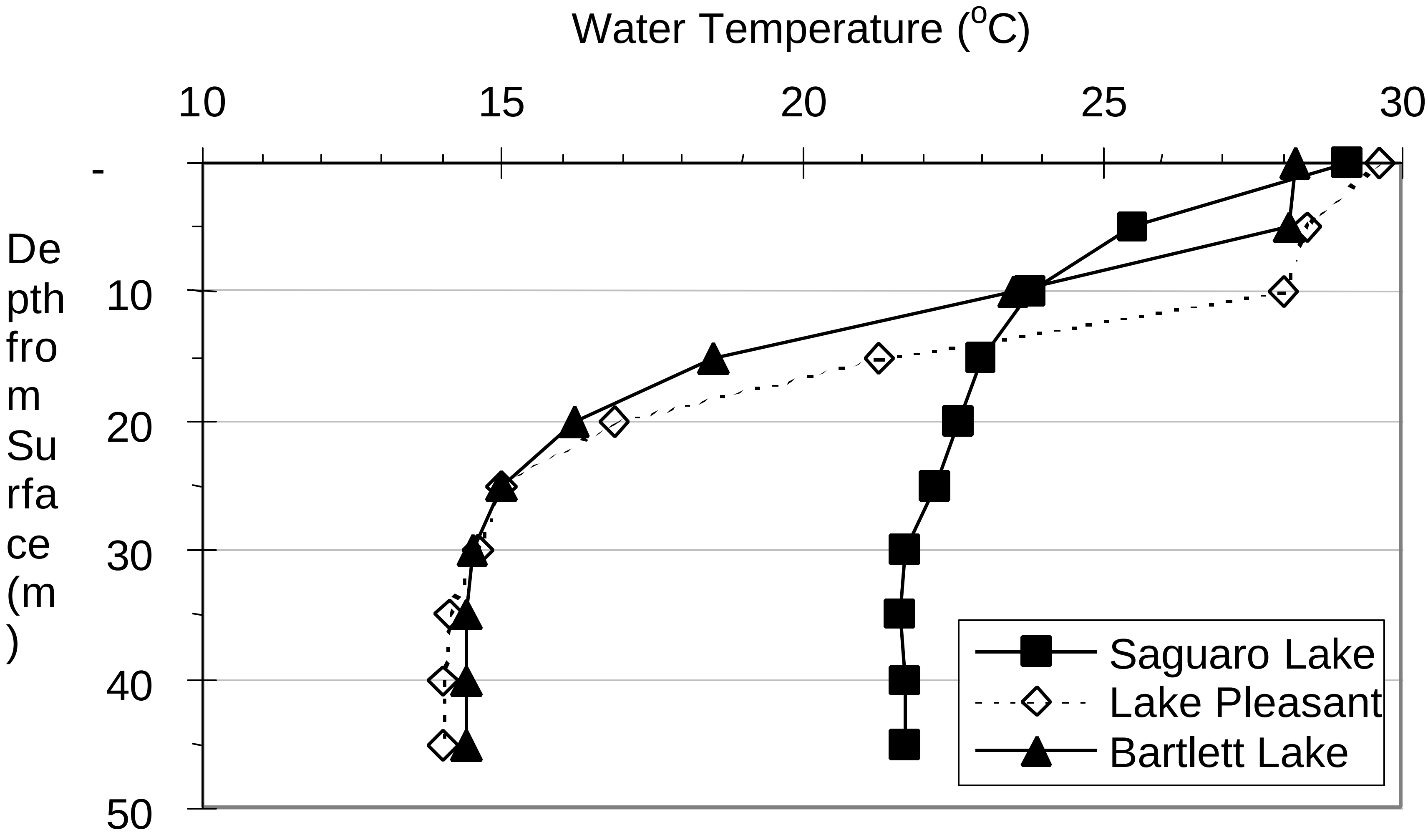
Assessment of in-plant controls (Task 3)

Purpose: To identify sources of T&O in WTPs and treatment capability to remove T&O compounds

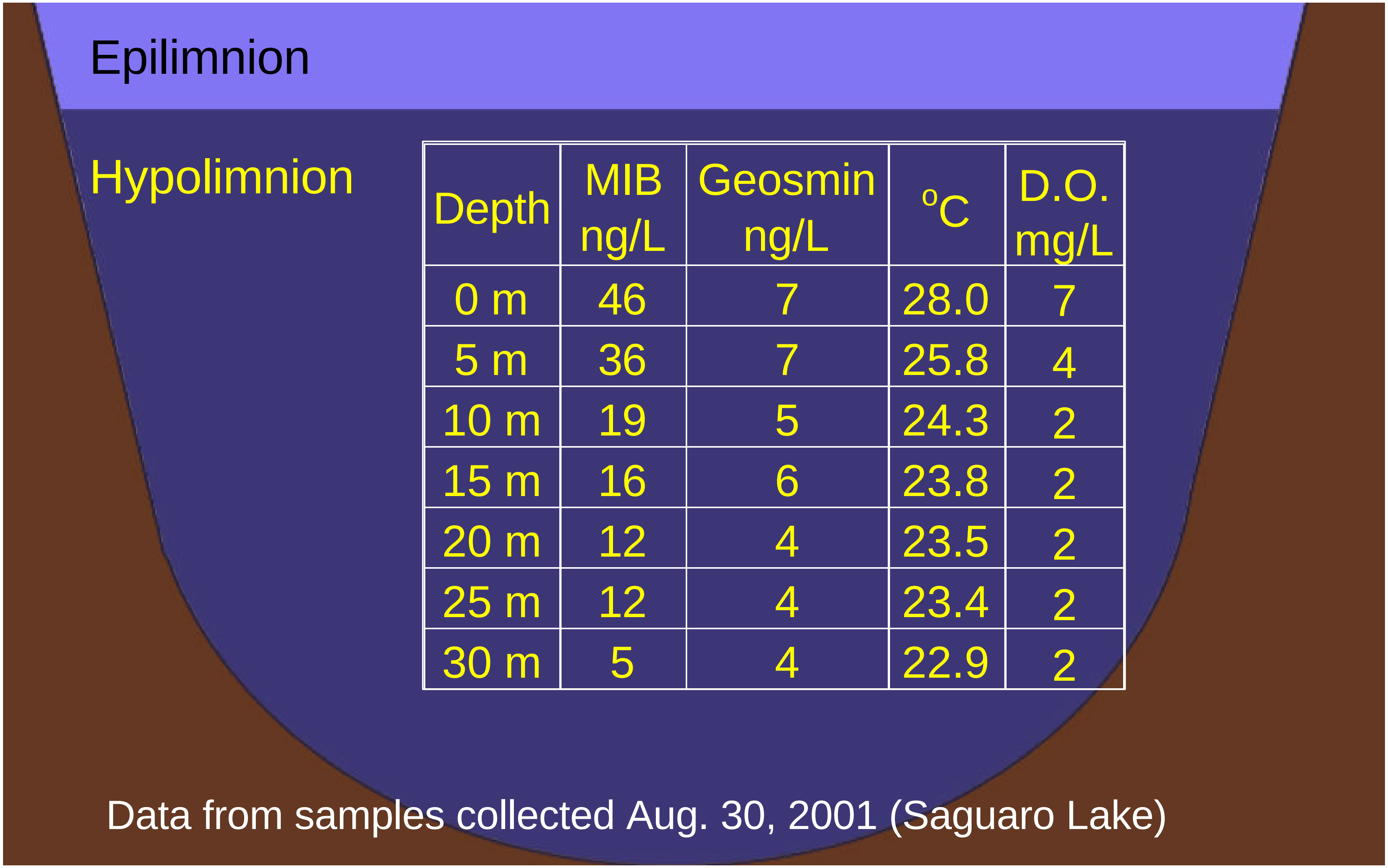
Sampling Program



Representative Data: Lake Stratification



Representative Data: MIB Depth Stratification

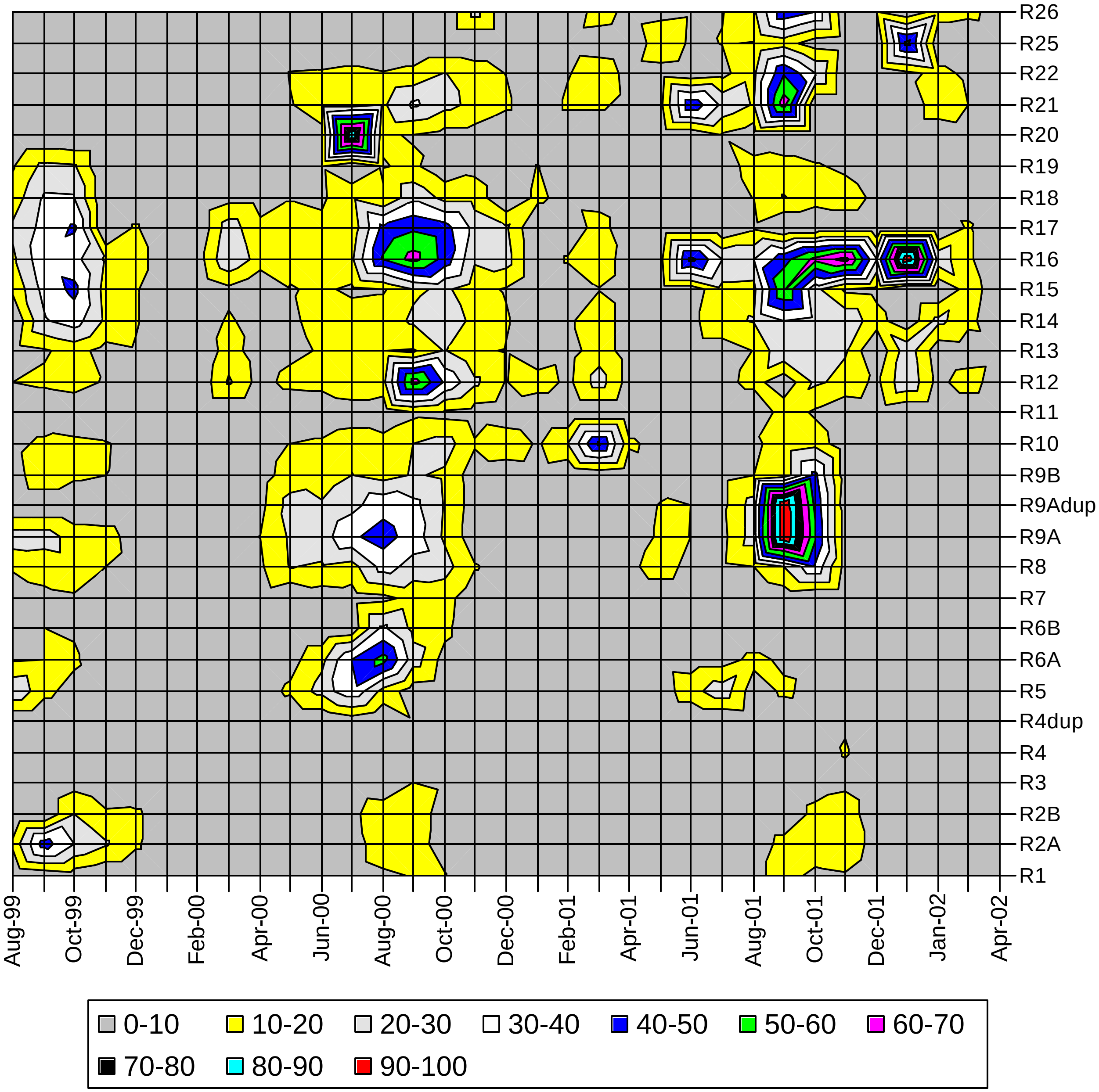


Depth	MIB ng/L	Geosmin ng/L	^{o}C	D.O. mg/L
0 m	46	7	28.0	7
5 m	36	7	25.8	4
10 m	19	5	24.3	2
15 m	16	6	23.8	2
20 m	12	4	23.5	2
25 m	12	4	23.4	2
30 m	5	4	22.9	2

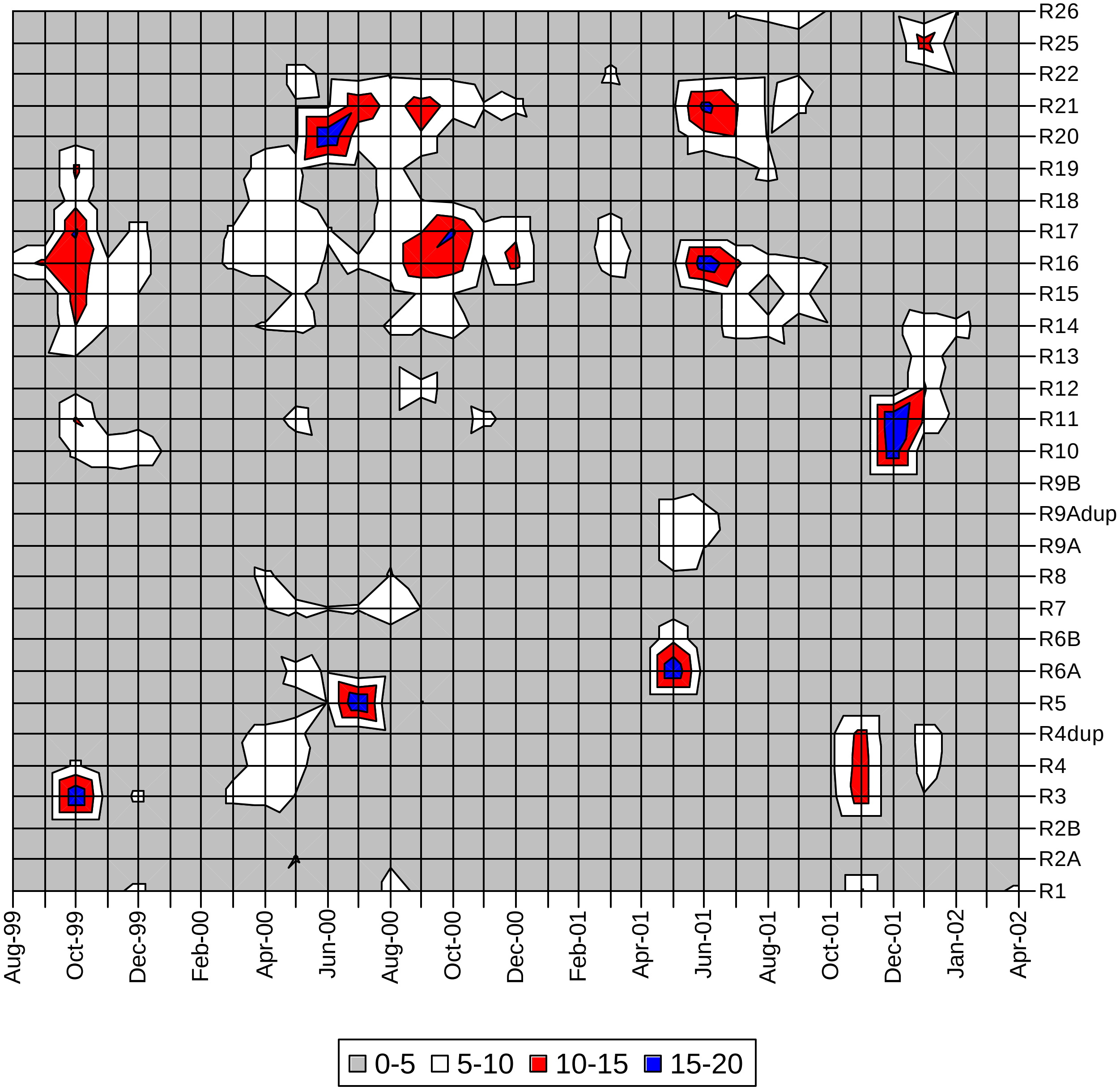
Data from samples collected Aug. 30, 2001 (Saguaro Lake)


Salty
Bitter
Sweet
Mouth Feel
Sour
Earthy/ Musty
Chemical
Chlorinous
Medicinal
Grassy/ Woody
Fishy
Swampy
Fragrant

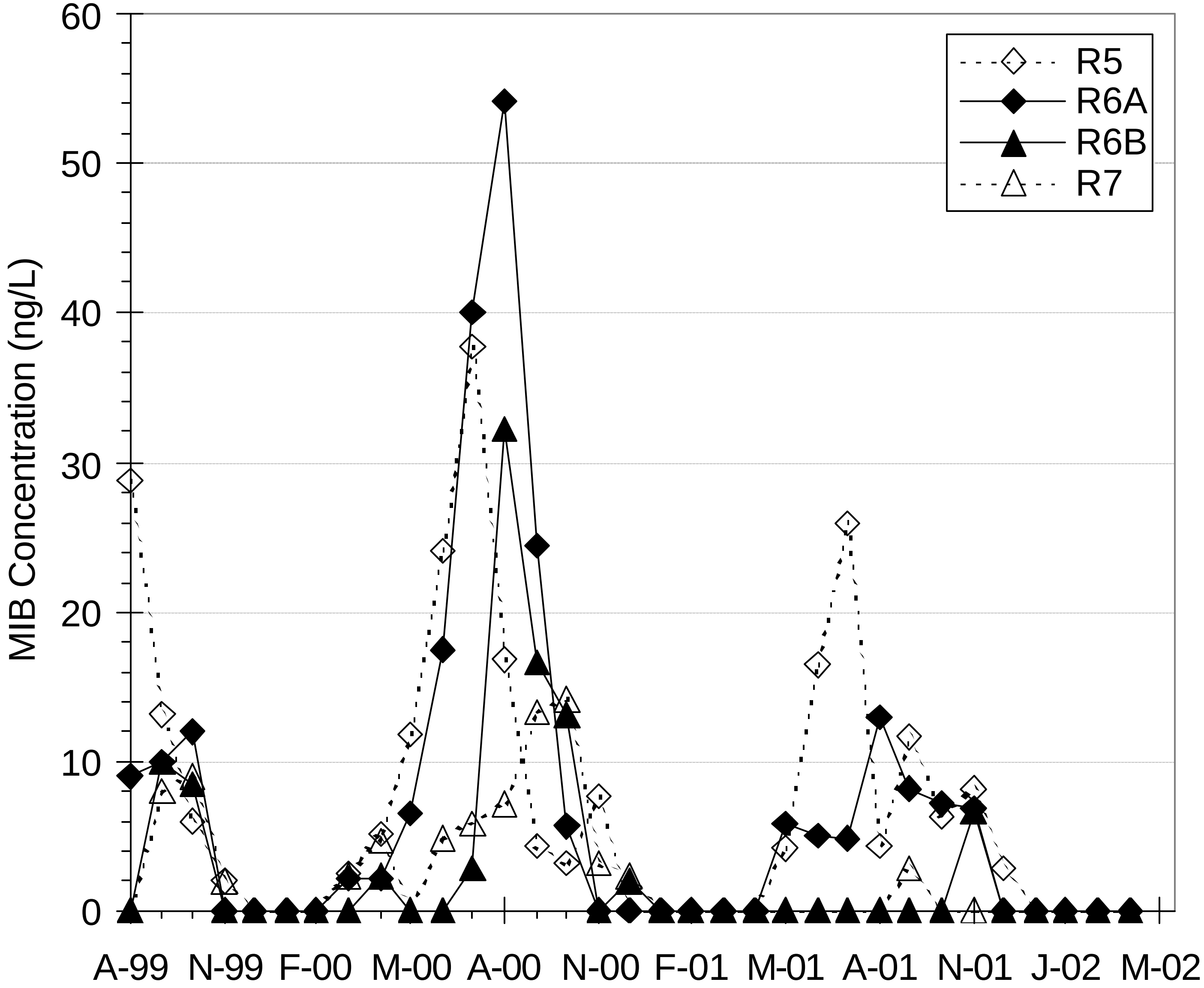
Representative Data: MIB



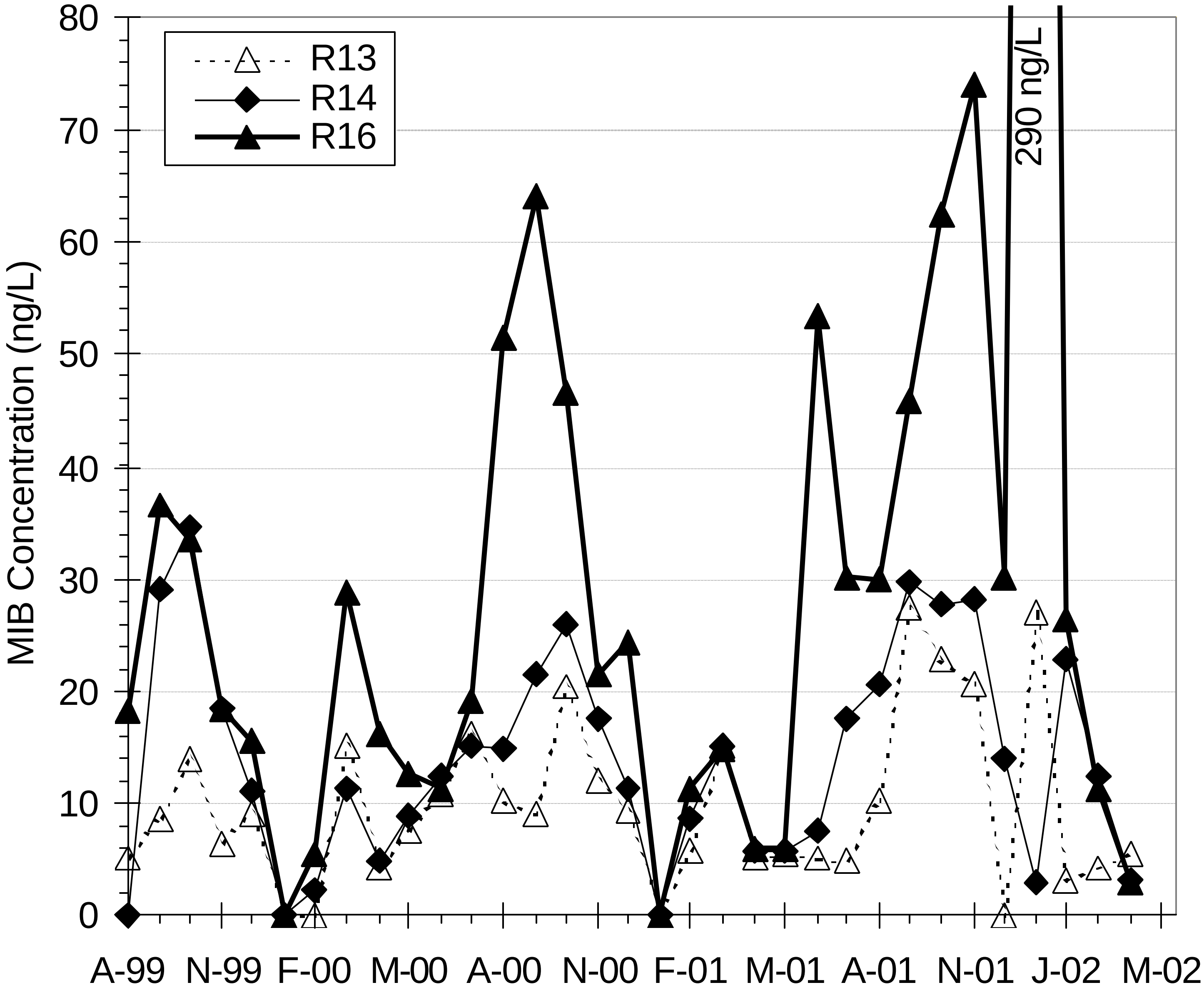
Representative Data: MIB > Geosmin



Representative Data: Temporal MIB (Lake)



Representative Data: Temporal MIB (Canal)



