Regional Water Quality Issues:
Algae and Associated Drinking Water Challenges

Workshop – September 2010

A Cooperative Research and Implementation Program
Arizona State University (Tempe, AZ)
Paul Westerhoff, Chao-An Chiu, Jacelyn Rice, Andrew Ellis,
Susanne Neuer, Phillip Tarrant and Marisa Masles

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

Agenda

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

- 8:15 Refreshments
- 8:30 Introductions
- 8:45 Project overview and Water Quality Trends
- 9:05 AWWA Project: In-plant Algae and T&O Sensing devices
- 9:20 Potential influences of Climate Change on Arizona Water
- 9:35 Stretch
- 9:45 Cost comparisons for Salt versus Verde Rivers
- 10:00 Strategies to remove and monitoring organic matter
- 10:20 In-situ GAC regeneration using Ferric Chloride
- 10:35 Future directions & discussion
- 11:00 Meeting adjournment

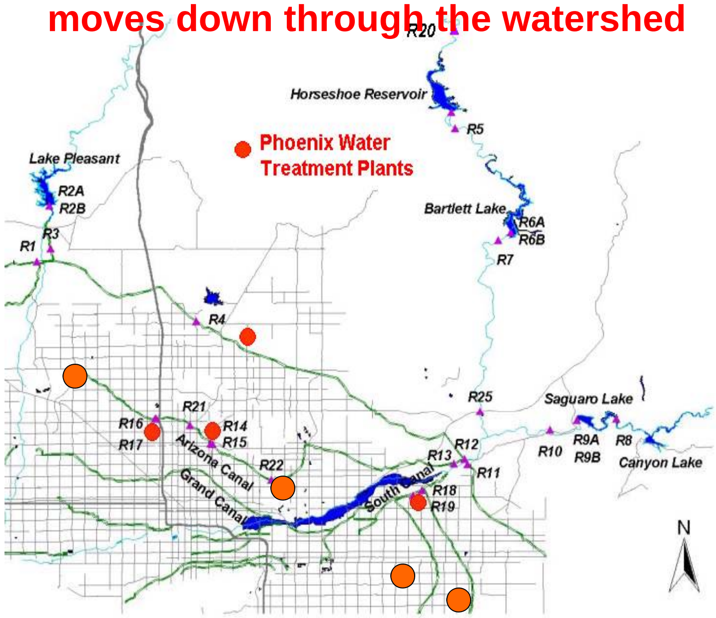
Introductions

Name?

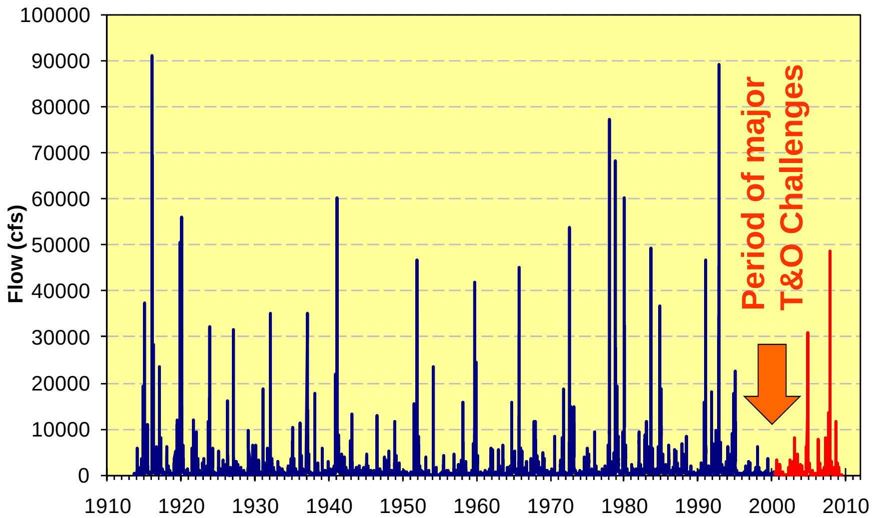
Affiliation?

What do you want to hear today?