Comprehensive Taxa List

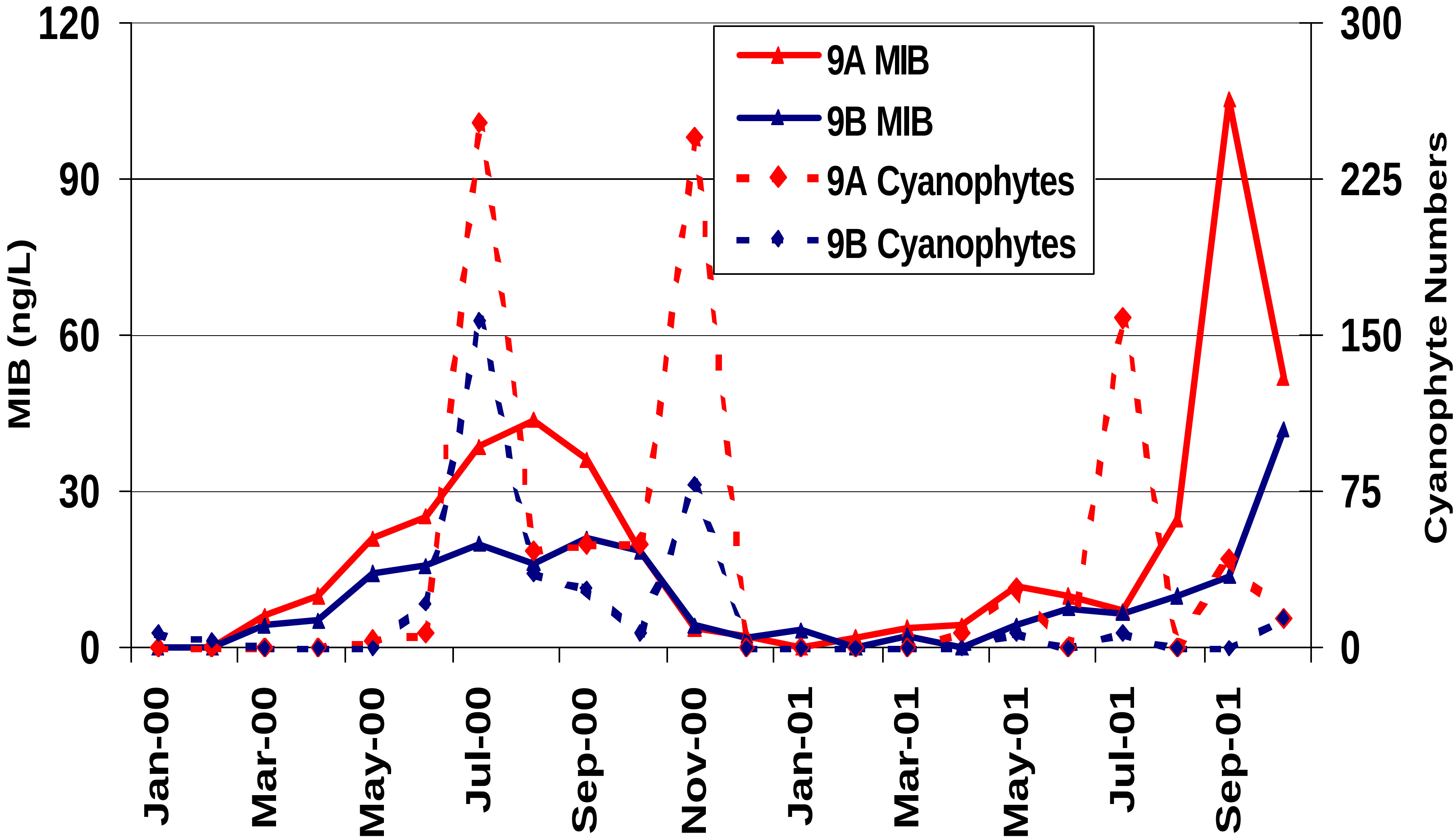
Diatoms (102)

Achnanthes coffieformis	*Denticula rainierensis*	*Mastogloia elliptica*	*Nitzschia paradoxa*
Achnanthes linearis	*Denticula sp.*	*Mastogloia smithii*	*Nitzschia parvula*
Achnanthes microcephala	*Diatoma anceps*	*Melosira granulata*	*Nitzschia tryblionella*
Achnanthes minutissima	*Diatoma hiemale*	*Melosira sp.*	*Nitzschia sigma*
Amphora ovalis	*Diatoma tenue*	*Melosira varians*	*Nitzschia sigmoidea*
Amphora venata	*Diatoma vulgare*	*Navicula accomoda*	*Nitzschia sinuata*
Asterionella formosa	*Diploneis smithii*	*Navicula cari*	*Nitzschia sp.*
Bacillaria paradoxa	*Entomoneis paludosa*	*Navicula cocconeiformis*	*Nitzschia vermicularis*
Biddulphia laevis	*Epithemia argus*	*Navicula cryptocephala*	*Pinnularia brebissonii*
Cocconeis diminuta	*Epithemia intermedia*	*Navicula decussis*	*Pleurosigma delicatum*
Cocconeis pediculus	*Epithemia sorex*	*Navicula exigua*	*Rhizosolenia sp.*
Coscinodiscus denarius	*Epithemia turgida*	*Navicula mutica*	*Rhoicosphenia curvata*
Cyclotella bodanica	*Eunotia sp.*	*Navicula pupula*	*Rhopalodia gibba*
Cyclotella meneghiniana	*Fragilaria arcus*	*Navicula sp.*	*Rhopalodia gibberula*
Cymatopleura solea	*Fragilaria brevistriata*	*Nitzschia accedans*	*Stephanodiscus sp.*
Cymatopleura sp.	*Fragilaria chains*	*Nitzschia acicularis*	*Surirella brightwellii*
Cymbella affinis	*Fragilaria construens*	*Nitzschia apiculata*	*Surirella ovalis*
Cymbella mexicana	*Fragilaria crotenensis*	*Nitzschia bicrena*	*Surirella striatula*
Cymbella minuta	*Fragilaria leptostauron*	*Nitzschia bita*	*Synedra actinostroides*
Cymbella norvegica	*Fragilaria sp.*	*Nitzschia capitellata*	*Synedra affinis*
Cymbella prostrata	*Gomphonema intricatum*	*Nitzschia communis*	*Synedra goulardii*
Cymbella pusilla	*Gomphonema olivaceum*	*Nitzschia denticula*	*Synedra rumpens*
Cymbella sp.	*Gomphonema parvulum*	*Nitzschia filiformis*	*Synedra sp.*
Cymbella turgida	*Gomphonema sp.*	*Nitzschia fonticola*	*Synedra ulna*
Cymbella ventricosa	*Gyrosigma sp.*	*Nitzschia frustulum*	
Denticula elegans	*Hantzschia amphioxys*	*Nitzschia palea*	

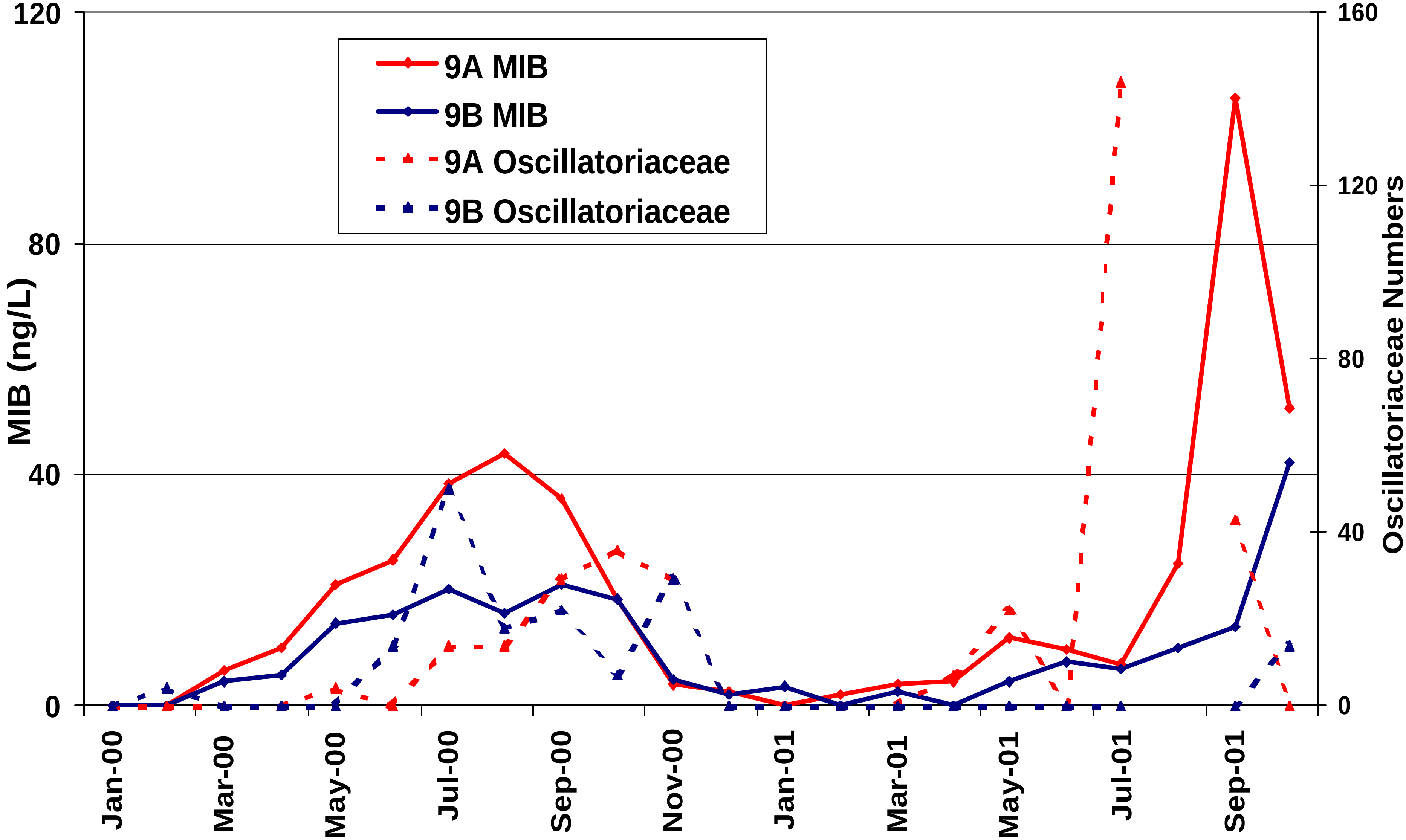
Comprehensive Taxa List (cont.)

Chlorophyta (24)	**Chlorophyta (cont.)**	**Other (10)**
Ankistrodesmus sp.	*Spirogyra sp.*	*Ceratium sp.*
Chlamydomonas sp.	*Staurastrum sp.*	*Cryptomonas sp.*
Chlorella sp.	*Tetracystis sp.*	*Dinobryon sp.*
Closterium sp.	*Tetrahedron sp.*	*Euglena sp.*
Coleochaete sp.	*Ulothrix sp.*	*Mallomonas sp.*
Cosmarium sp.		*Ophiocytium sp.*
Eudorina sp.	**Cyanophyta (12)**	*Peridinium sp.*
Franceia sp.	*Anabaena sp.*	*Phacus sp.*
Golenkinia minutissima	*Aphanothece sp.*	*Synura sp.*
Golenkinia sp.	*Chroothece sp.*	*Vaucheria sp.*
Gonium sp.	*Cylindrospermum sp.*	
Microspora sp.	*Gloeocapsa sp.*	
Mougeoutia sp.	*Gomphosphaeria sp.*	
Oocystis sp.	*Merismopedia sp.*	
Pandorina sp.	*Microcystis sp.*	
Pediastrum sp.	*Oscillatoria sp.*	
Pyramimonas sp.	*Phormidium sp.*	
Scenedesmus sp.	*Pseudanabaena sp.*	
Selenastrum sp.	*Spirulina sp.*	

Saguaro Lake MIB Concentrations and Cyanophyte Numbers



Saguaro Lake MIB Concentrations and Oscillatoriaceae Numbers



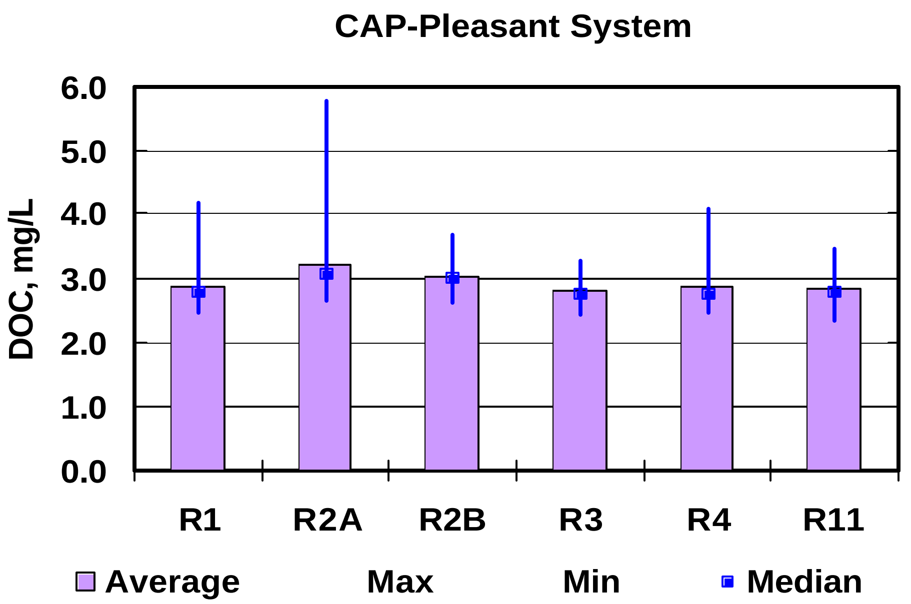
Summary & Conclusions (Task 1)

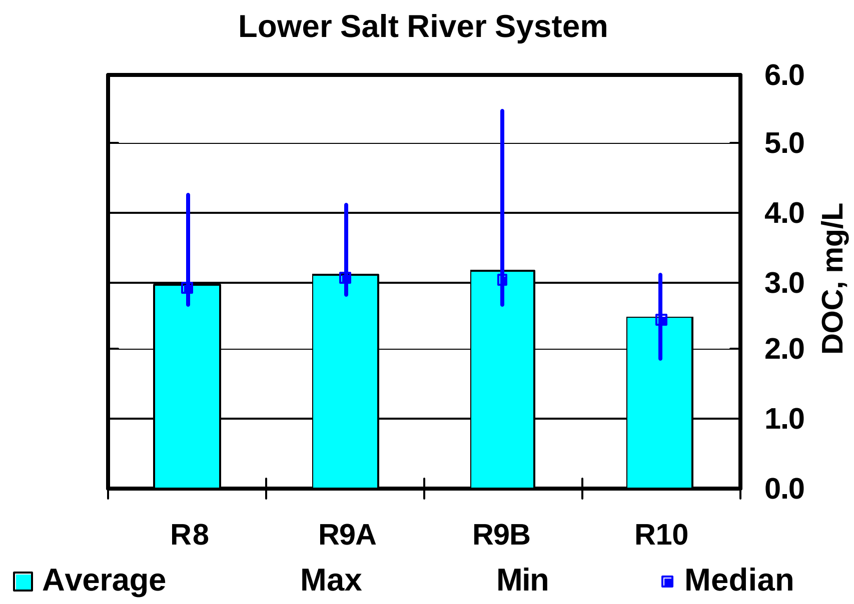
- MIB was dominant T&O compound in watershed and finished water
- # of algae species capable of producing T&O compounds is a very small amount of the total biomass
- "Hot spots" for T&O production exist in epilimnion of lakes and localized canal sections
- Temperature in lakes is a good indicator for T&O concentrations, whereas nutrient levels and chlorophyll-a are not related
- Lake destratification can cause a pulse of T&O for 1-2 months

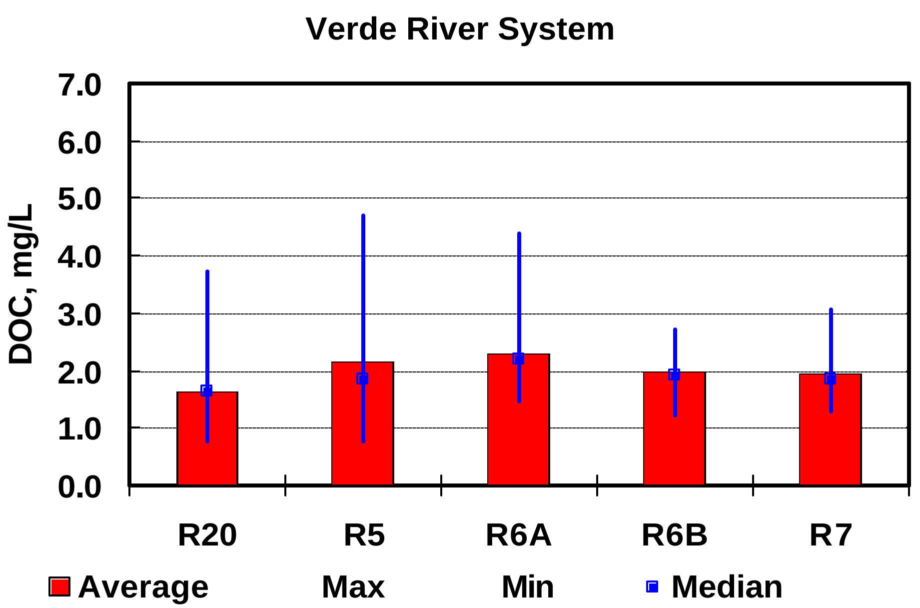
Summary of Monitoring-Related Activities

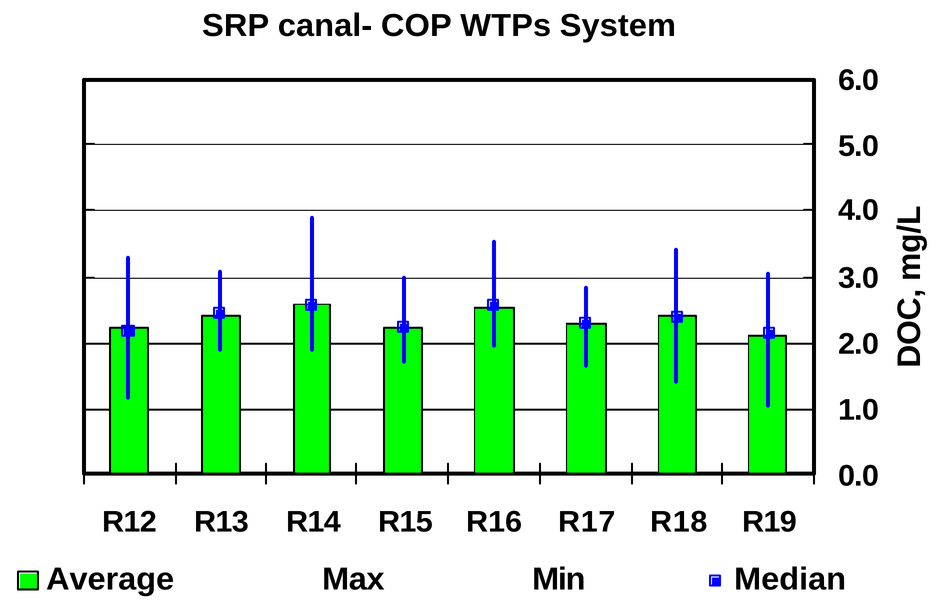
- Baseline monitoring program (Task 1)
  - Purpose: To understand spatial and temporal patterns in water quality parameters that affect algae productivity and occurrence of T&O compounds
- **Studies of DOC sources and characterization (Task 5)**
  - **Purpose: To identify algae-sources of DOC and characterize DOC in the watershed**
- Assessment of in-plant controls (Task 3)
  - Purpose: To identify sources of T&O in WTPs and treatment capability to remove T&O compounds

DOC Concentrations

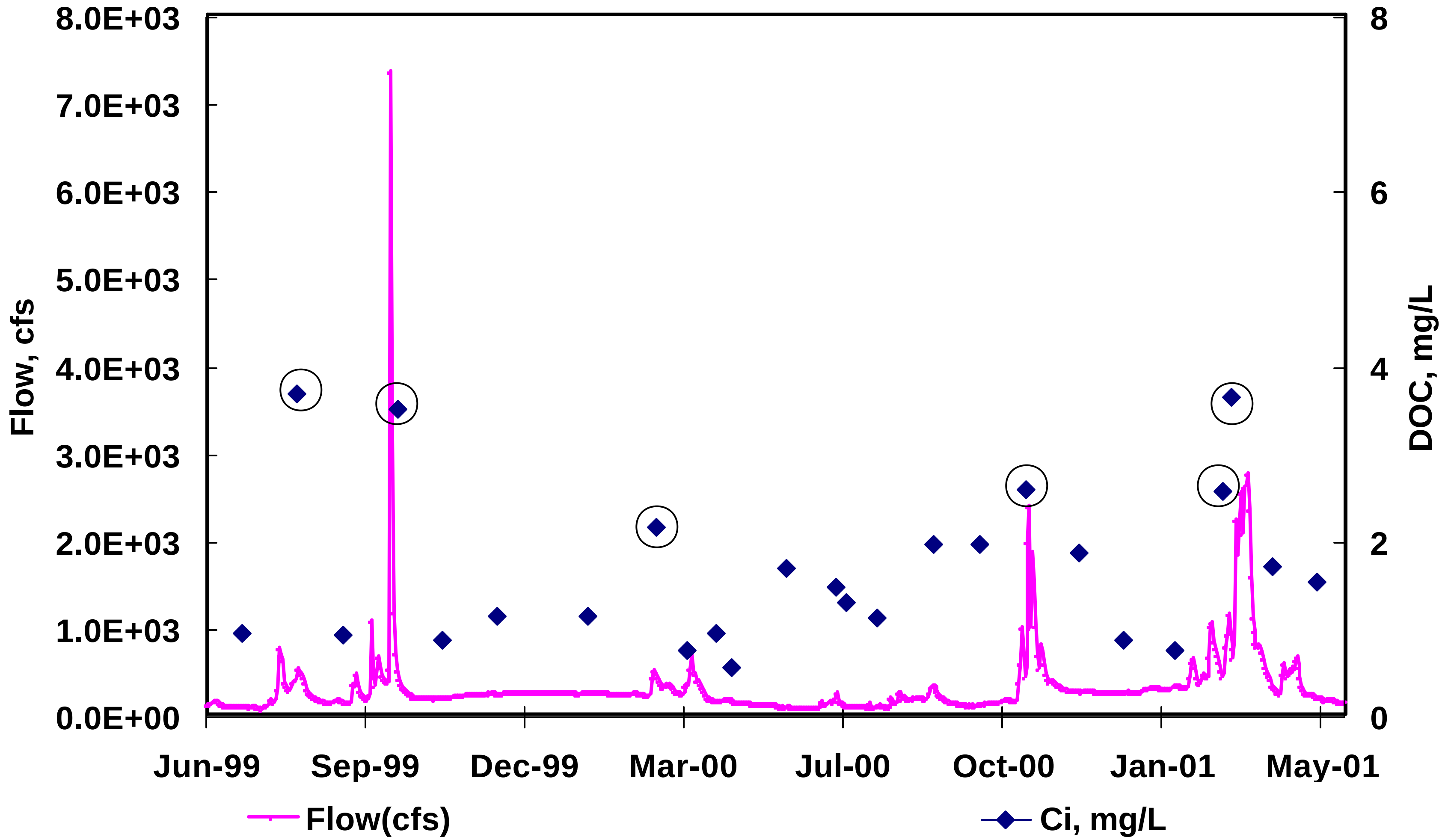








Influence of Hydrology on DOC Transport



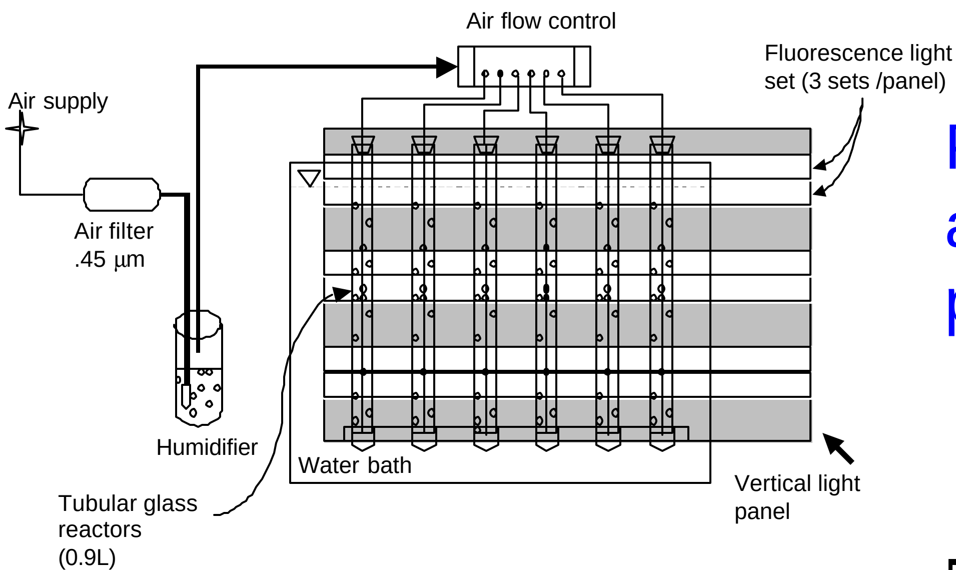
Max flow (9/24/99): 7350 cfs

Average flow: 313 cfs

Min flow (7/5/99): 67 cfs

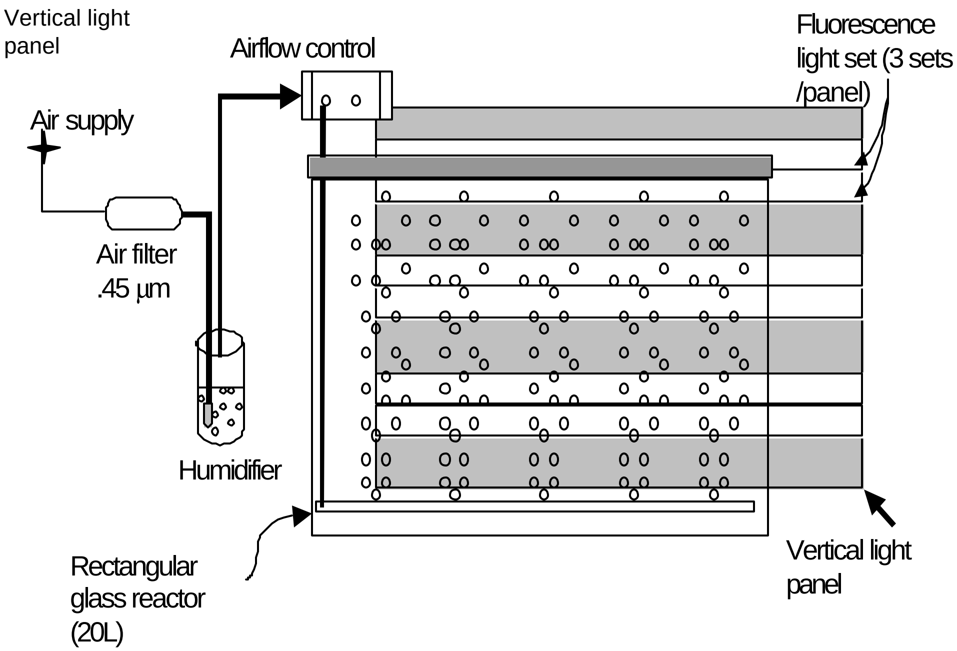
Median flow: 240 cfs

Algae growth experiment

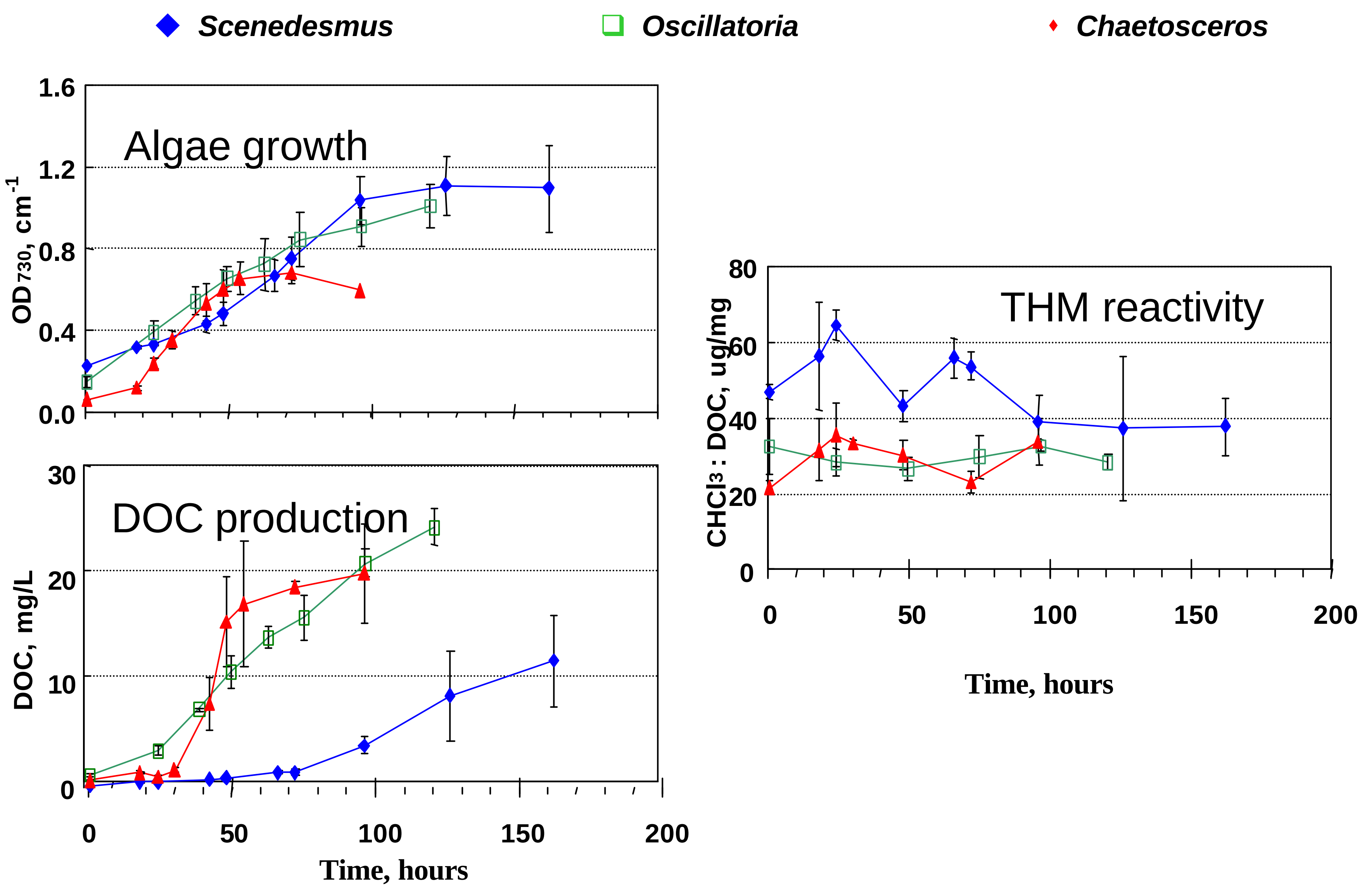


Phase I- Three different algae speices: Growth,DOC production, THM formation

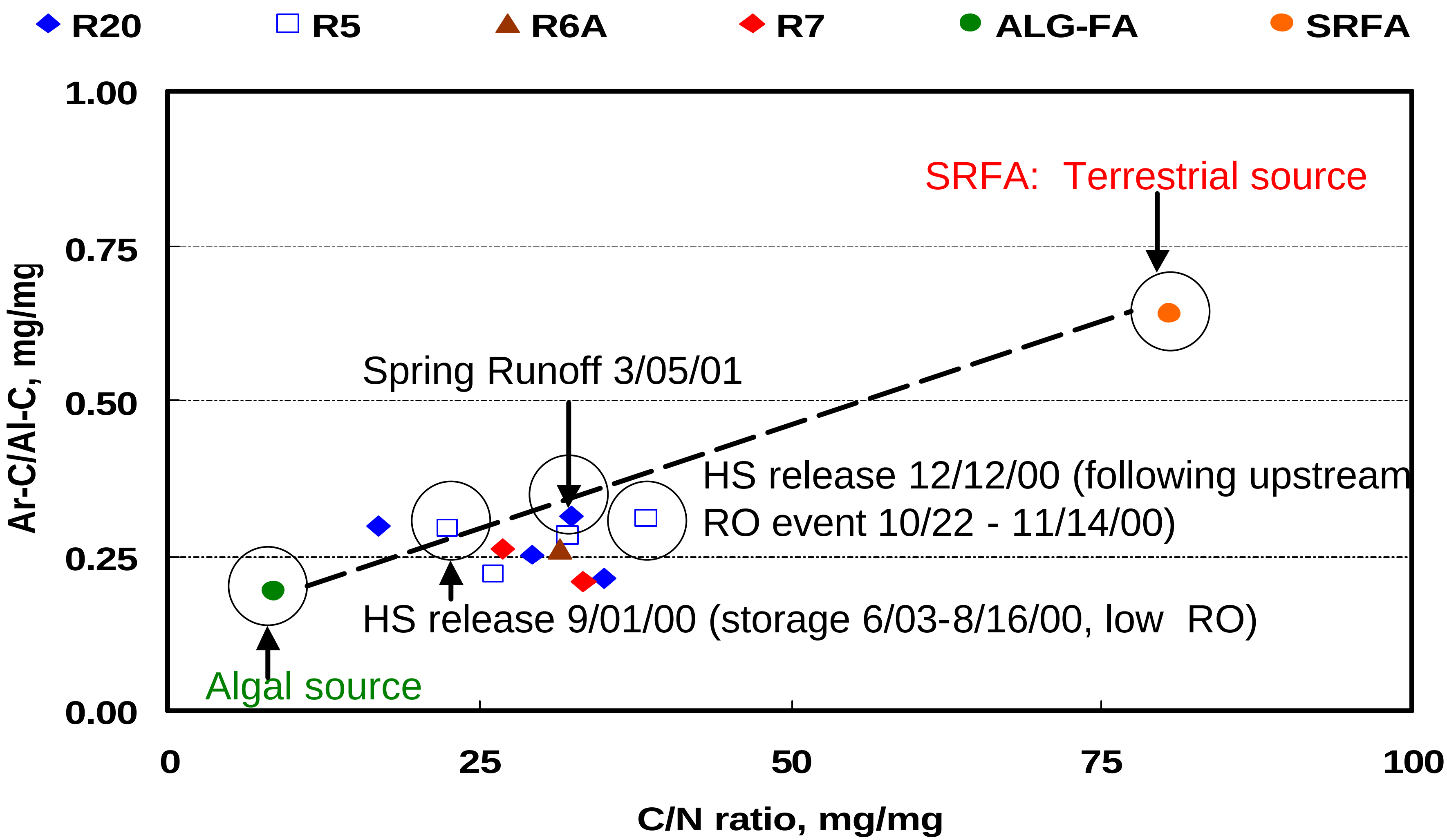
Phase II- Green algae DOC characterization



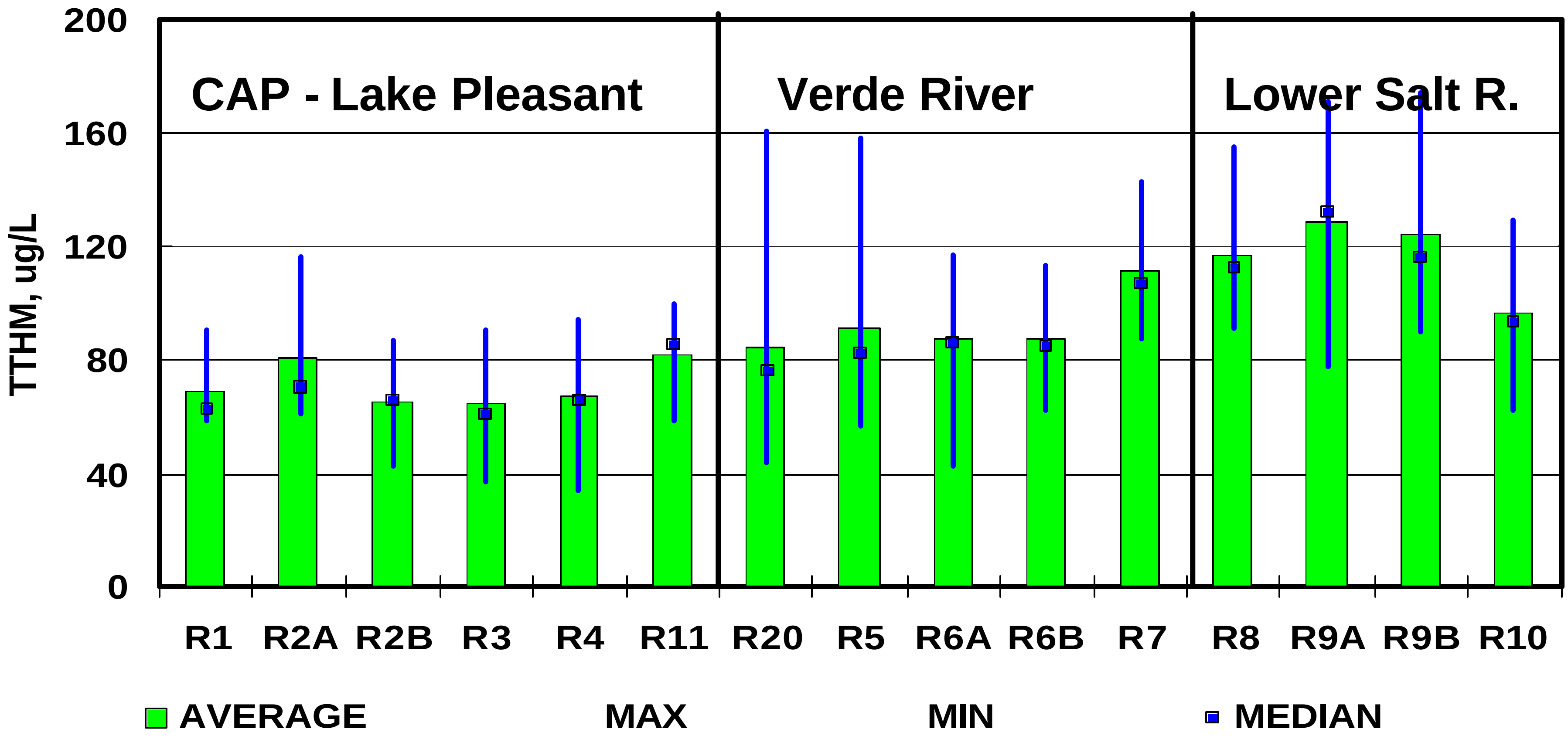
Phase I- Results



Characteristics of Fulvic Acids Isolated from the Verde River System



Source Water THM Formation (SDS)



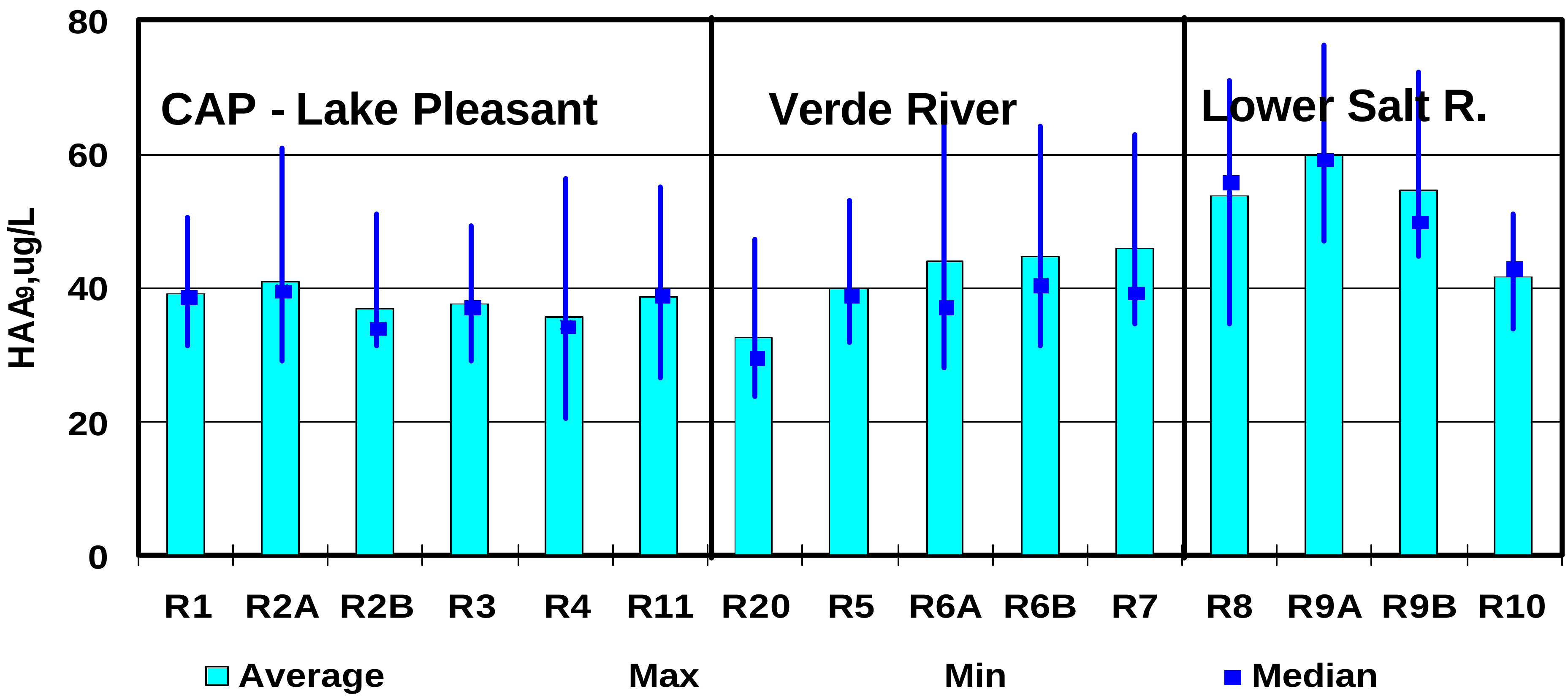
Low Bromide incorporated THM, n £ 1

CAP-Pleasant TTHM/DOC: 21 ± 2 mg/mg

Verde system TTHM/DOC: 42 ± 10 mg/mg

Lower Salt R. TTHM/DOC: 33 ± 2 mg/mg

Source Water HAA_9 Formation (SDS)



CAP-Pleasant: HAA_5/DOC > 7 ± 1 mg/mg

Verde system: HAA_5/DOC > 15 ± 2 mg/mg

Lower Salt R.: HAA_5/DOC > 9 ± 0 mg/mg

DiHAA dominate

Summary & Conclusions (Task 5)

- DOC sources include: snowmelt and monsoon runoff, algae
- DOC in southwestern US (DOC/DON ~ 15) differs from DOC east of the Mississippi
- Algae-DOC can be rapidly biodegraded
- Increasing reservoir HRTs allows algae-DOC to biodegrade
- Watershed DOC produces more THMs than HAAs. Algae-DOC produces more HAAs than THMs.
- Salt River > Verde River > CAP for DBP formation
- DOC removal by COP WTPs ranged from 5% to 55% (median = 15%)
- Data provides baseline to evaluate future conditions (e.g., impacts of fires, high-runoff years)

Summary of Monitoring-Related Activities

Baseline monitoring program (Task 1)

Purpose: To understand spatial and temporal patterns in water quality parameters that affect algae productivity and occurrence of T&O compounds

Studies of DOC sources and characterization (Task 5)

Purpose: To identify algae-sources of DOC and characterize DOC in the watershed

Assessment of in-plant controls (Task 3)

Purpose: To identify sources of T&O in WTPs and treatment capability to remove T&O compounds

Conclusions from In-Plant Interviews, Tours, Monthly visits conducted

- No in-plant T&O production observed, probably due to periodic prechlorination
- T&O removal only occurred while adding PAC
- Historic low-bid approach for PAC selection did not optimize T&O removal
- PAC feed systems are rated too low (< 15 ppm) and should be improved
- Basis for adding PAC or selecting PAC dose was arbitrary
- Minimizing T&O levels in the raw water is critical
- GAC filter caps or GAC adsorption would improve T&O removal and reduce PAC usage; also improve DOC removal

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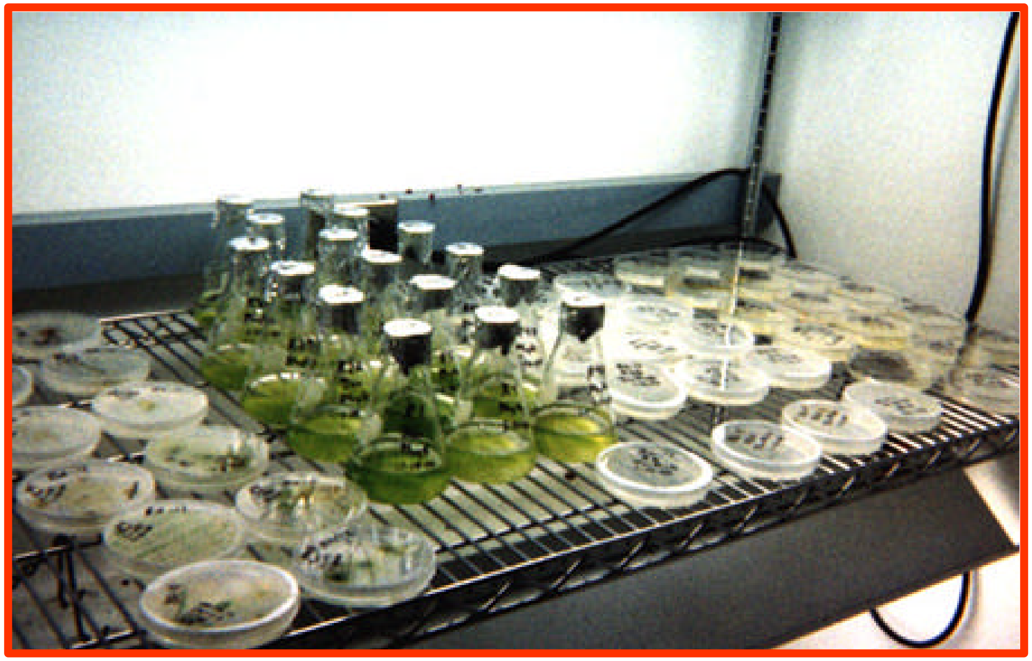
- Summary of Research Products
- Summary of Monitoring Activities
- **Summary of Research Activities**
- Summary of Implementation Activities
- Overview of Guidance Manual
- Integration for Regional T&O Control
- Recommendations & Future Needs

Laboratory Experiments (Task 4)

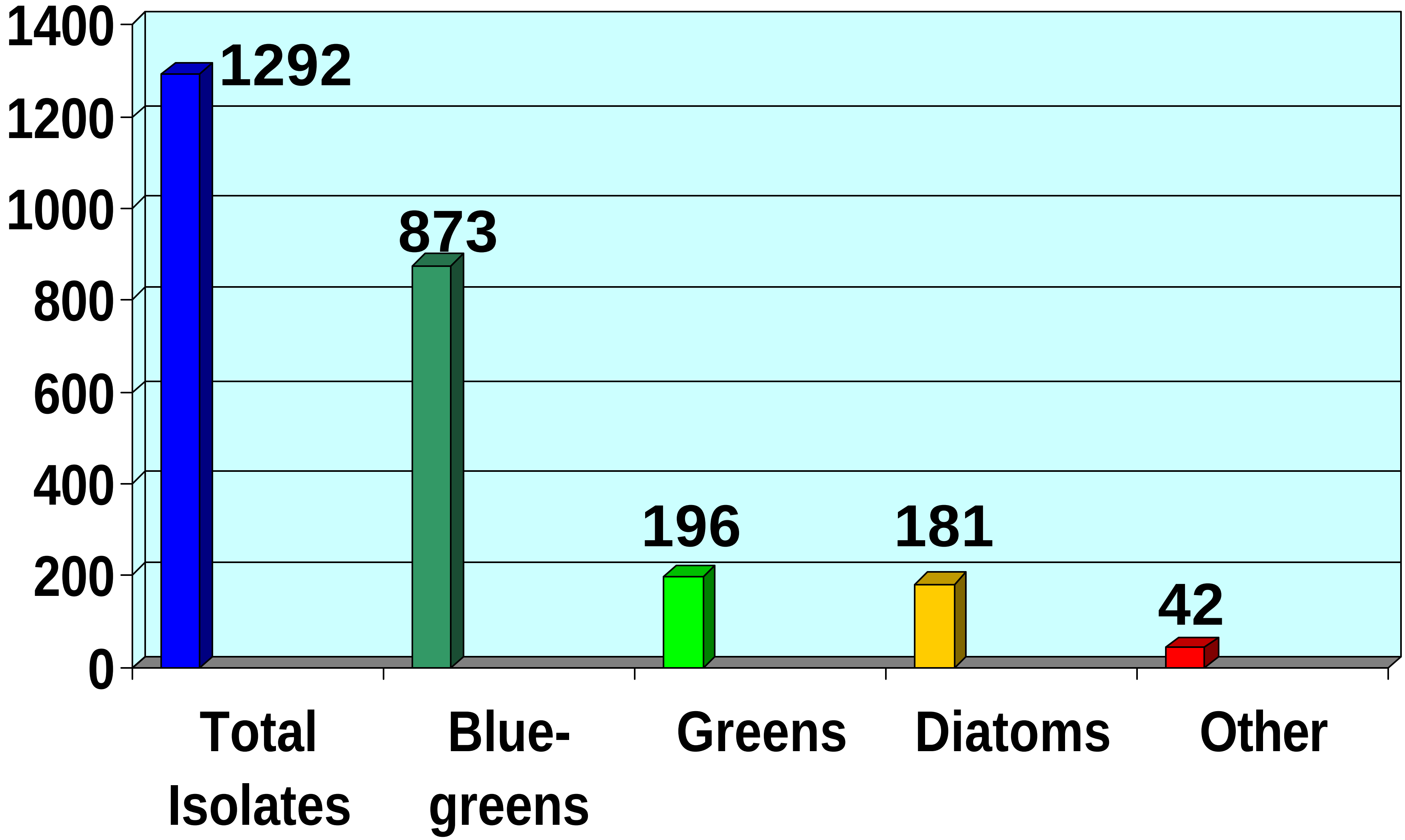
Algae related:

- **Isolation of MIB/geosmin producers**
- **Confirmation of MIB/geosmin production**
- **Effect of environmental conditions on production**
  - **Temperature**
  - **Light**
  - **Nutrients**
- **Intra-and extra-cellular MIB/geosmin**