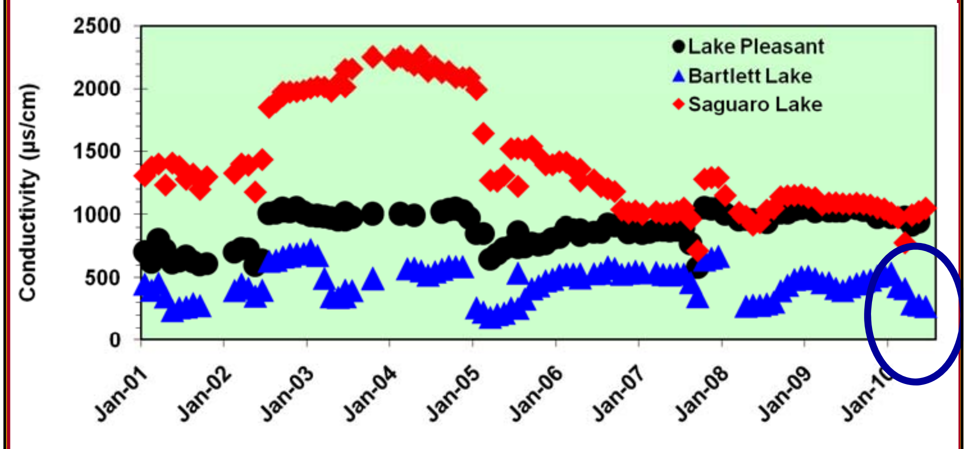
Workshop will present results as water moves down through the watershed



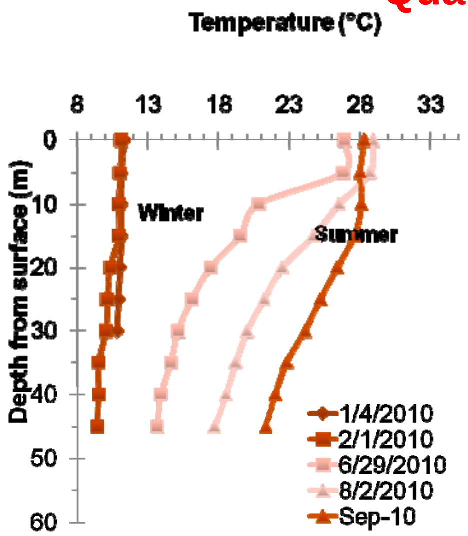
Salt River Above Roosevelt



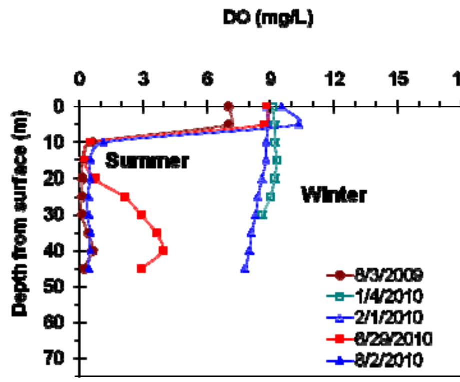
Hydrology Affects Water Quality (conductance can affect algal dominance)



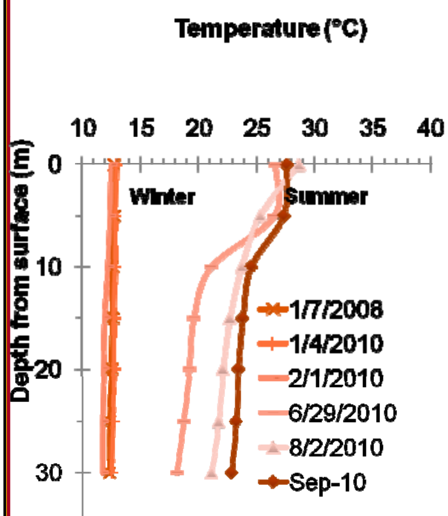
Reservoir Conditions Affect Water Quality



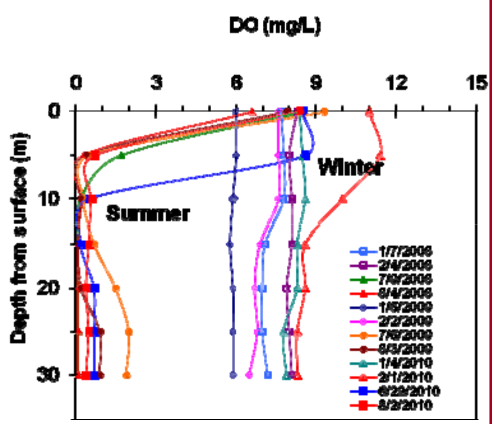
Bartlett Lake



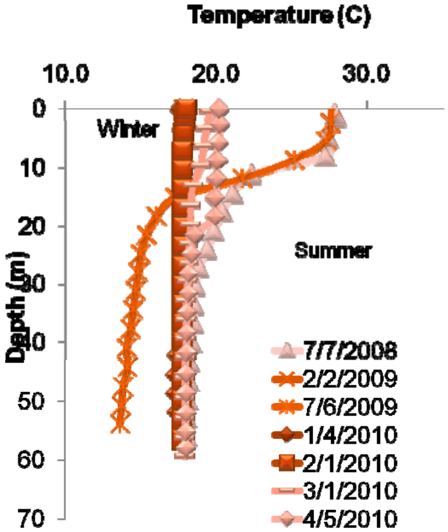
Reservoirs are destratifying



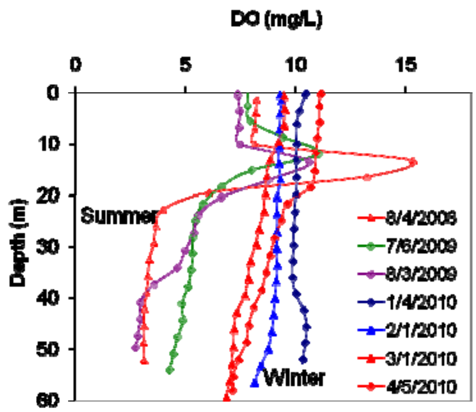
Saguaro Lake



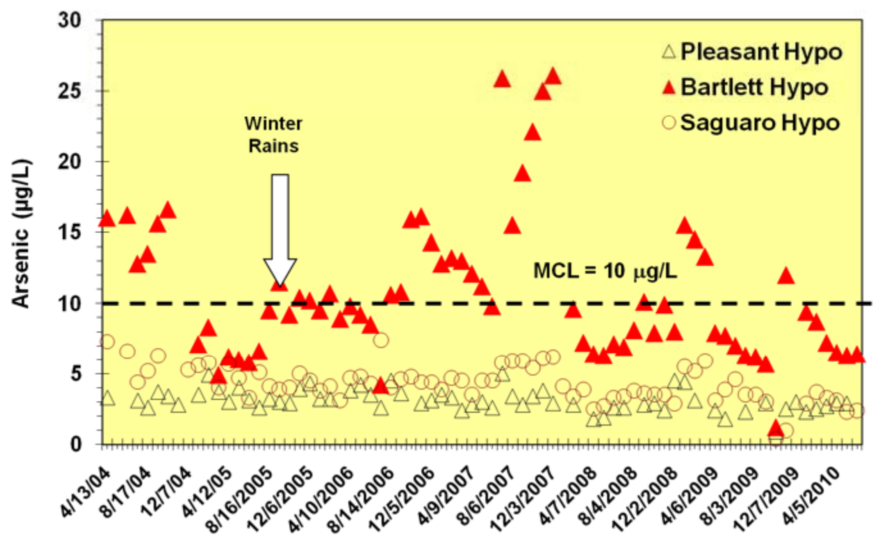
Reservoir Conditions Affect Water Quality