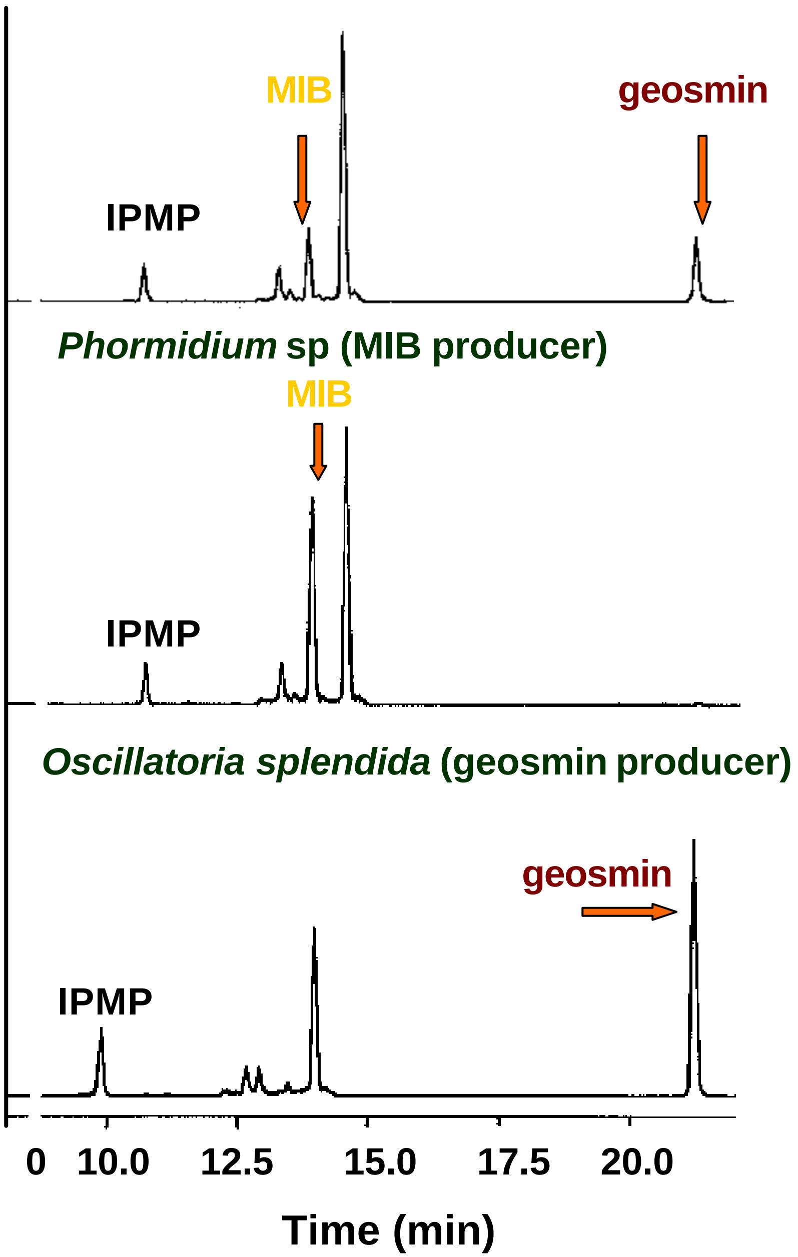
Culturing and Isolation

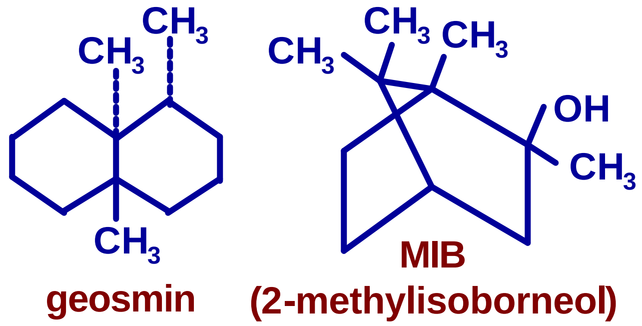


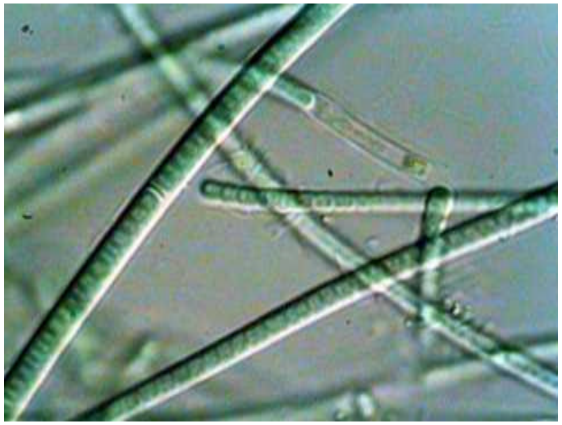
Algae Isolates from All Sites

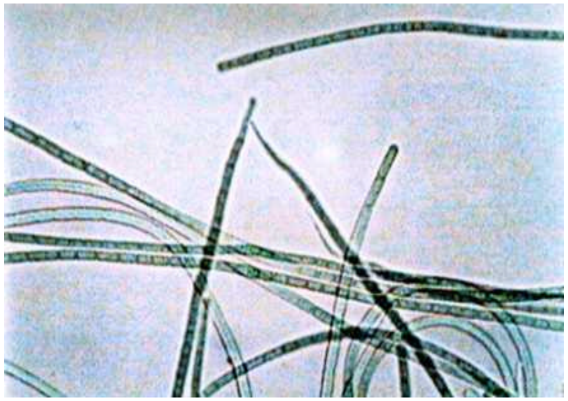


MIB & Geosmin Standards (20 ng/L each)









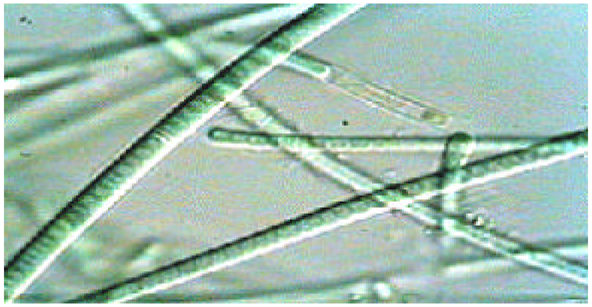
Confirmed Producers

MIB Producers	Geosmin Producers
Phormidium sp.	*Oscillatoria agardhii*
Pseudanabaena sp. #1	*Oscillatoria splendida*
Pseudanabaena sp. #2	*Streptomyces sp.*
Pseudanabaena sp. #3	

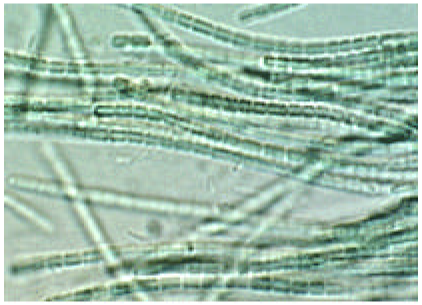
Producers of MIB and Geosmin

MIB Producers

Phormidium sp.

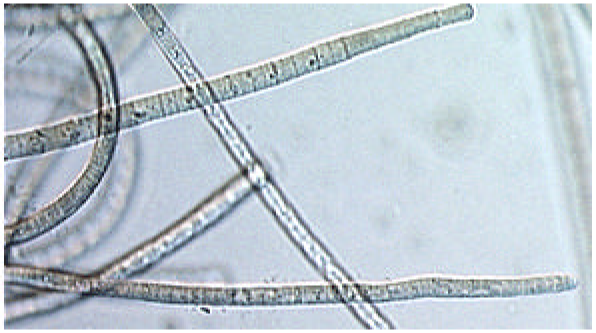


Pseudanabaena sp.

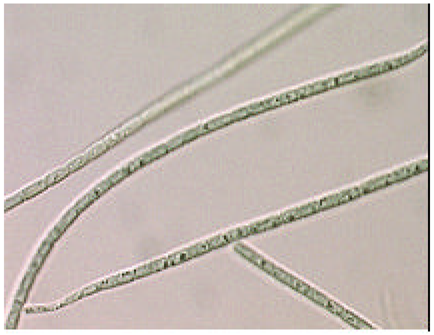


Geosmin Producers

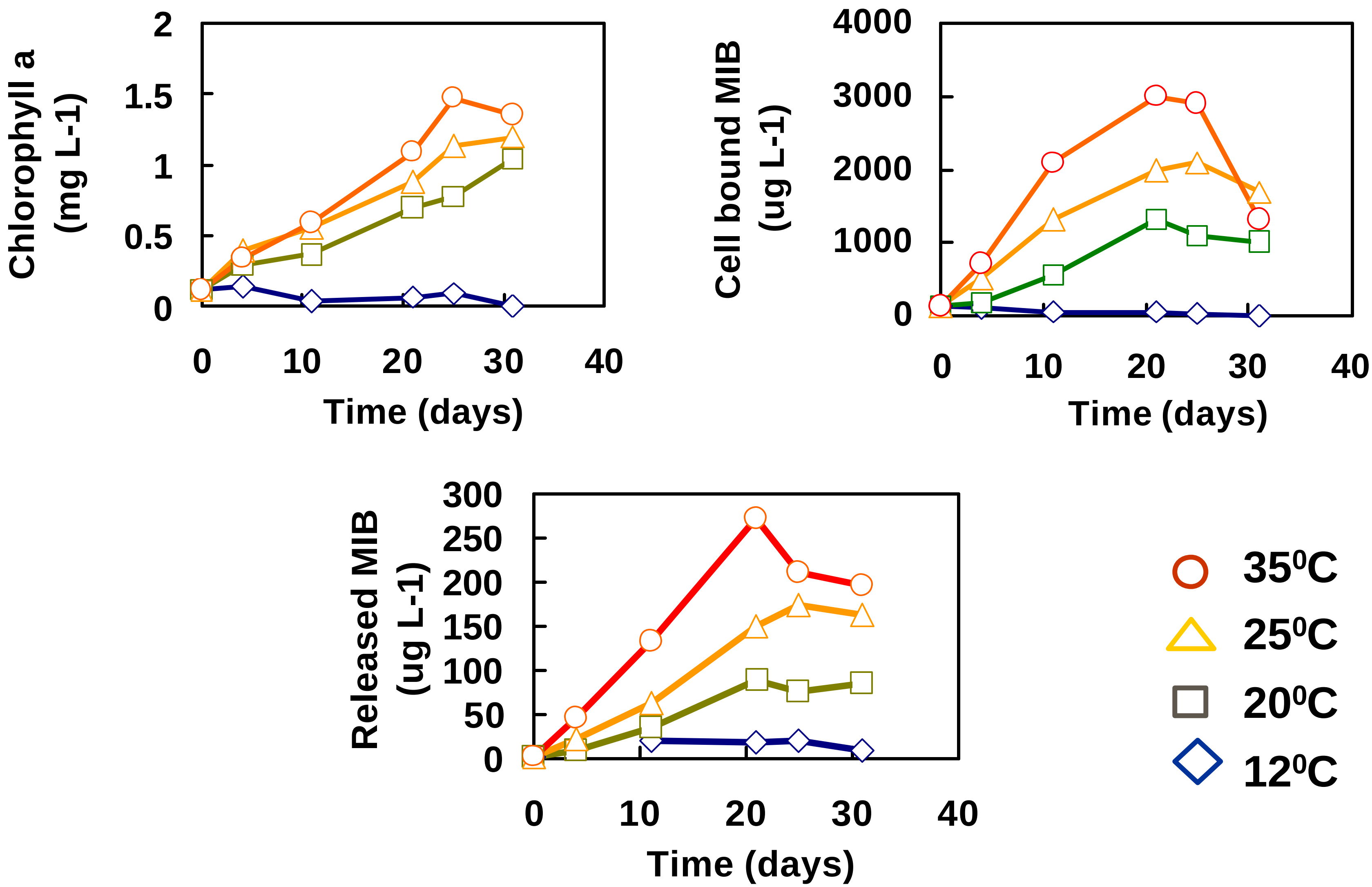
Oscillatoria agardhii



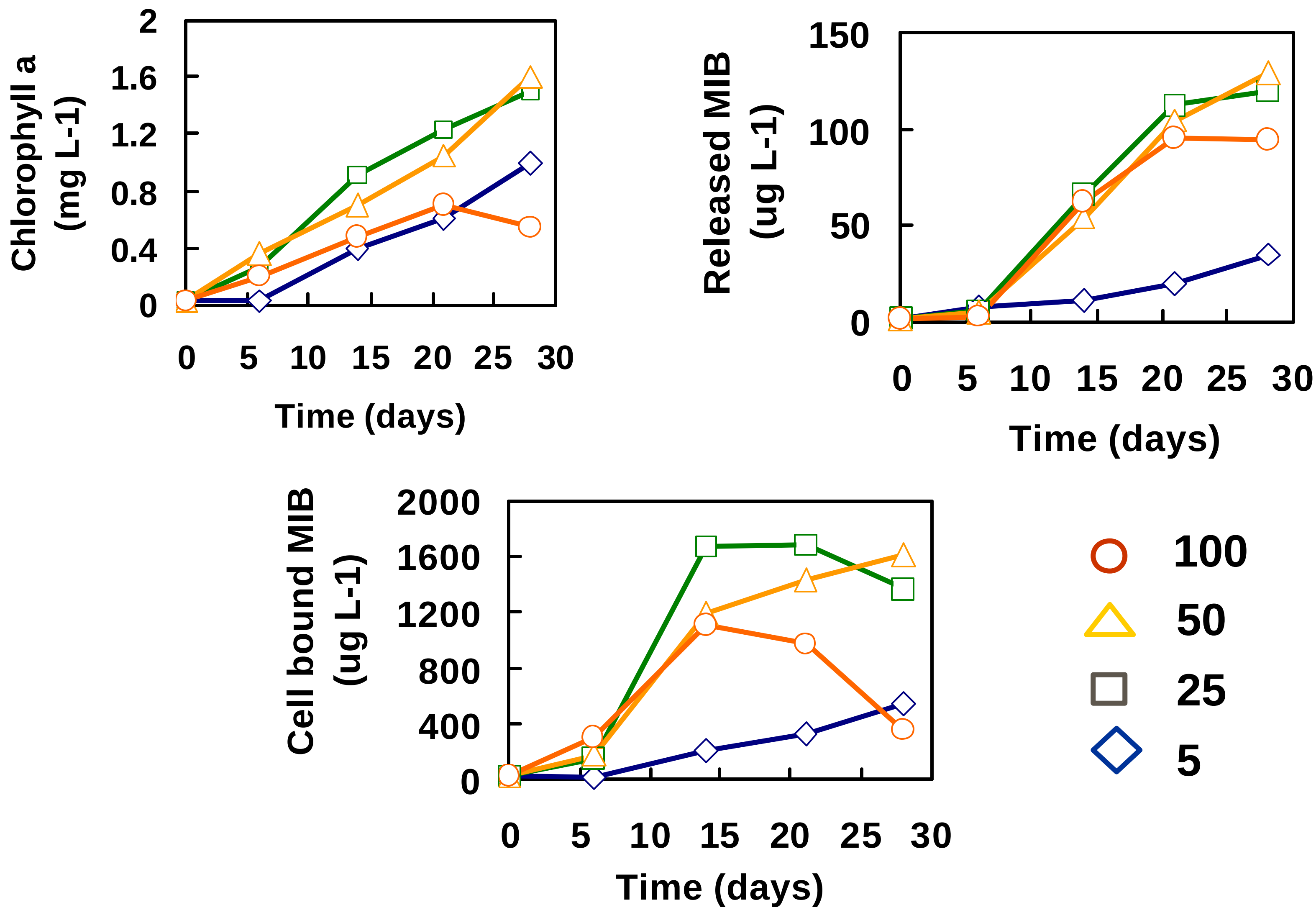
Oscillatoria splendida



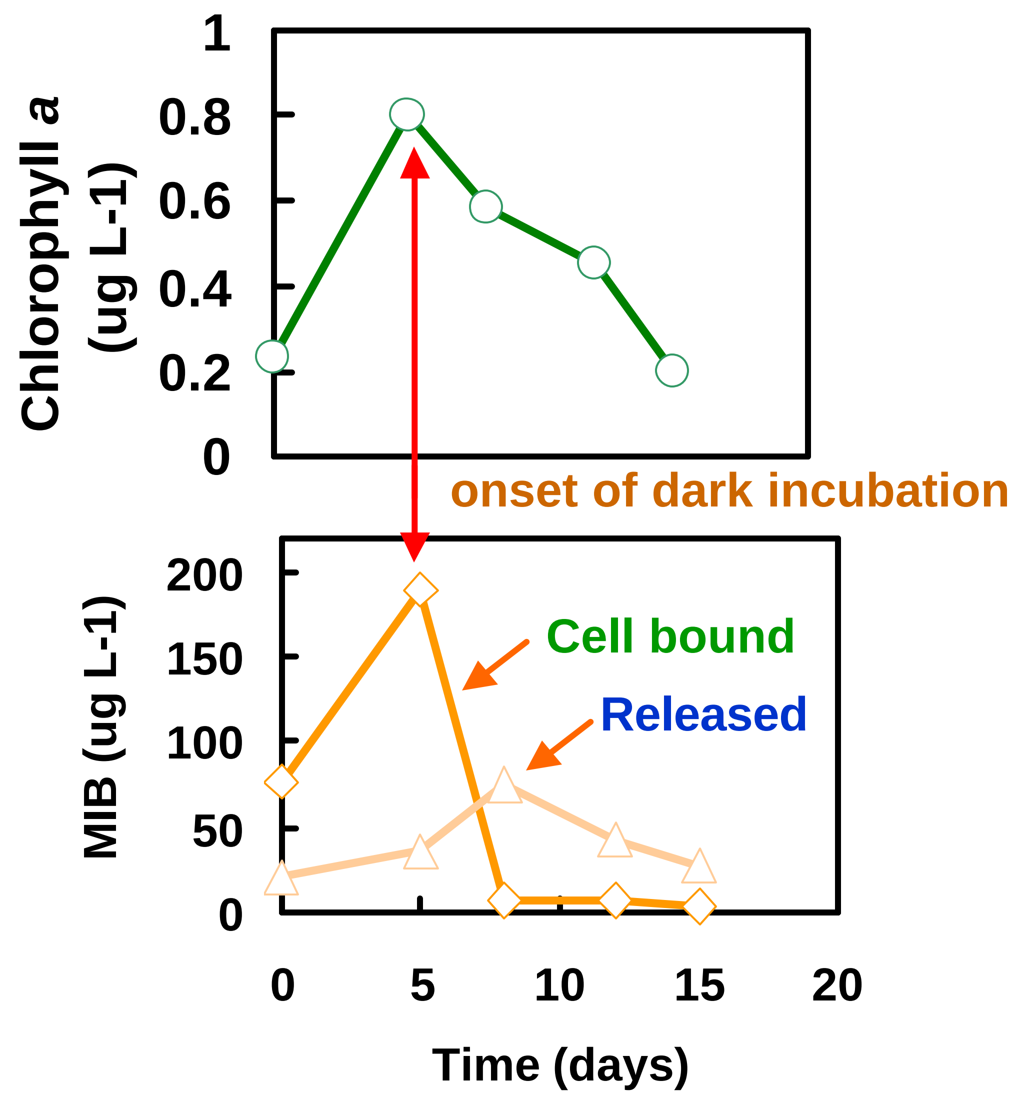
Effect of temperature on growth, production and release of MIB by *Pseudanabaena* sp.



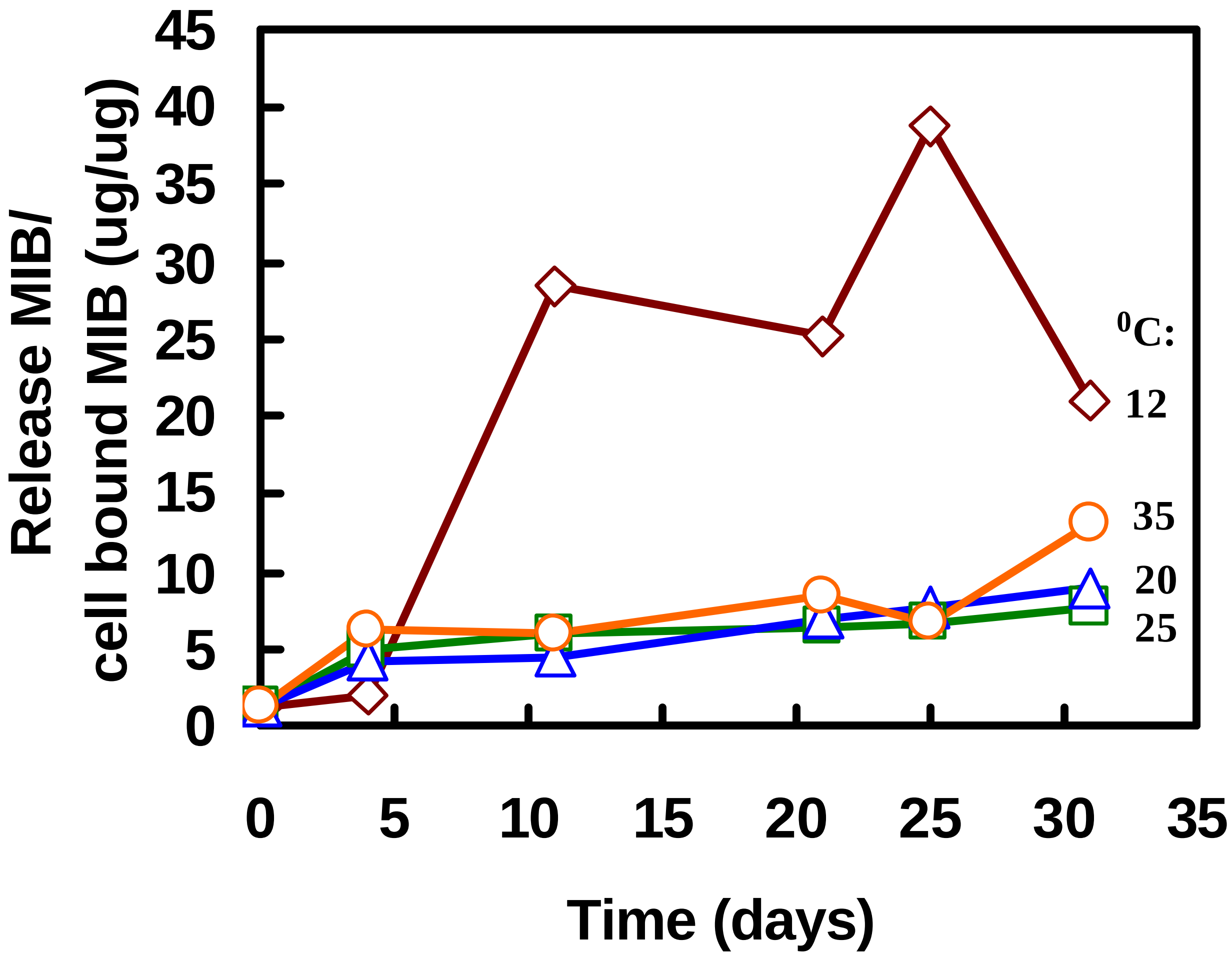
Effect of light intensity on growth, production and release of MIB in *Pseudanabaena* sp.



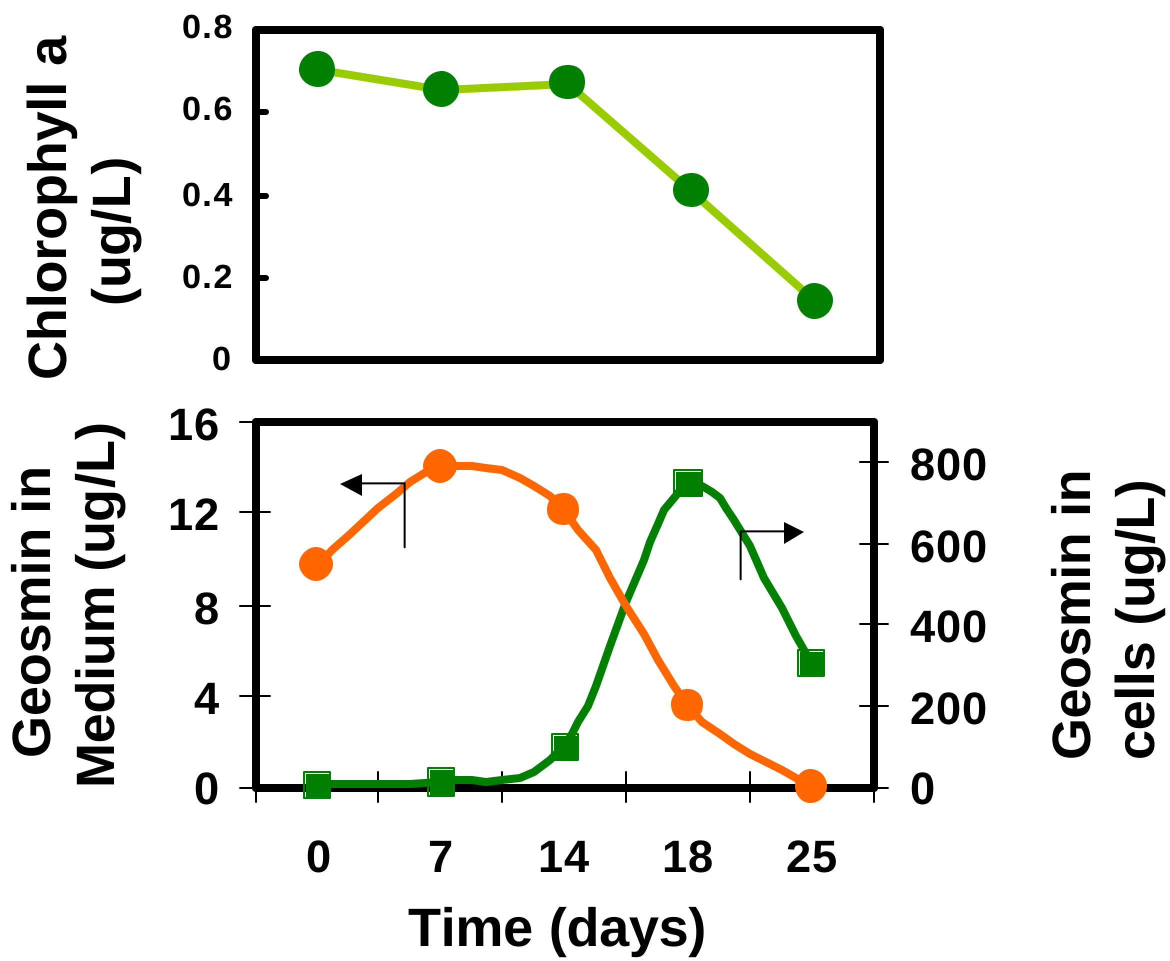
Effect of dark incubation on production and release of MIB in *Pseudanabaena* sp.