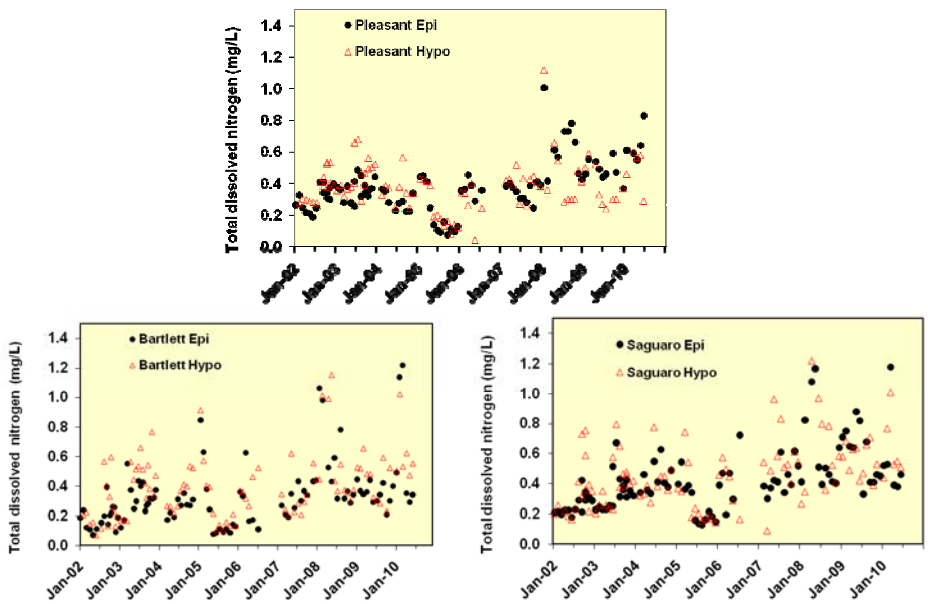
Lake Pleasant



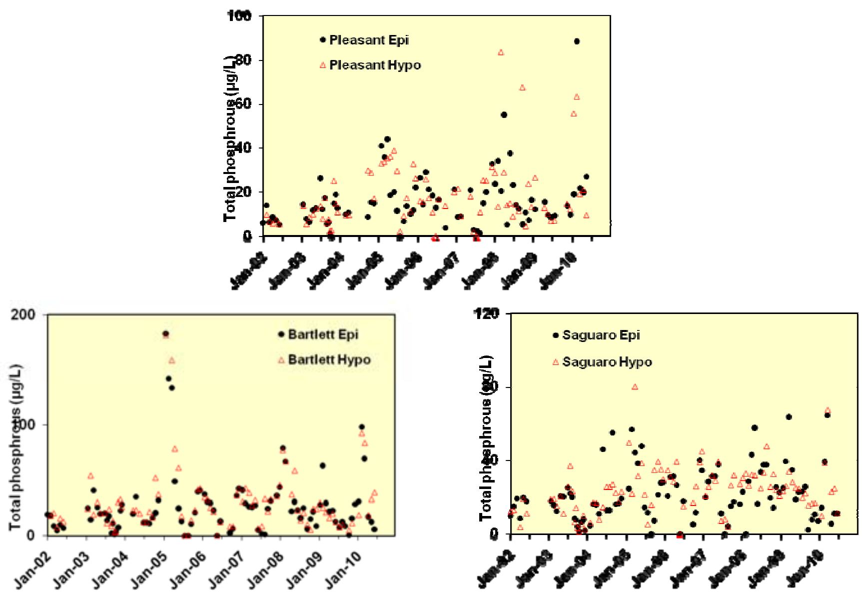
Arsenic



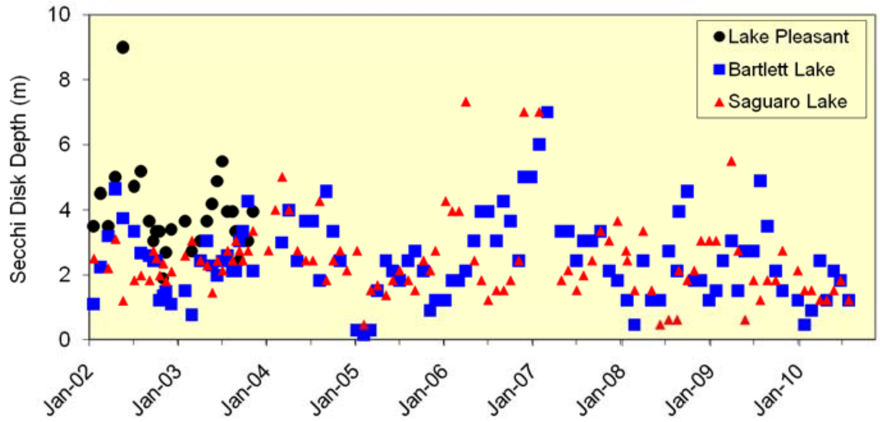
Dissolved Nitrogen Trends in Reservoirs



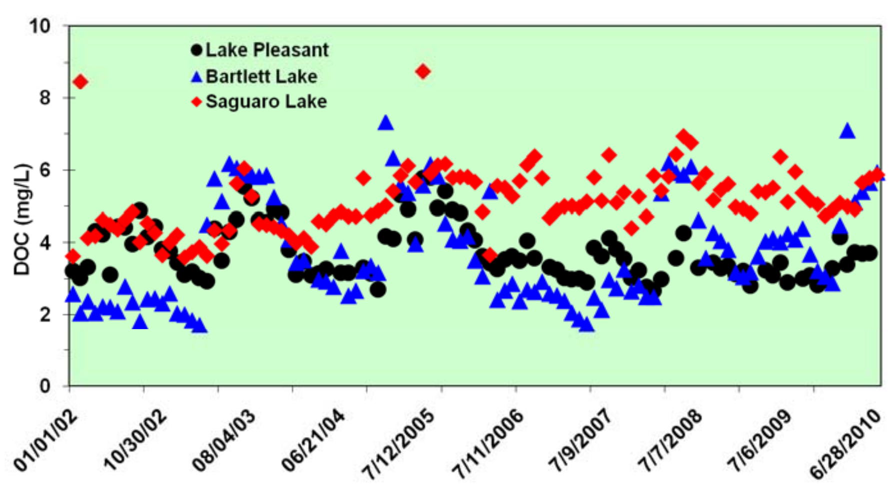
Total Phosphorous



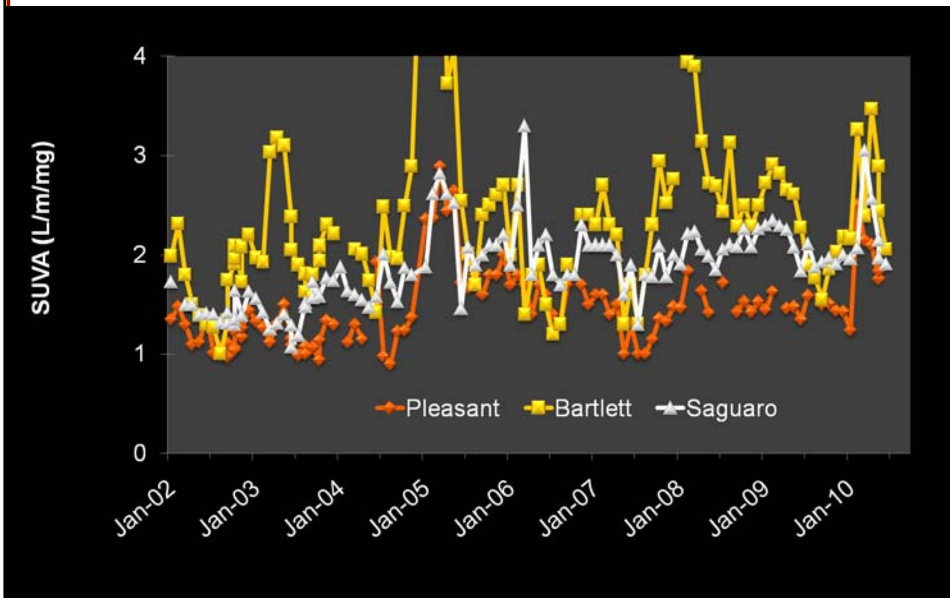
Secchi Disk Depth Influenced by Inorganic Suspended Sediment and/or Organic Biomass