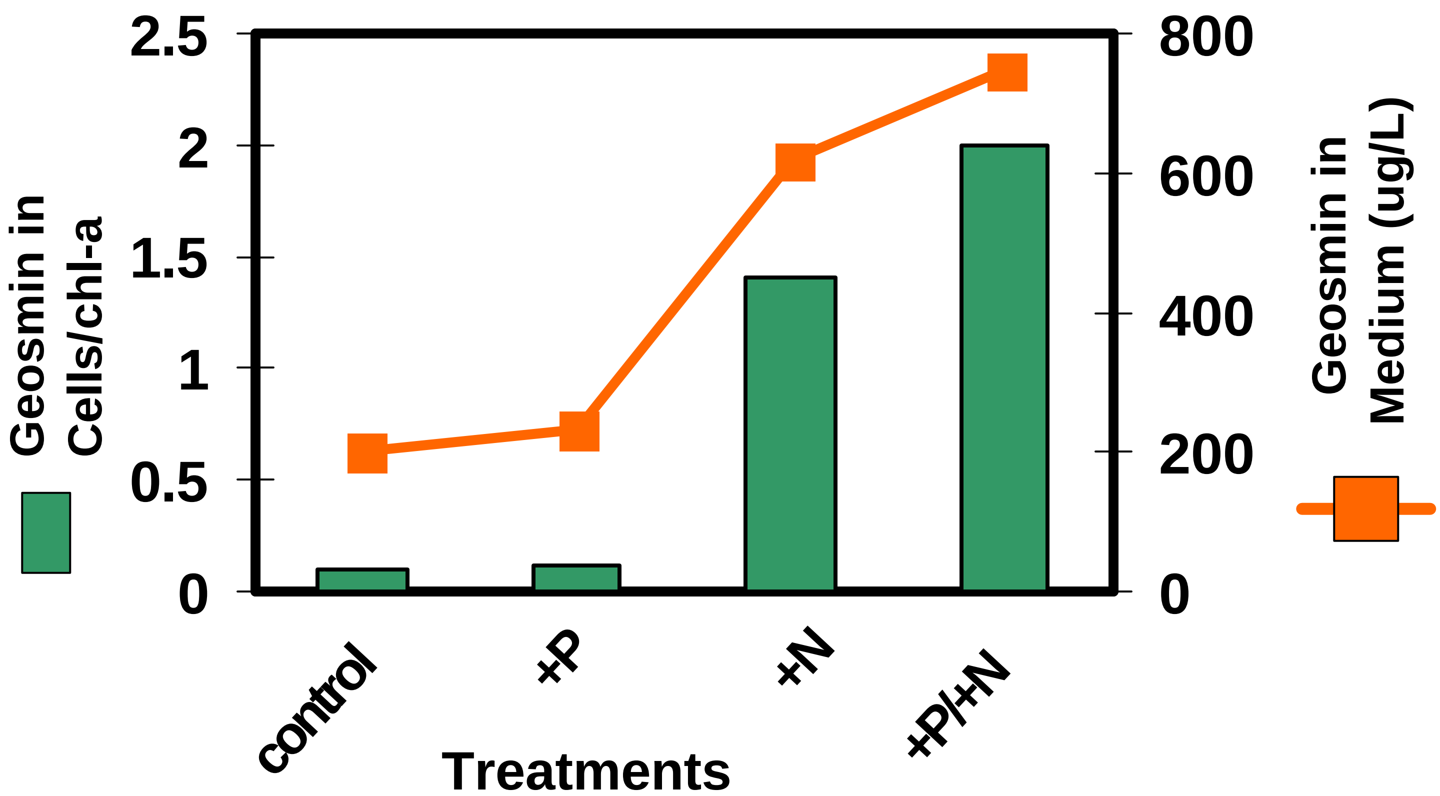
Effect of temperature on the ratio of MIB released relative to MIB produced in cultures of Pseudanabaena sp.



Effect of dark incubation on chlorophyll a content, the production and release of geosmin



Effect of nitrate and phosphate on the growth and release of geosmin

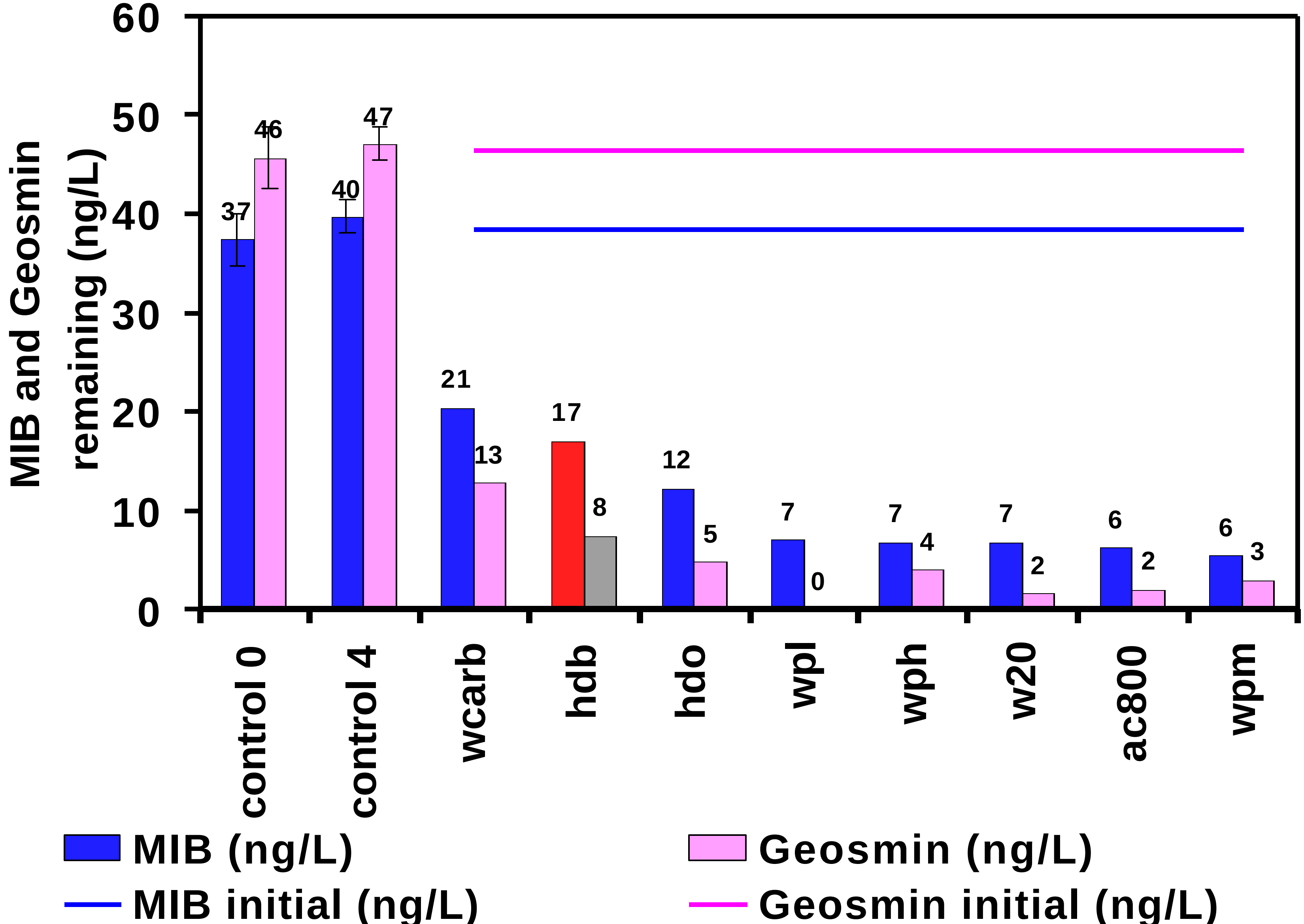


Laboratory Experiments (Task 4)

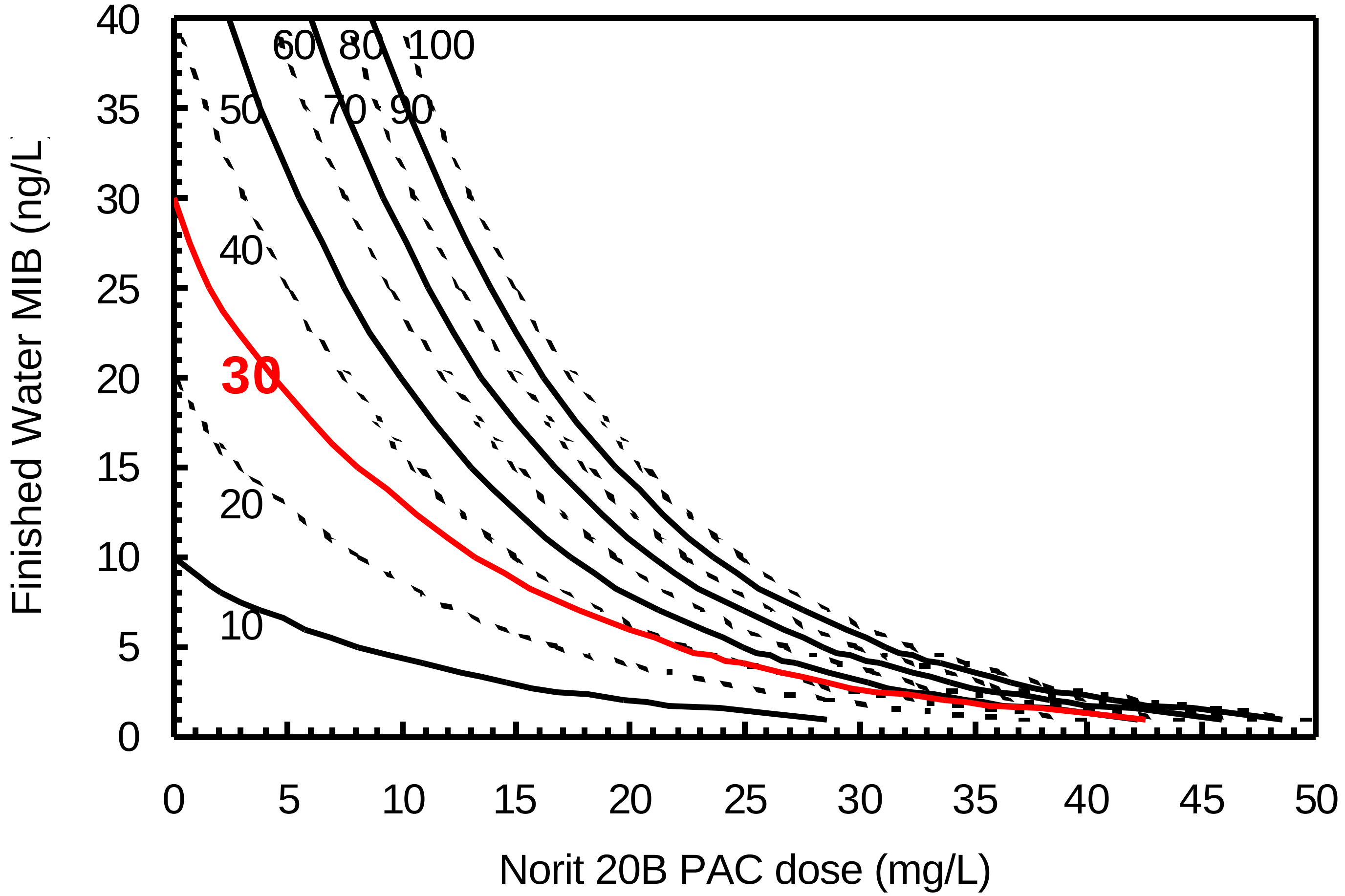
- Water treatment related:
  - Comparative effectiveness of PAC types
  - PAC dosing to achieve removal to 10 ng/L
  - Ozone oxidation of MIB/geosmin

PAC Experiments (AZ Canal)

Removal of MIB & Geosmin



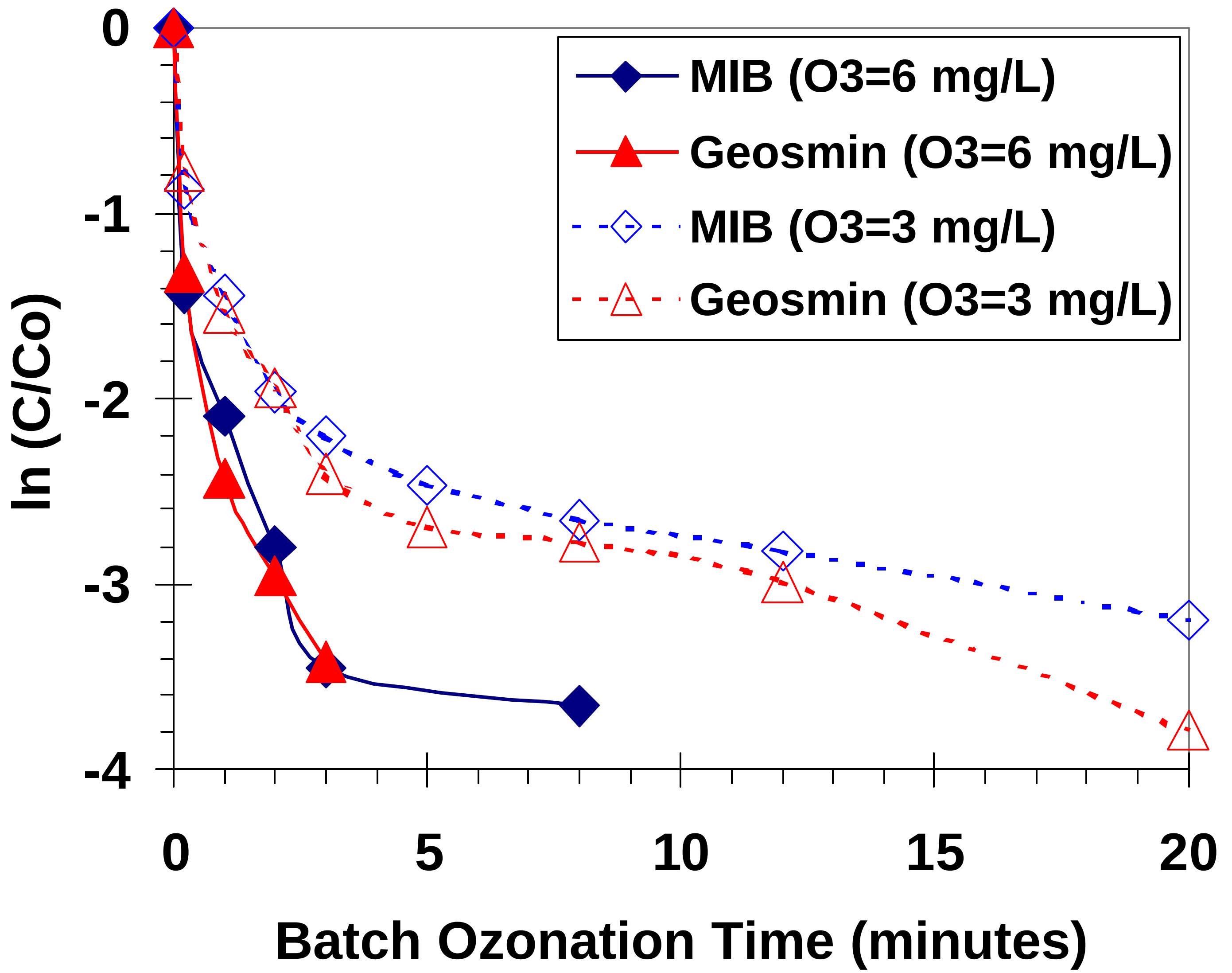
PAC Dosing



Predicting MIB removal to achieve 10 ng/L MIB in finished water:

PAC Dose (mgNorit 20B/L) = 10.8xln(MIB_{raw}) – 24.8

Ozonation in SRP Water
(HO radicals more important than O3)



Laboratory Experiments (Task 4, Continued)

- Effectiveness of biocides
  - Copper
  - Chlorine
- Effectiveness of surface coatings

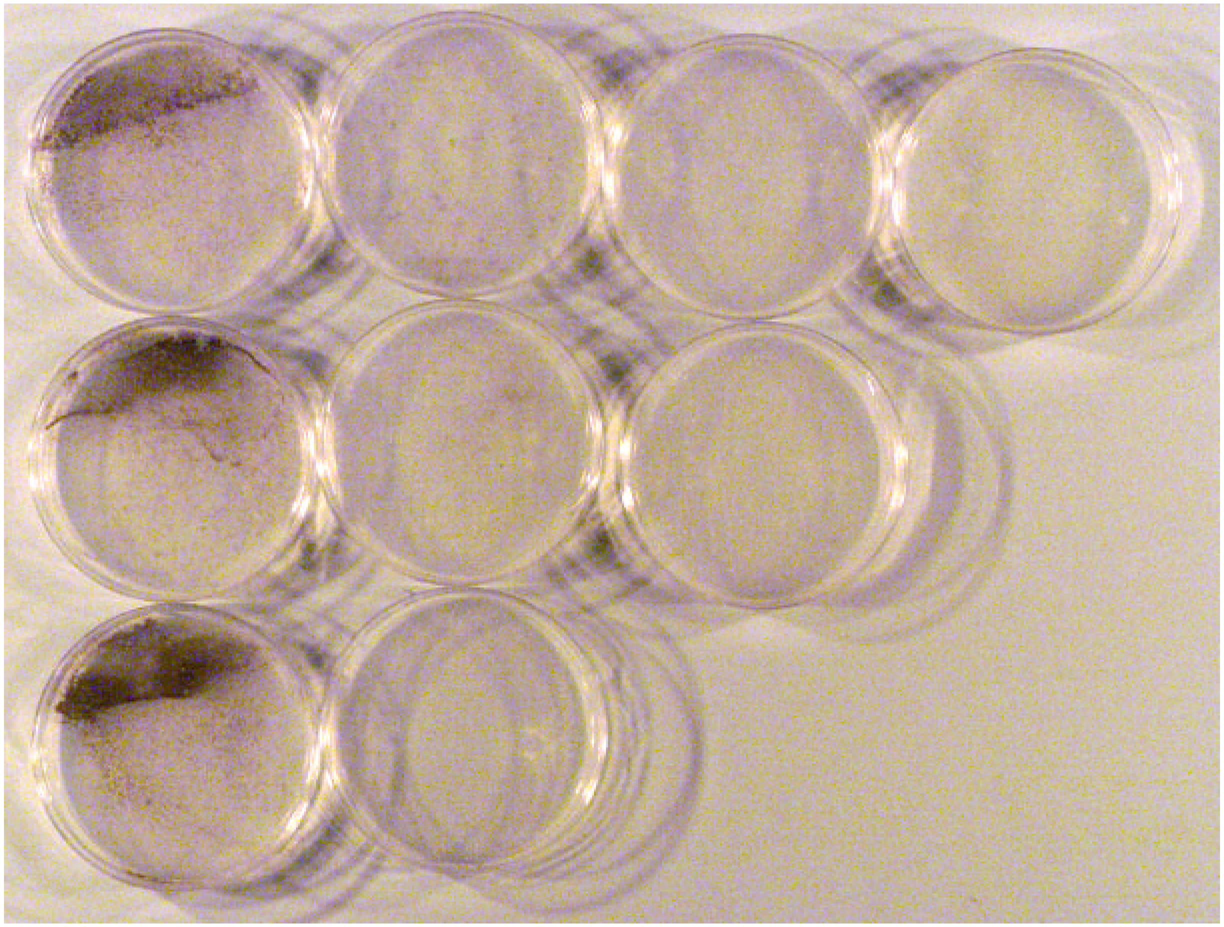
Effect of Cu^{2+} on the viability of *Pseudoanabaena* sp.

Time

2 h

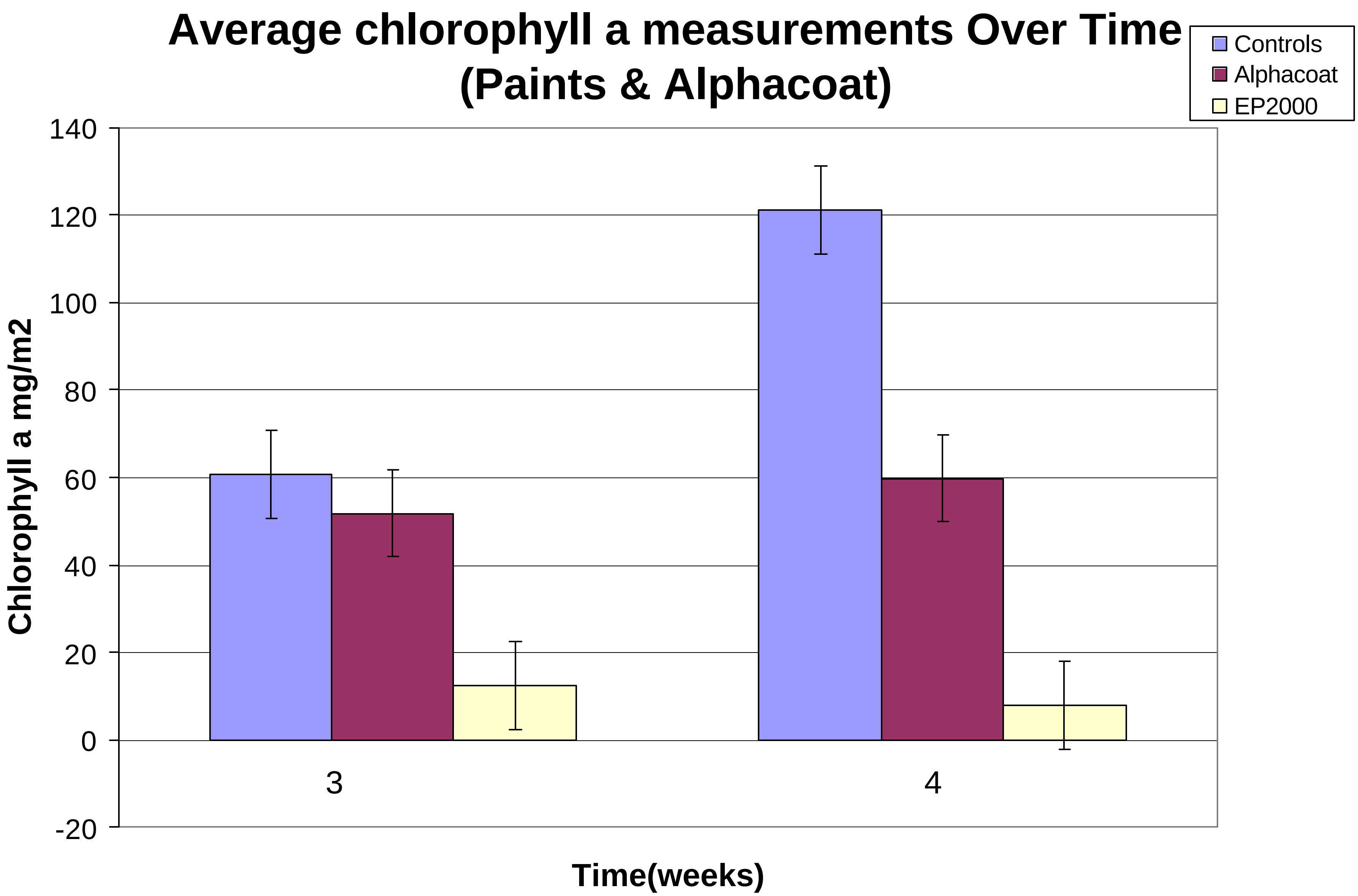
4 h

6 h



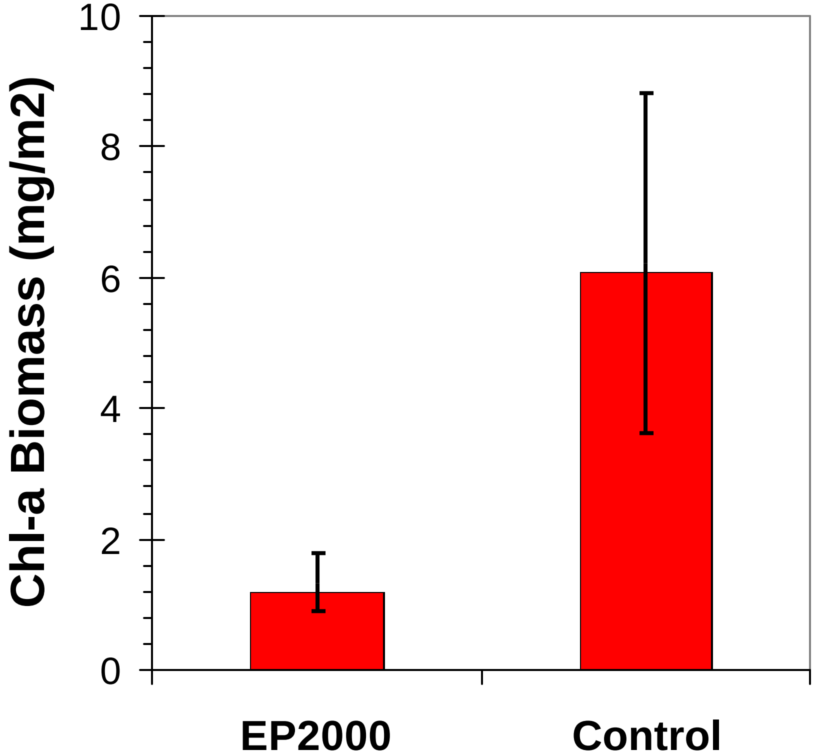
Cu^{2+} (mg/L): 0 0.03 0.1 0.3

Laboratory tests



Fixed Surface Biocides Hold Promise as a Permanent Canal Treatment

- **EP2000 TiO2 paint coatings evaluated with field apparatus**



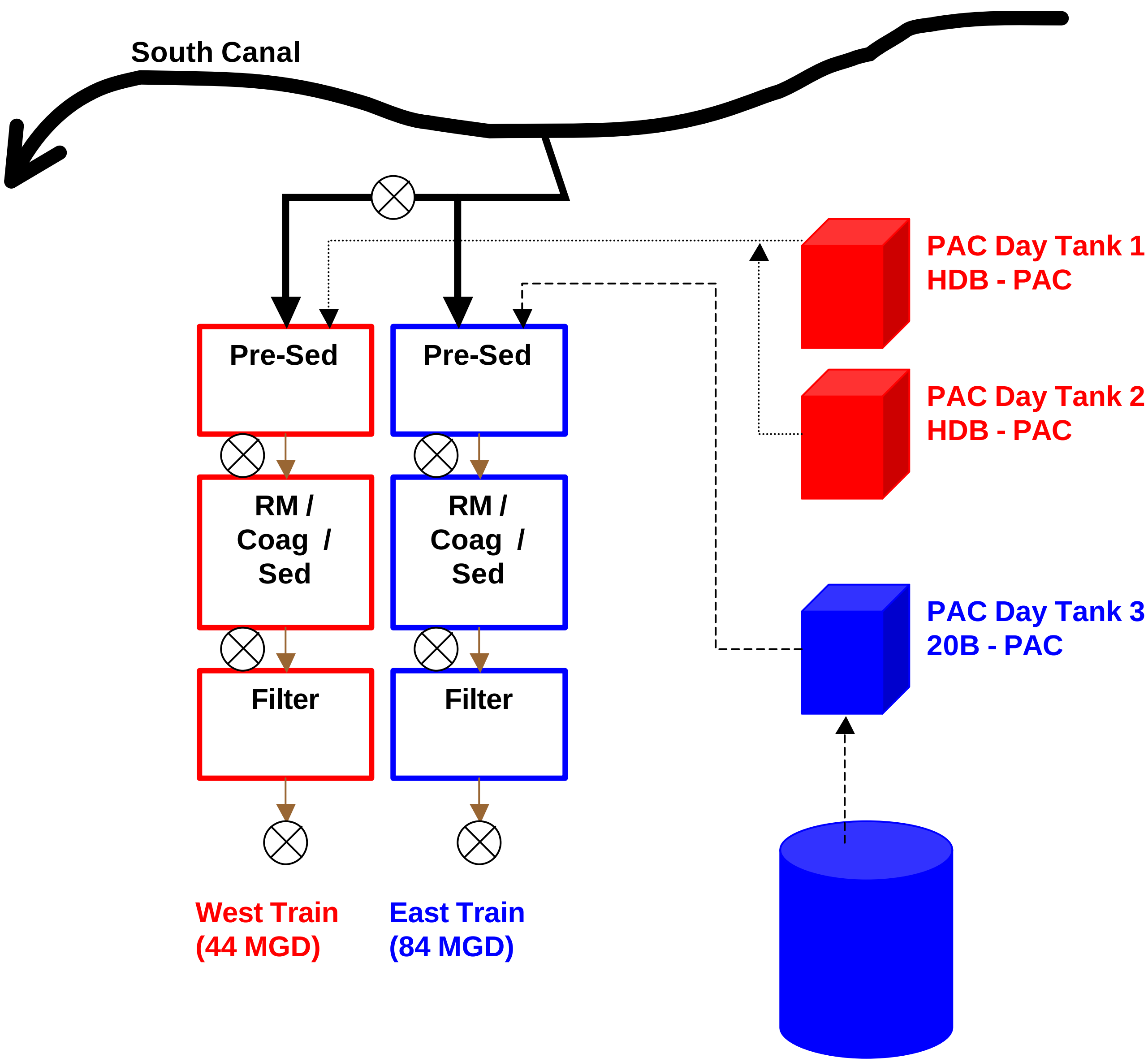
Benefits from Experimentation Laboratory

- Identified culprit producer algae
- Understand relationship between environmental conditions and production of MIB/geosmin in culprit algae
- Learned that culprit algae differ in tolerance of biocides
- Powdered Activated Carbon (PAC) types differ in MIB removal effectiveness
- Specification for PAC should be performance based
- Nomographs for PAC dosing were developed for WTP use

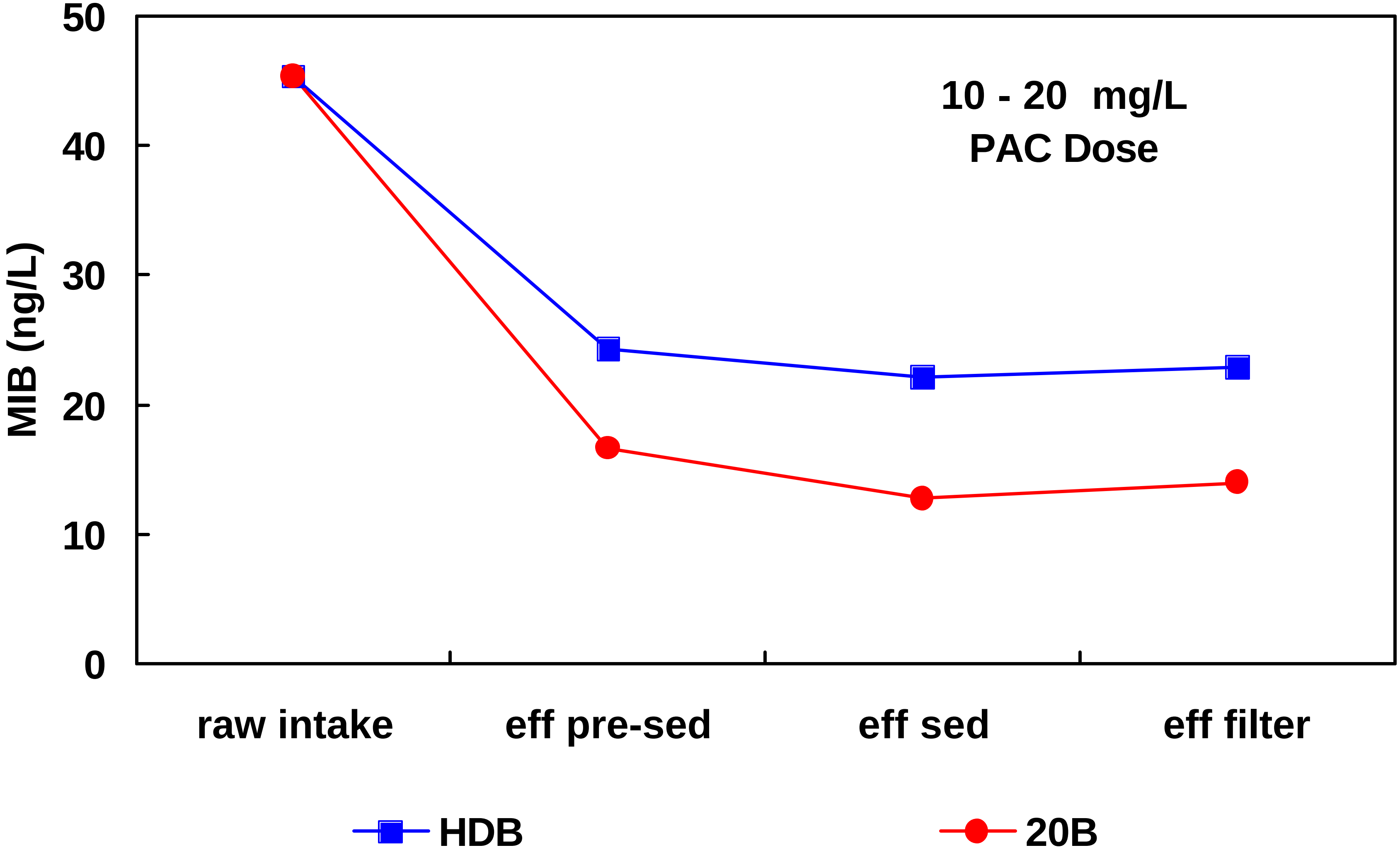
Field-Scale Experiments (Task 2)

- Comparison of PAC types at WTP
- Effect of canal brushing on algae biomass
- Effect of canal brushing on MIB/geosmin
- Comparison of biocide canal coatings on algae biomass

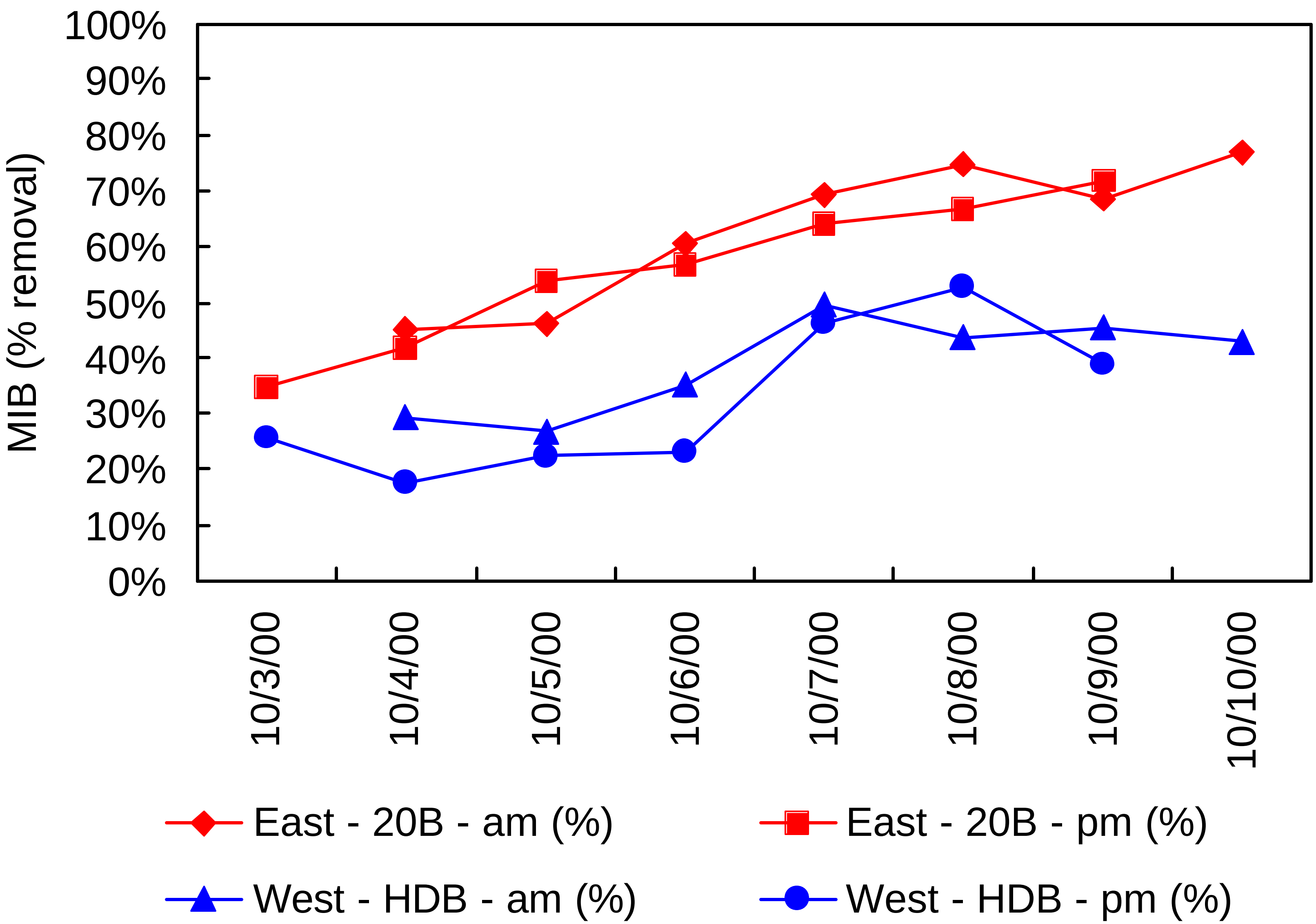
Val Vista WTP



MIB Removal in WTP



East Plant with Norit 20B had higher MIB removal than West Plant with Norit HDB

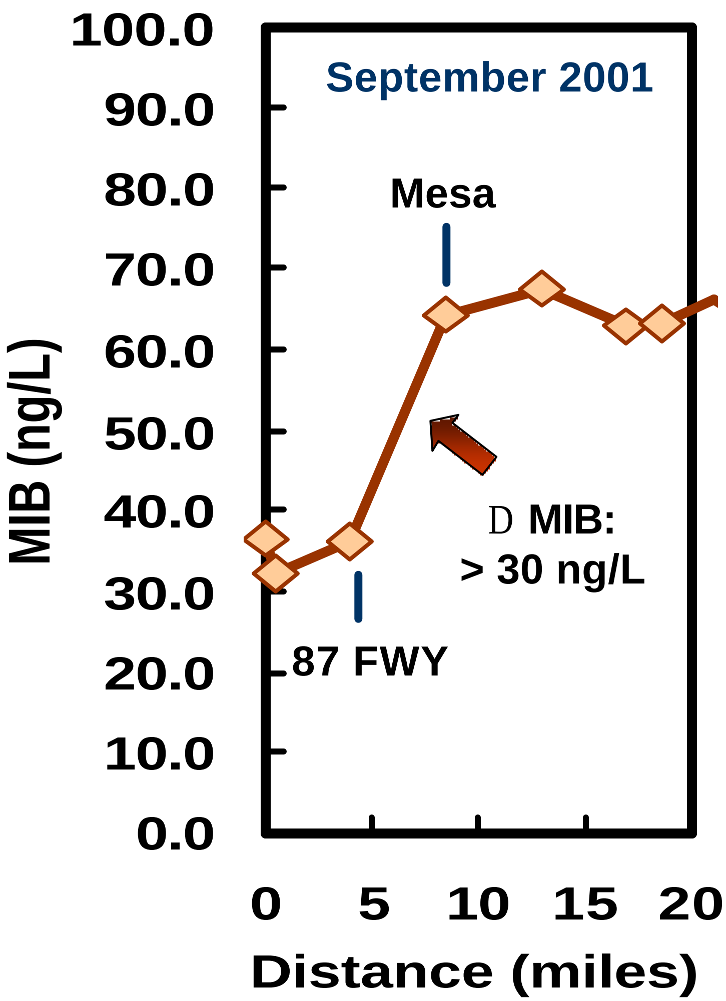


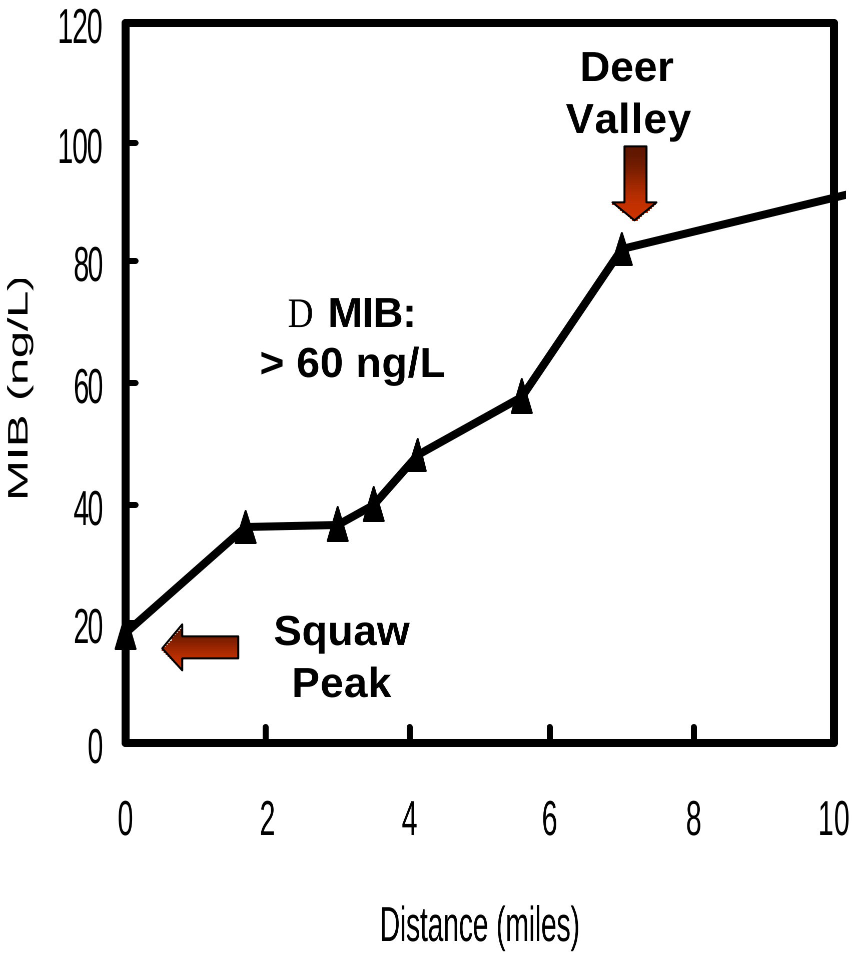
Field-Scale Experiments (Task 2, Continued)

- Copper application
- Effectiveness of copper in reducing canal MIB

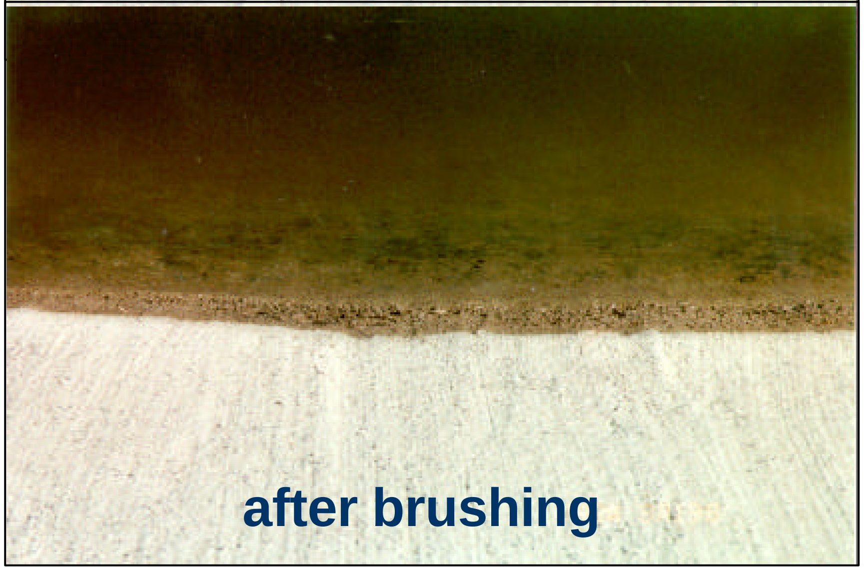
Background

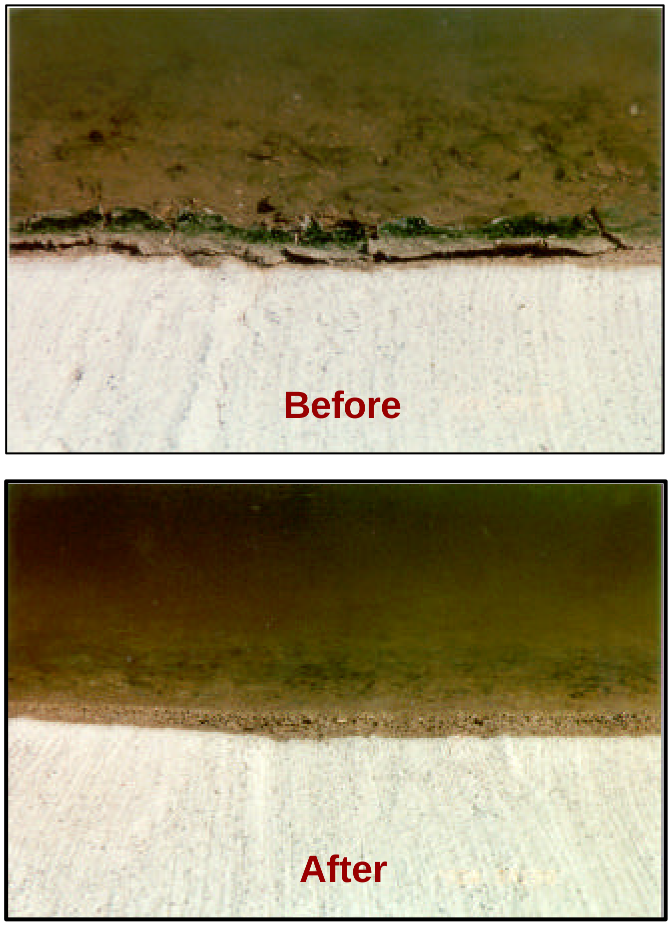
Production of MIB and major hotspots in the Arizona Canal

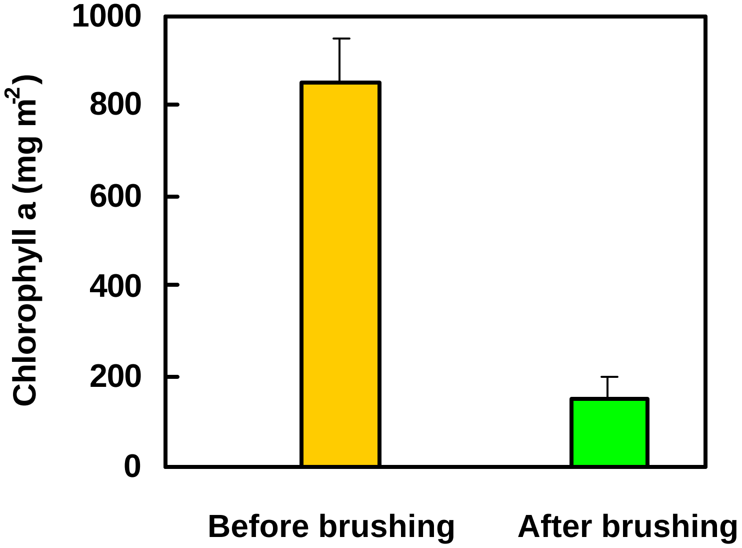




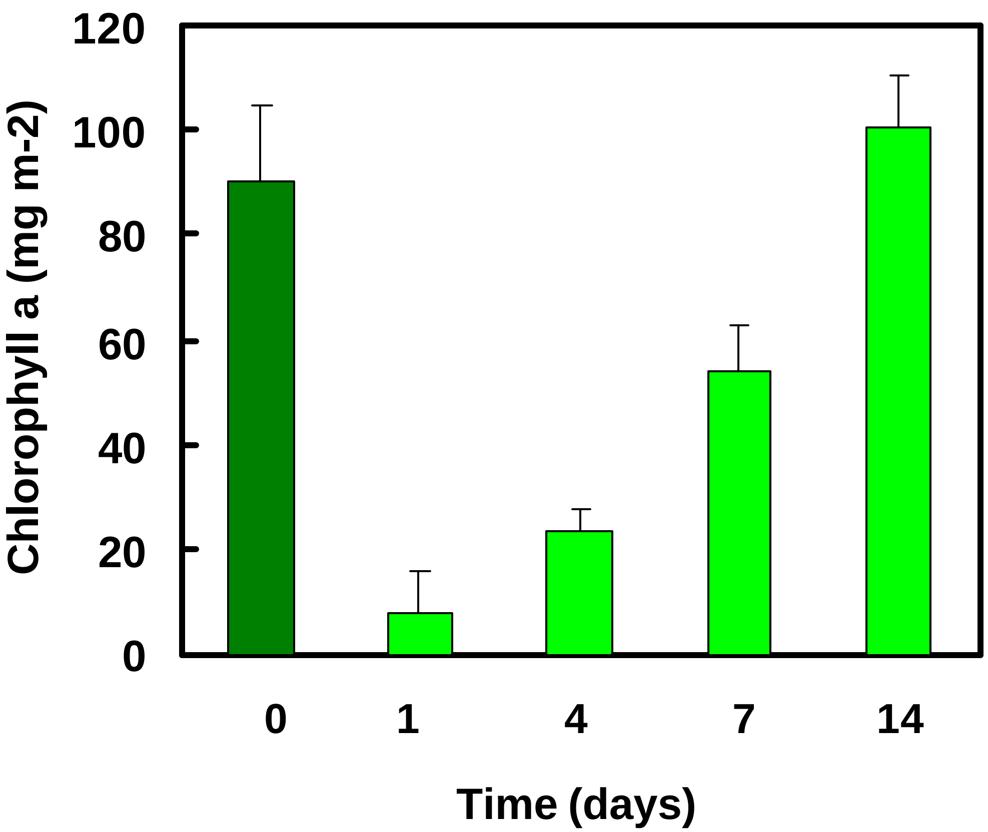
Canal Wall Brushing



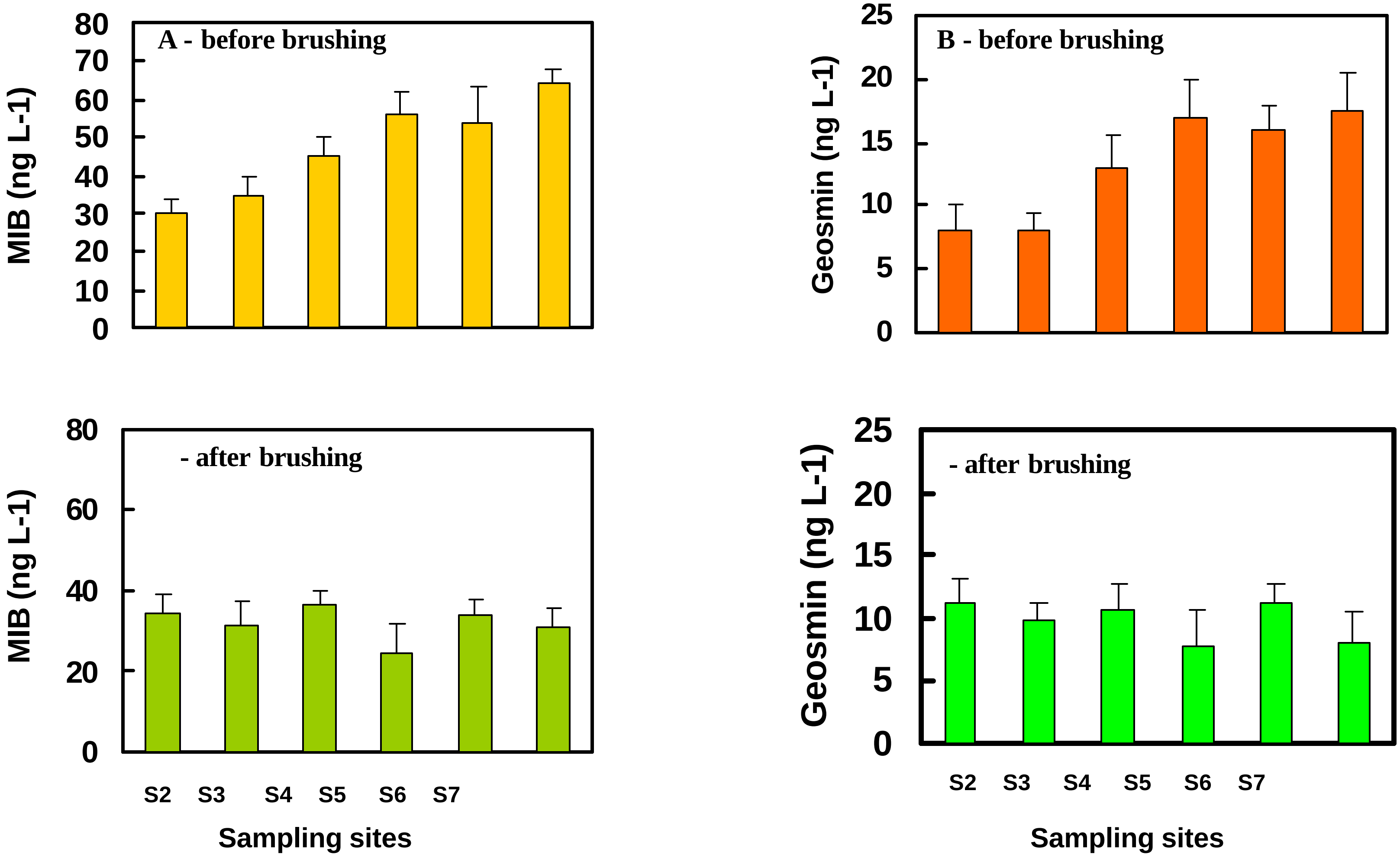

Before
After


1000
800
600
400
200
0
Chlorophyll a (mg m-2)
Before brushing
After brushing

Increase in periphyton biomass on the canal walls over time following brushing treatment (in August 2000)



Concentration of MIB (A) and geosmin (B) in the canal section Before and after brushing treatment (in August 2000)

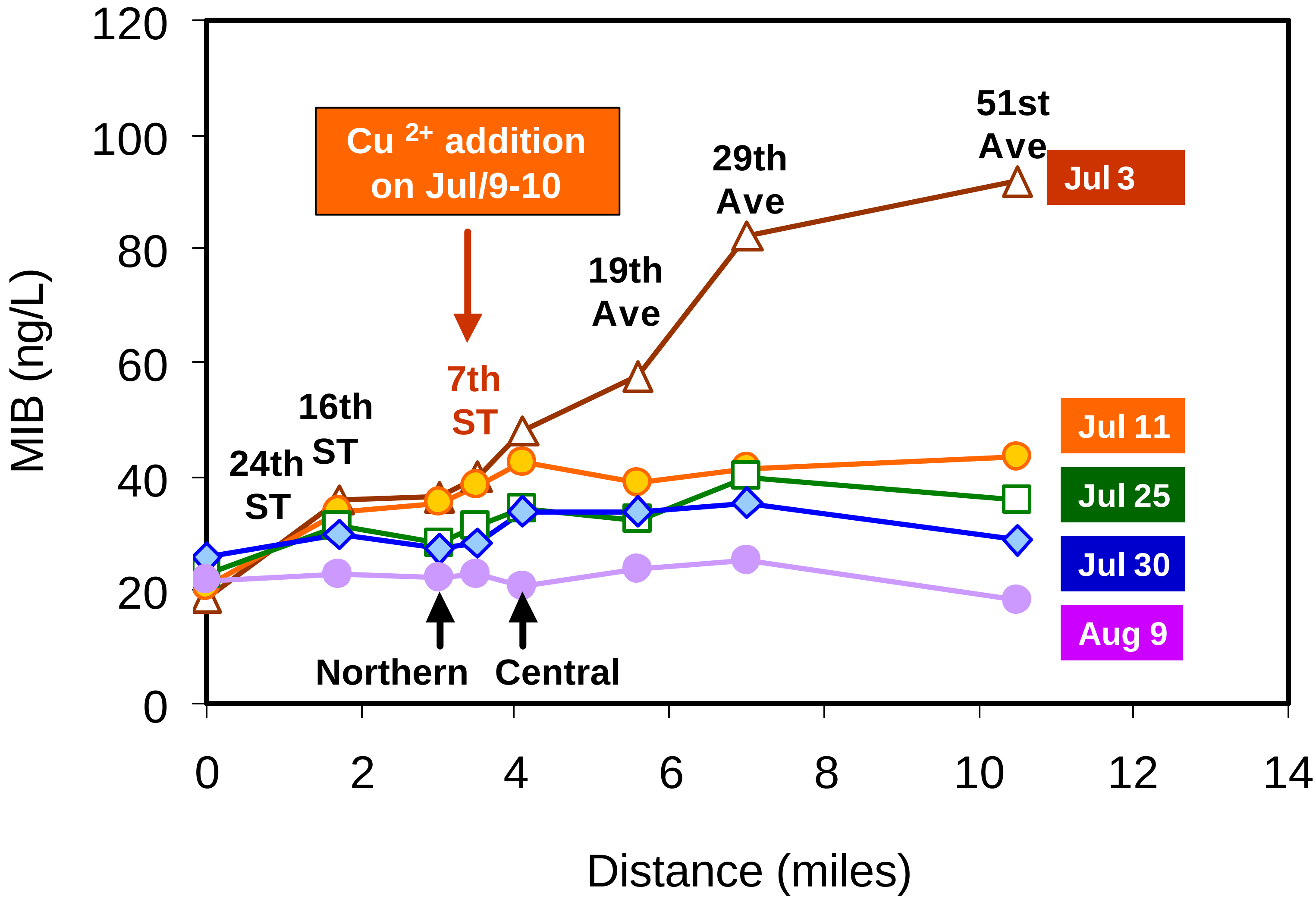


Canal Brushing Field Experiments

- **Short test sections (~10 m) brushed once, twice, or three times**
- **One pass brushing removed >80% of periphytic biomass**
- **Biomass re-establishes within 2-weeks, but MIB & Geosmin remain low**
- **Effective in areas of dense biomass on canal walls**
- **No downstream complaints from turbidity spikes**
- **Other cities have recently scheduled SRP brushing**

Copper Application

Decrease in MIB concentration over one month in the Canal section following copper application



Canal Treatments

Brushing

Positive

- Good at removing algae on walls; 2-3 week effectiveness
- Beneficial for removing dense localized periphyton

Negative

- Operational and scheduling challenges
- Slow (several days to brush several miles)
- Labor intensive

Copper Treatment

Positive

- Easy to schedule (1-3 days)
- Low effort - one operator, 8 hours
- Copper residual for > 5 miles
- Effective at reducing MIB over greater canal reach than brushing

Negative

- Cutrine elevated chlorine demand (switched product)
- Possible development of toxicity resistance
- Possible fish kill at > 0.5 ppm

Benefits from Experimentation

- Objectively evaluated sources and fate of T&O compounds
- Methodology to purchase and dose PAC in WTPs has been adopted by Phoenix and other cities
- Field work quantified effects of canal brushing and copper addition on canal biomass and T&O
- Several cities have arranged with SRP to treat canals specifically for T&O problems given this studies findings

Presentation Outline

- Summary of Research Products
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- Recommendations & Future Needs

Summary of Implementation

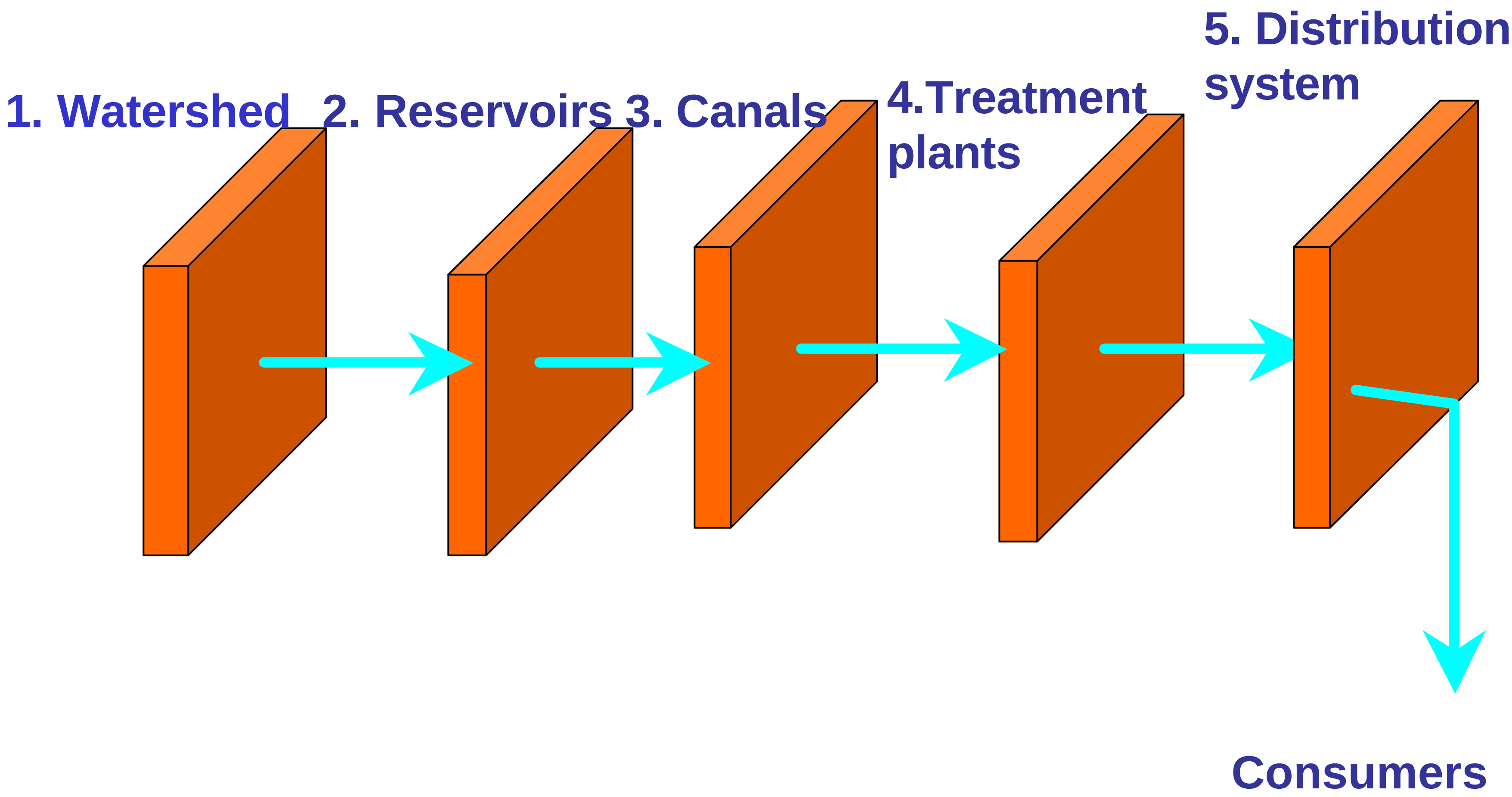
Midcourse Evaluation (Task 6)

Purpose: To evaluate technical, economic, and political issues for potential multiple-barrier T&O control options

Phased-In Implementation (Task 7)

Purpose: To implementation measures expected to cause a measurable decrease in T&O causing compounds and an improvement in the taste of the water provided to consumers in a significant portion of Phoenix's water supply system

Multiple Barrier Approach for T&O Management



Summary
Specific T&O control measures

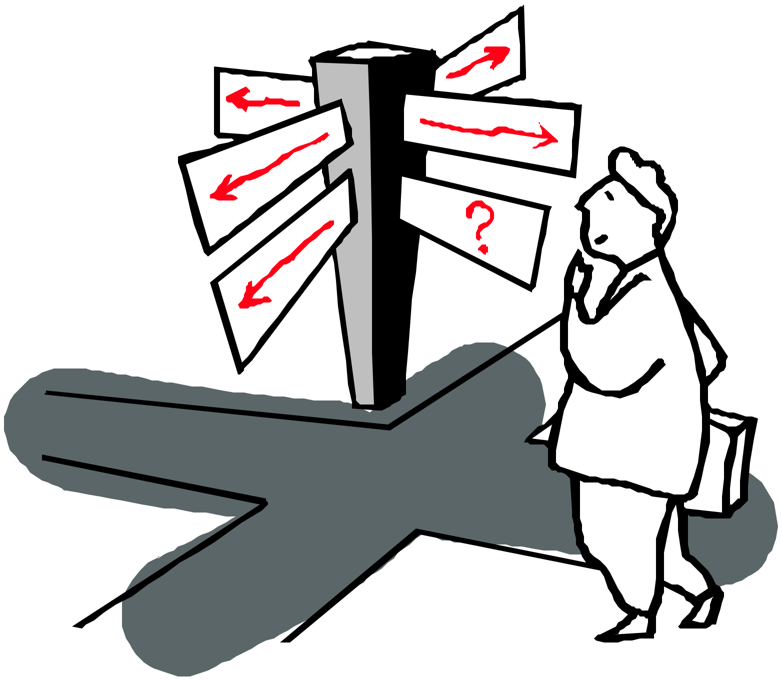
Practice	Technical	Economic	Legal/ instit.
Watershed nutrient control	*	?	?
Source water selection			
Stepped-up production at Union Hills	****	***	***
Modified CAP flow regime	****	***	*****
Blending at Cross-connect	****	**	**

Summary of T&O control measures (cont'd)

Practice	Technical	Economic	Legal/inst.
Reservoir treatment			
Copper sulfate	**	**	****
Destratification	**	**	?
Canal treatment			
Mechanical cleaning	***	****	****
Copper sulfate	**	****	****
PAC treatment	****	**	****
Ozonation	****	**	****
Algae maintenance in WTPs	*	***	****

Quantifying Benefits Gained through T&O Control

- **A new concept developed: *Consumer Days Below T&O Threshold (CDBT)***
- **Goals for CDBT-10 and CDBT-20 ng/L evaluated**
- **CDBT can be used to compare and evaluate T&O Implementation activities**



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Phased-In Implementation (Task 7)

Purpose: To implementation measures expected to cause a measurable decrease in T&O causing compounds and an improvement in the taste of the water provided to consumers in a significant portion of Phoenix's water supply system

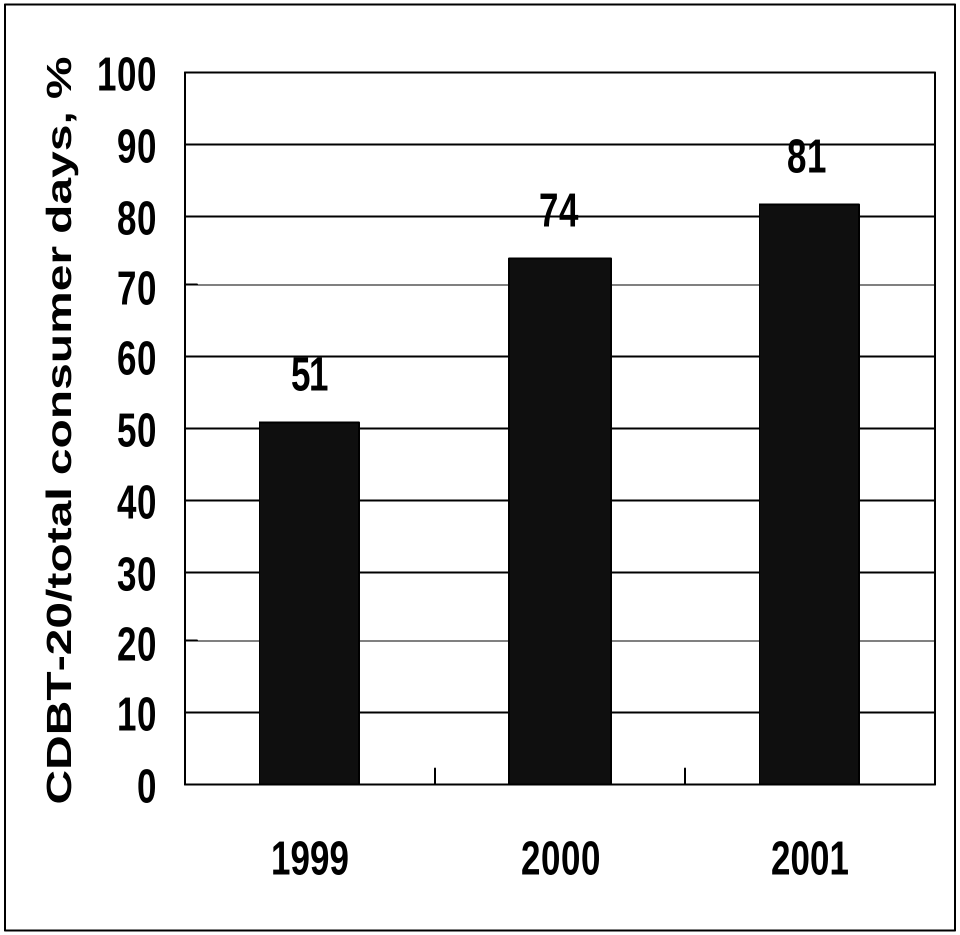
Implementation Activities Undertaken

- Process Control Monitoring (Critical!) with rapid information dissemination

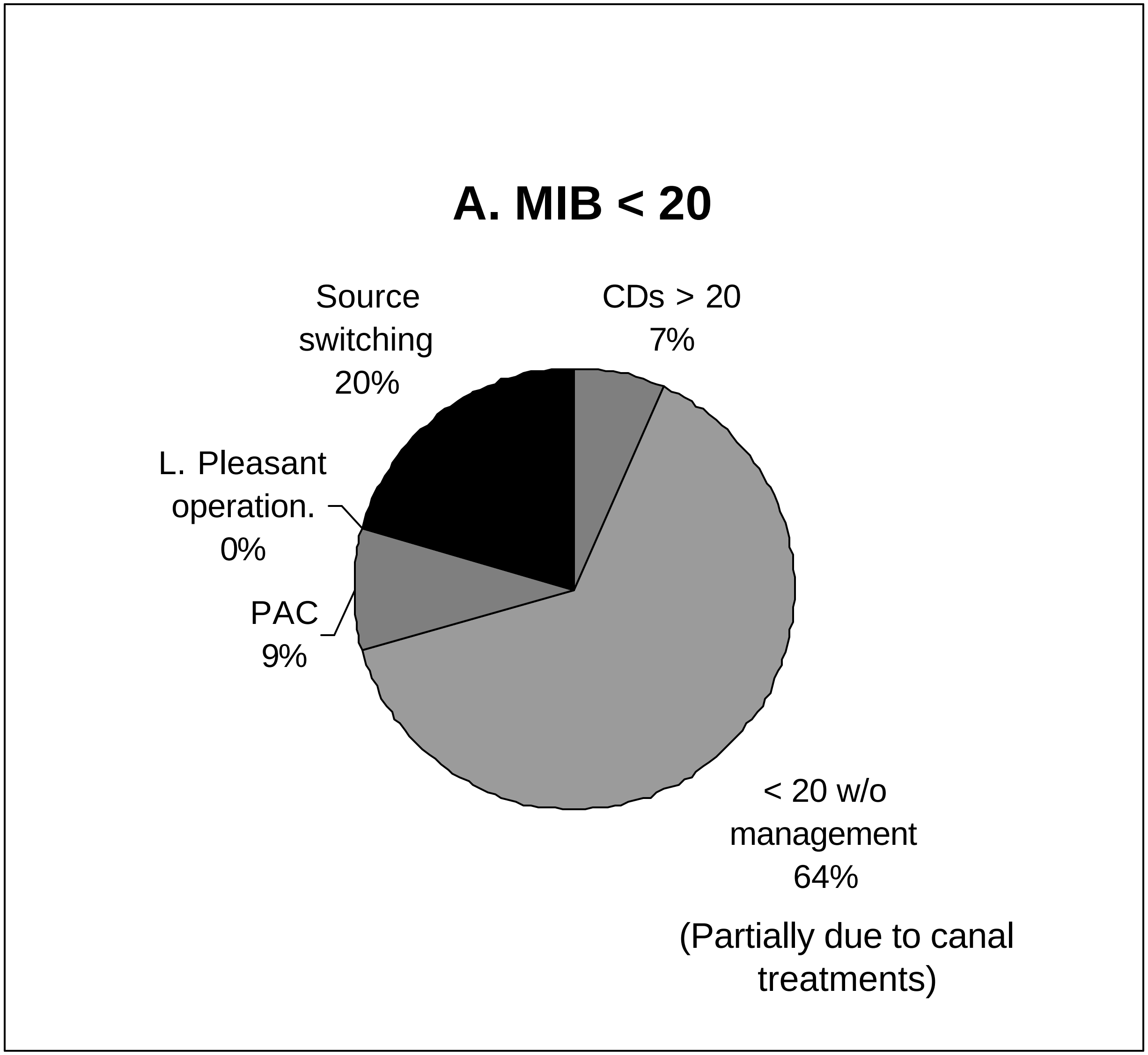
- Modification of Lake Pleasant: hypolimnion release (UofA recommendation)
- CAP water by-passing Lake Pleasant Wadell Canal (No Lk Pleasant Release)
- Blending CAP and SRP water at Granite Reef
- Switching water production to different WTPs with lower influent T&O levels
- Copper application in Arizona Canal
- Mechanical brushing in Arizona Canal
- PAC addition in WTPs

Was Implementation Successful?

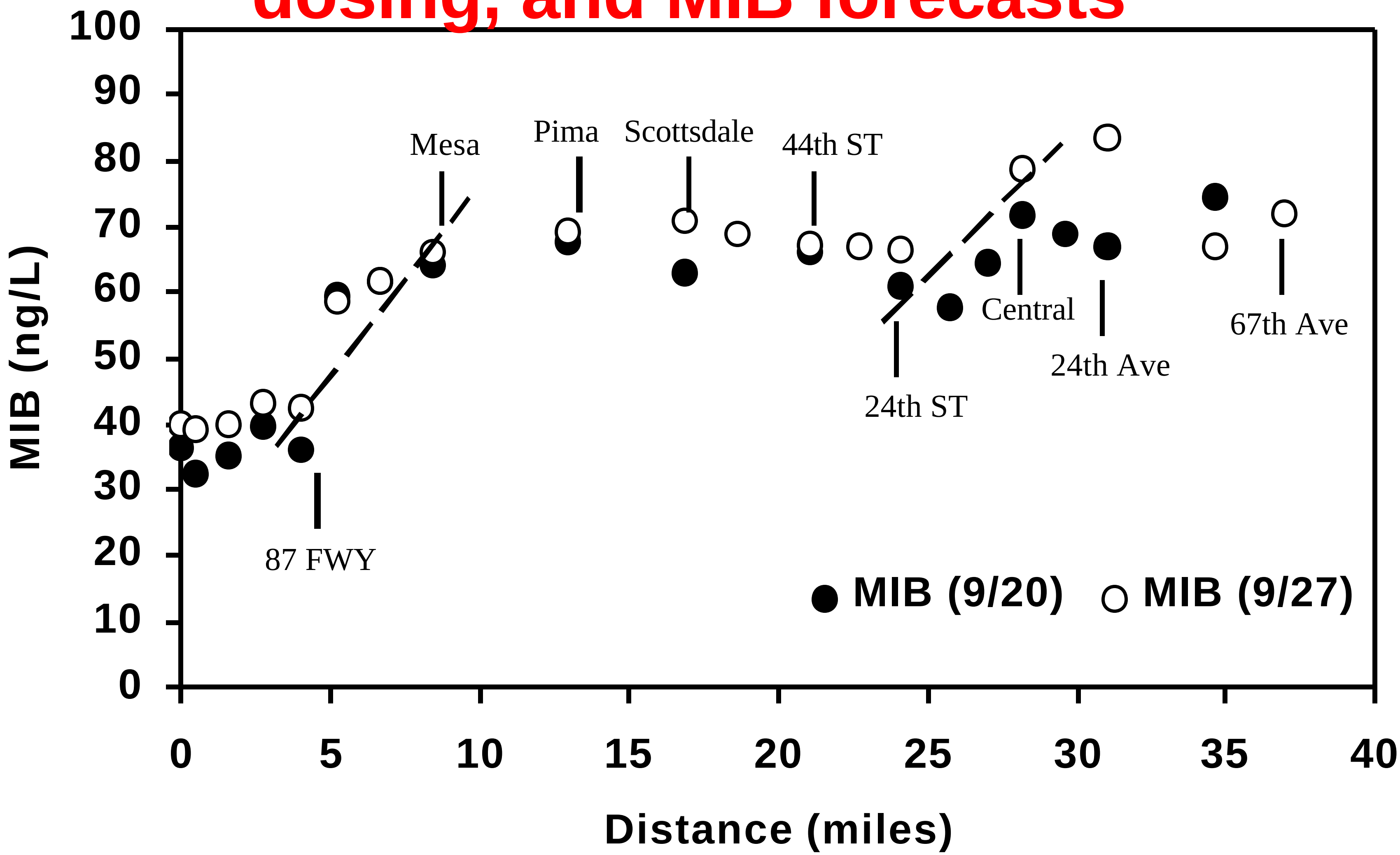
- Implementation activities added 100 to 130 million CDBT-20
- This is a 33% to 44% increase over prior years without implementation
- CDBT-10 was also increased



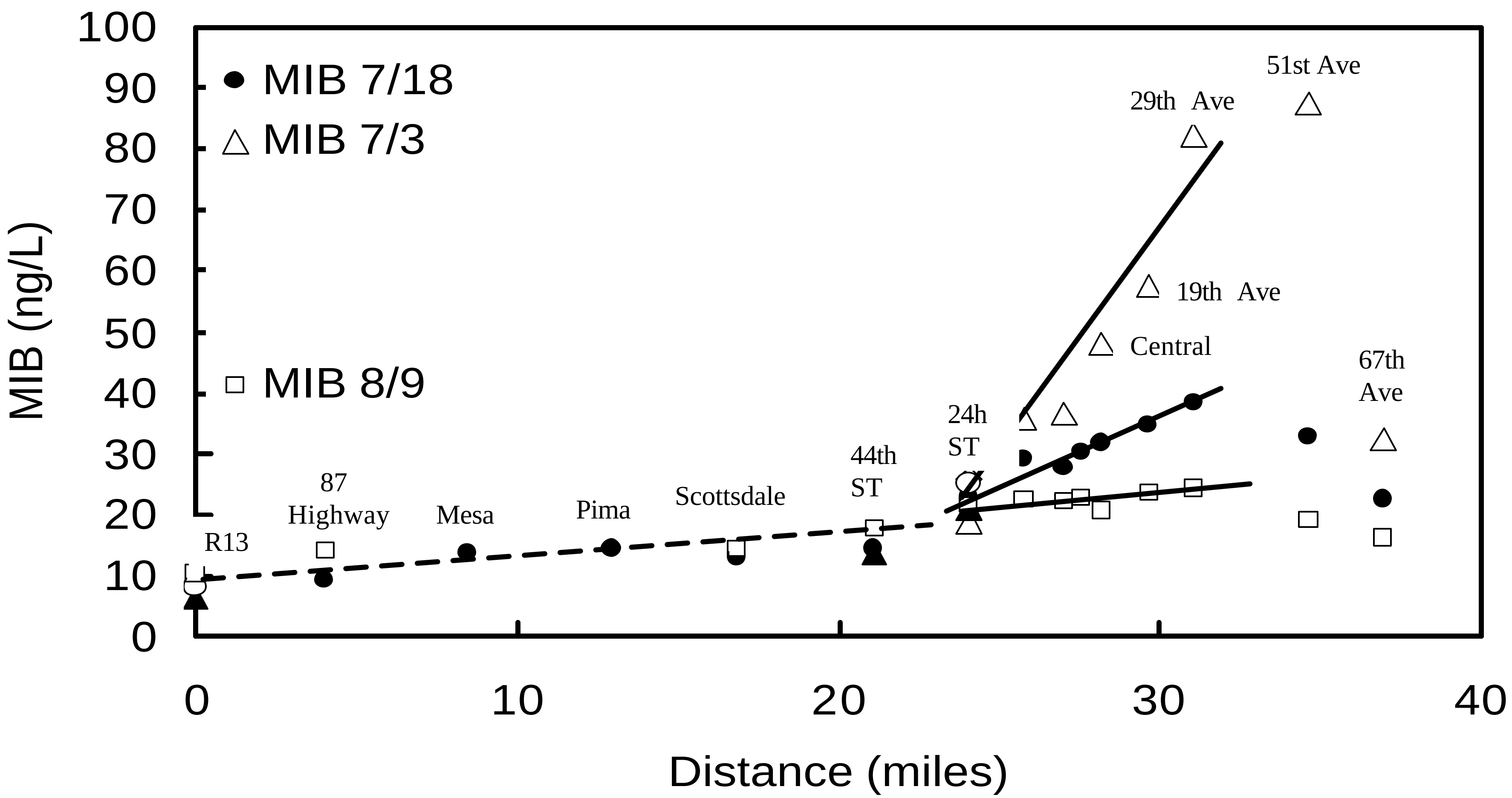
What Implementation Activities had largest Impact in 2001?



Process Control Monitoring Identifies "hot spots", serves as basis for PAC dosing, and MIB forecasts



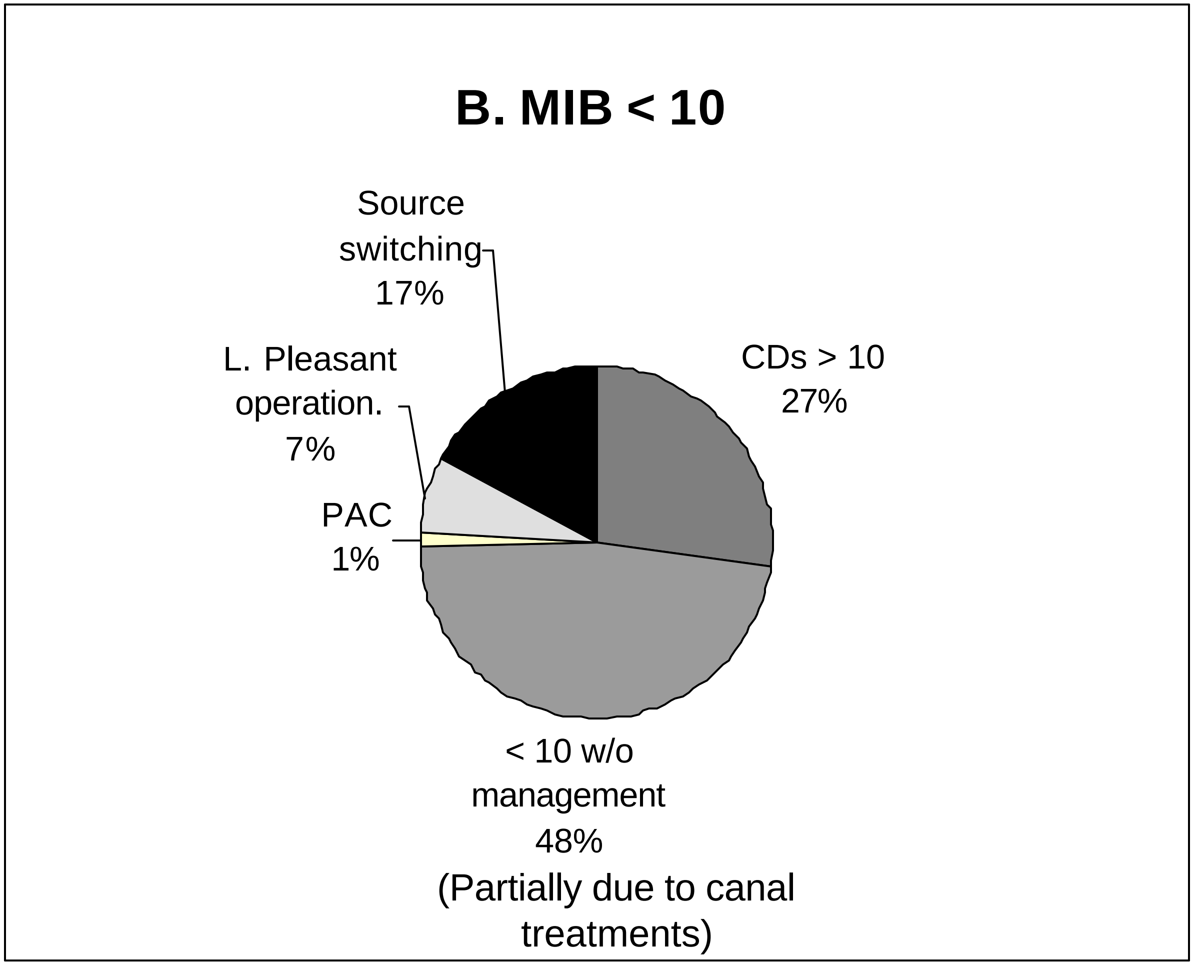
Canal Activities reduce Raw Water MIB



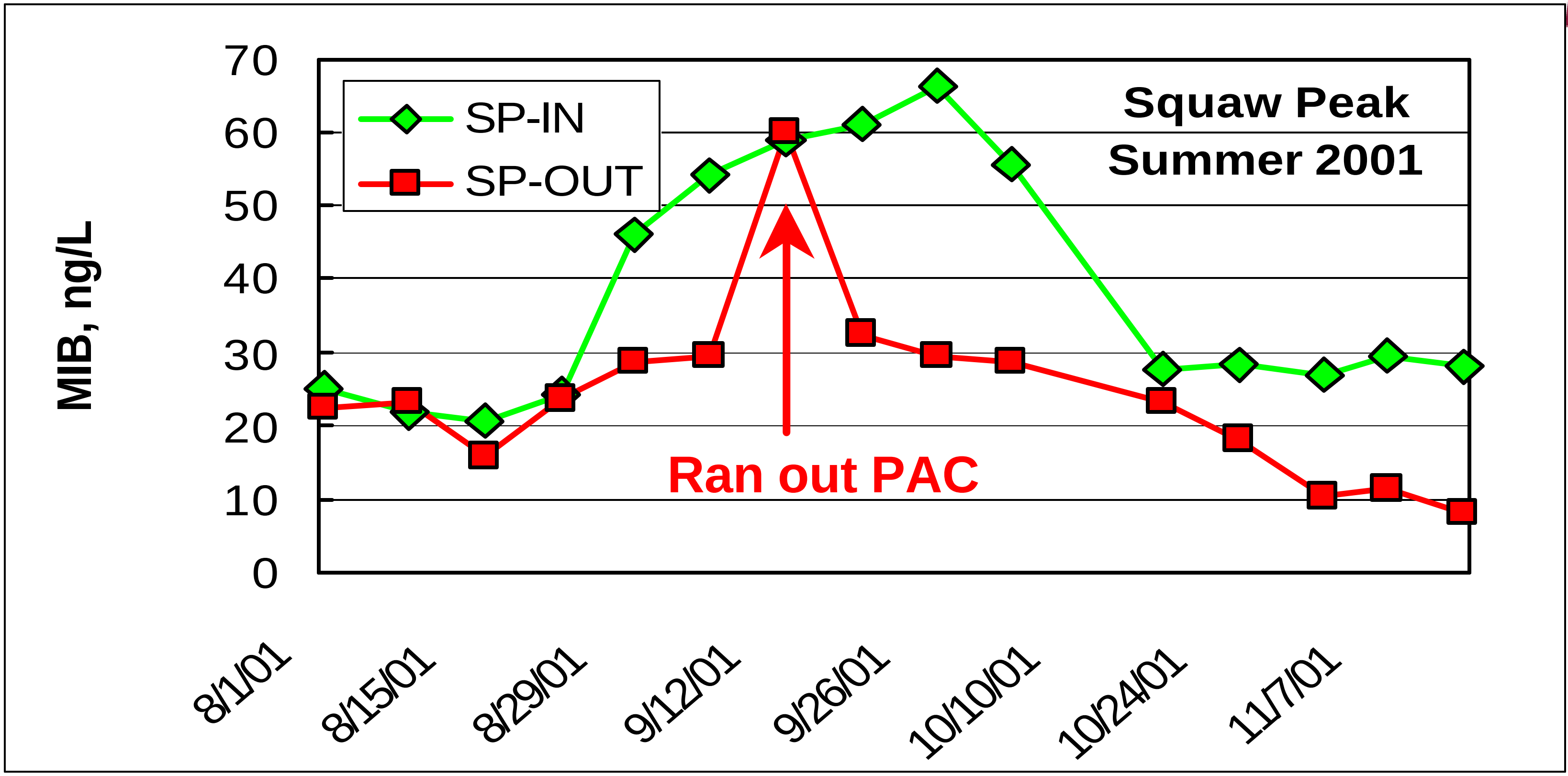
Copper applied — **July 9th and 10**

Brushing conducted — **July 24, August 1**

What Implementation Activities had largest Impact in 2001?



PAC did not reduce MIB to < 10 ng/L due to (1) PAC feed capabilities, and (2) Source switching reduced need for PAC



PAC in Squaw Peak

Summary		
MIB, ng/l	In, %	Out, %
< 10	0.0	6.7
< 15	0.0	20.0
<20	0.0	33.3

SUMMARY

What works? What doesn't? What needs improvement?

∗∗∗∗∗ = excellent; cost-effective; proven; widely effective
∗∗∗∗ = very good; demonstrated effectiveness; widely effective
∗∗∗ = good; may have greater potential
∗∗ = fair; contributes at times
(∗) = could work better with development

- Process control monitoring ∗∗∗∗∗
- CAP-Lake Pleasant operation ∗∗∗
- CAP-SRP blending ∗(∗)
- Source switching with WTPs ∗∗∗∗∗
- Canal management ∗ ∗ (∗)
- PAC treatment in WTPs ∗ ∗ (∗∗)

Cumulatively – multiple barrier implementation activities jointly lead to significant T&O level reductions for Phoenix customers (Mesa, Peoria, Glendale also had benefits)

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Guidance Manual

Reducing 2-Methylisoborneol (MIB) and Geosmin in the Metropolitan-Phoenix Area Water Supply

A Cooperative Research and Implementation Program by
Arizona State University
City of Phoenix
Salt River Project
Central Arizona Project
July 2002

Guidance Manual

Taste and Odor Control for Water Supplies in Arid Regions

1. Introduction
2. Background on T&O Problems
3. Multiple Barrier Controls
4. Monitoring Programs
5. Specific Management Barriers
6. Program Assessment
7. Case Studies

Introduction

Historical Perspective

- Seasonal customer complaints
- Established flavor profile analysis panels
- Treated canals
- Applied Powdered Activated Carbon at WTPs
- Effectiveness of treatment largely unknown

Underpinning Principles for Study

- A Multiple Barrier Concept
- Continuous Monitoring
- Rapid Response System
- Broad Collaboration
- Sustainable Program

Implementation Goals for T&O Control Program

- Comprehensive system monitoring to detect T&O compounds
- Managing water resources to minimize T&O compounds in raw water
- Optimizing treatment practices in canals
- Optimizing water production at WTPs receiving higher quality water
- Optimizing MIB/geosmin removal

Background on Taste & Odor Problems

- Biological source of taste & odor compounds
- Frequency and distribution of taste & odor episodes
  - Seasonal patterns
  - Frequency of problems
- Origin of taste & odor compounds
  - Reservoirs
  - Arizona Canal
  - Water treatment plants

Multiple Barrier Strategy

- Reservoir Management
  - Lake Pleasant Depth of Release
  - CAP Water Supplementation/Substitution
- Canal Treatments
- SRP-CAP Blending
- Source Switching Among WTPs
- In-Plant Treatment

Monitoring and Prediction

- Sampling Locations
- Sampling Frequency
- Recommended parameters to Monitor
  - MIB, Geosmin (cyclocitral)
  - Temperature
  - Dissolved oxygen
  - Specific Conductance
  - Nitrate
  - Algae
- Prediction of T&O Problems
  - Temperature
  - Nitrate
  - Specific Conductance
  - Algae Types

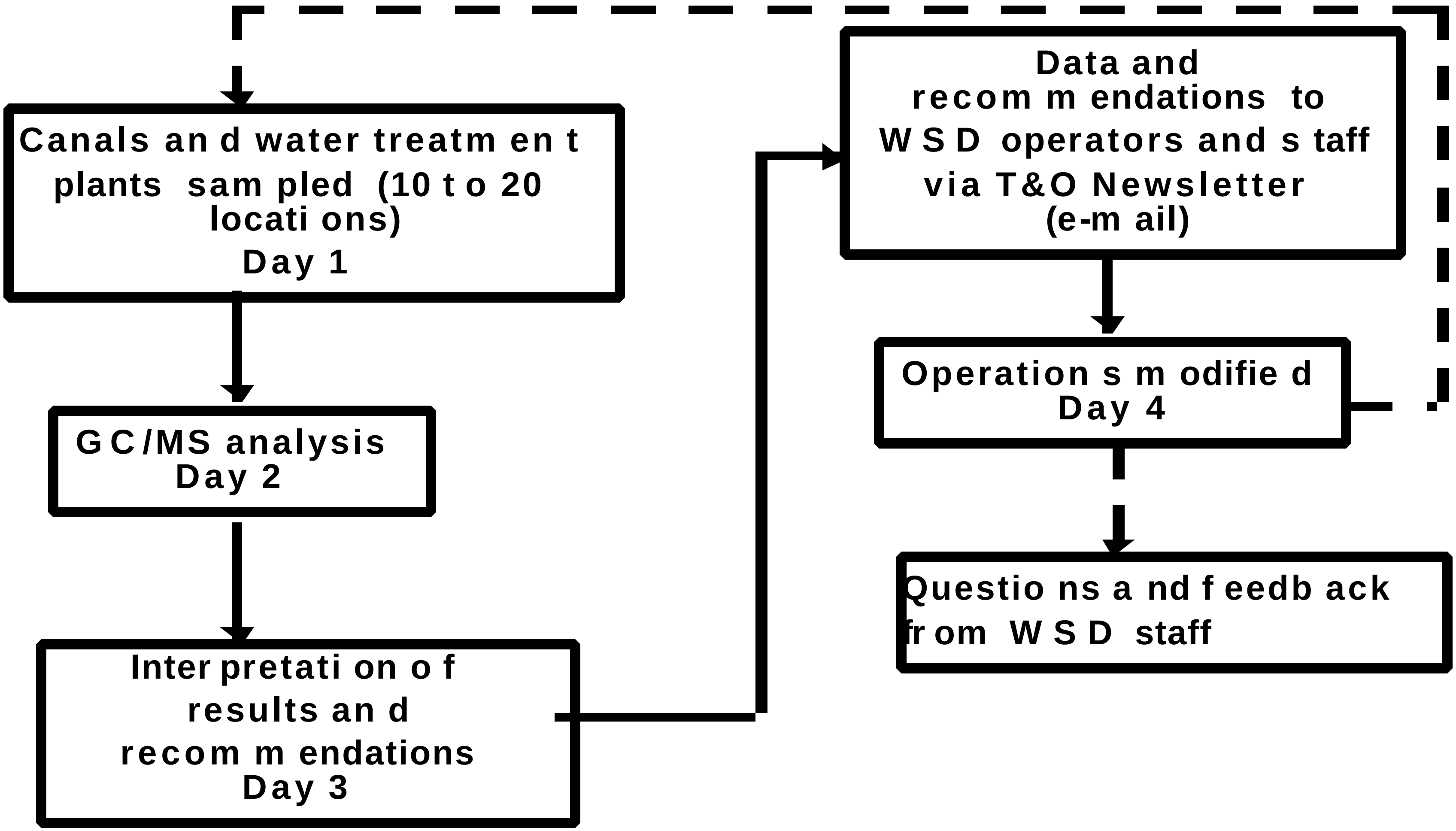
Benefits of Monitoring and Prediction

- **Some T&O episodes can be prevented**
- **Some T&O episodes can be avoided**
- **Some T&O episodes can be treated**

Rapid Response System

- Intensive Monitoring
  - Weekly along canals
  - Monthly or bimonthly in reservoirs
- Electronic Communication
  - T&O Newsletter
  - T&O website

Flow Chart of the Rapid Response System



Specific Management Barriers

- Water Supply Operations
  - Lake Pleasant Options
  - SRP-CAP Blending
- Management of Canals
  - Copper Treatment
  - Canal Wall Brushing
  - Biocide Coating
- Water Treatment Plant
  - Source Switching
  - Prevent In-Plant Production
  - PAC Application
  - AC Filter Caps or GAC Adsorbers
  - Advanced Oxidation

Program Assessment

- Communications/Feedback
  - Taste and Odor Newsletter
  - Semi-Annual Workshops
- Technical Evaluation
  - Metrics For Consumer Satisfaction
  - Operational Issues
  - Economic and Political Review

Case Studies

#1 – High MIB In Saguaro Lake

#2 – High MIB in Arizona Canal

#3 – High MIB in treatment plant influent water

Benefit of Guidance Manual

- **Tool for T&O Management**
  - **Outline integrated strategies for minimizing T&O episodes**
  - **Useful in detection of T&O compounds**
  - **Useful in identifying "culprit" algae**
  - **Recommends sampling sites and intervals**
  - **Establishes a protocol for communication and response to T&O problems**

Interactive Taxonomic Guide

Presentation Outline

Summary of Research Products

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Overview of Guidance Manual

Integration for Regional T&O Control

Recommendations & Future Needs

Regional T&O Implementation

- One unified process control sampling program with rapid turnaround
- Monitoring lakes with SRP provides MIB forecasts, since lakes are major sources of MIB in late fall
- Provides long-term unified database to evaluate drought, normal, wet years and impacts of disturbances (fires)
- Canal treatment costs could be shared by utilities
- Canal treatment costs are less than PAC
- PAC bid selection and appropriate dosing is critical; PAC costs have decreased regionally in part due to improved performance-based specifications
- One entity should manage and communicate T&O information

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Recommendations

- Upstream T&O control is more cost-effective than PAC addition
- Shift water production to up-canal WTPs
- In-plant T&O control is necessary, GAC adsorption is recommended over PAC (achieves DOC and T&O removal)
- ~50% of DBPs leaving the plant formed before entering clearwell (improve DOC removal using GAC and delay point of chlorination)
- Continue in-plant algae control (copper recommended)
- Wet years could produce higher T&O levels due to nutrient stimulation of algae and flushing of damp soils
- Process control monitoring, rapid data turnaround, and empowering WTP staff to USE T&O data is critical

Future Initiatives

- **Watershed scale:**
  - **Continue monitoring to learn what happens during periods of increased rainfall (DOC and T&O)**
  - **Assess impacts of Salt River watershed fires (contrast against Verde River) (DOC and T&O)**
  - **Affect of changing salt ion balance on stimulation of MIB or Geosmin production**
- **Canals:**
  - **Implement genetic monitoring for culprit algae as part of Early Detection program**
  - **Apply EP2000 biocide coating to 10-20 m sections of Arizona Canal and monitor for 1 year**
  - **Use canal coupon prototype device to investigate algae colonization and impacts of algacides**
- **Water Treatment Plants:**
  - **Ongoing AWWARF project on O3-Biofiltration**
  - **Interest in GAC filter caps**
  - **Use kinetic models to optimize PAC dosing**
  - **Evaluate fate of algal biotoxins during water treatment**

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Reducing Taste and Odor and Other Algae-Related Problems for Surface Water Supplies in Arid Environments

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Central Arizona Project

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Cities of Tempe, Chandler, Scottsdale, Gilbert, Glendale

ARIZONA STATE UNIVERSITY

Taste and Odor Website

http://ceaspub.eas.asu.edu/pwest/tasteandodor.htm