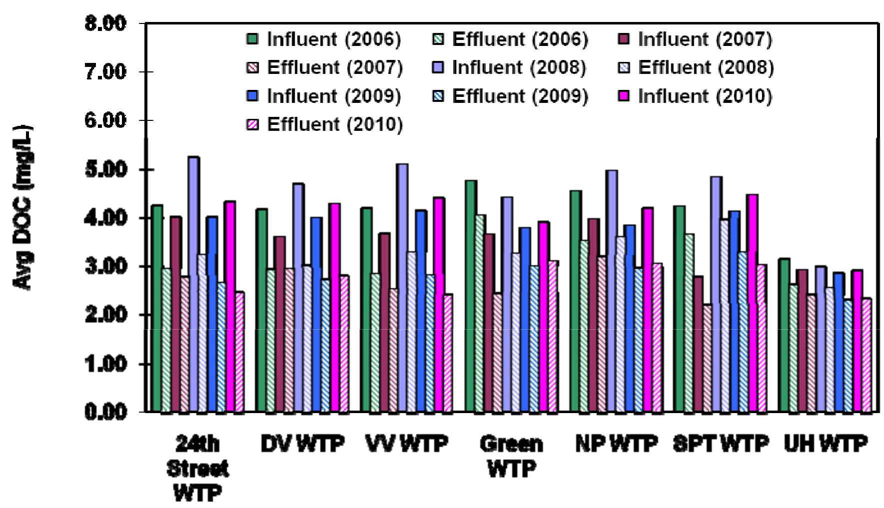
Up-stream reservoirs attenuate DOC

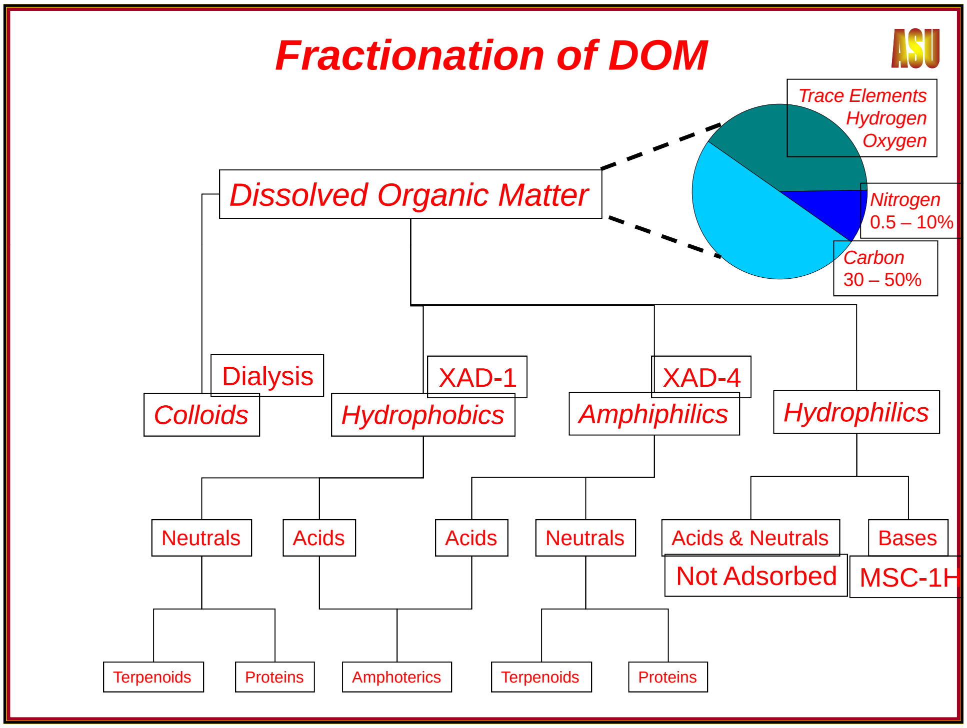


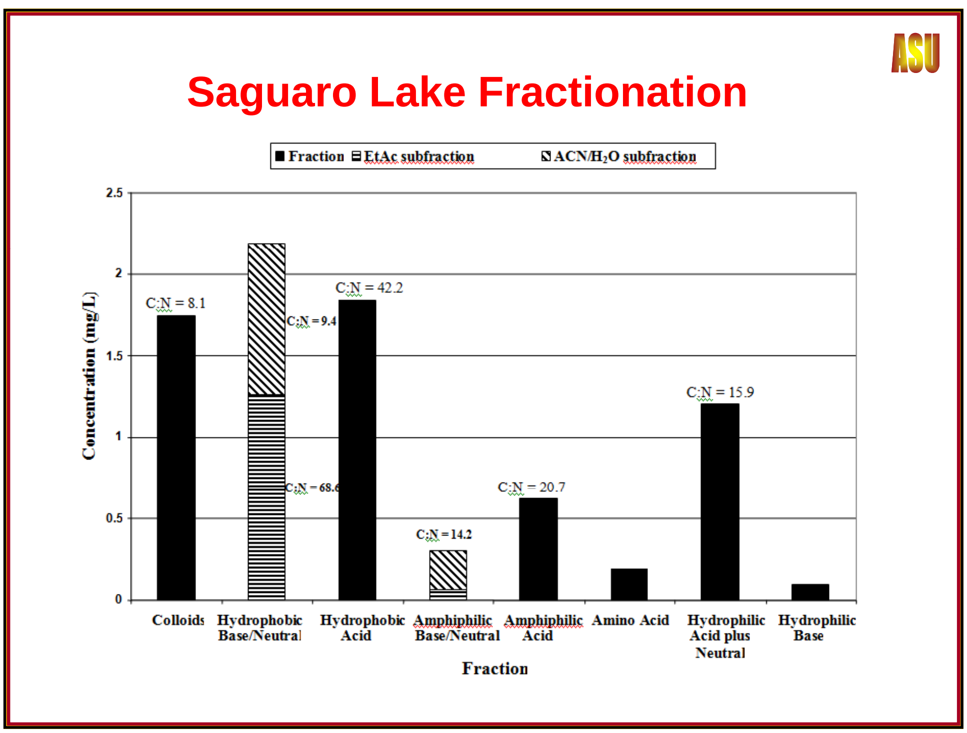
Specific UV Absorbance at 254 nm



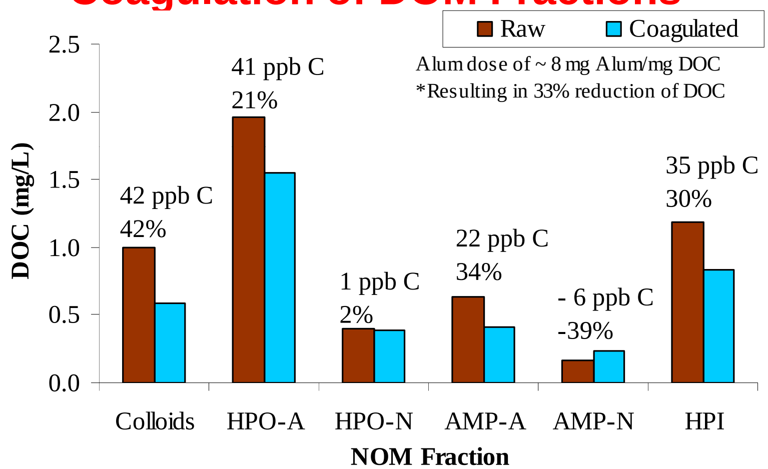
DOC Removal by WTP




Fractionation of DOM
Dissolved Organic Matter
Trace Elements
Hydrogen
Oxygen
Nitrogen
0.5 – 10%
Carbon
30 – 50%
Dialysis
Colloids
XAD-1
Hydrophobics
XAD-4
Amphiphilics
Hydrophilics
Neutrals
Acids
Acids
Neutrals
Acids & Neutrals
Bases
Not Adsorbed
MSC-1H
Terpenoids
Proteins
Amphoterics
Terpenoids
Proteins

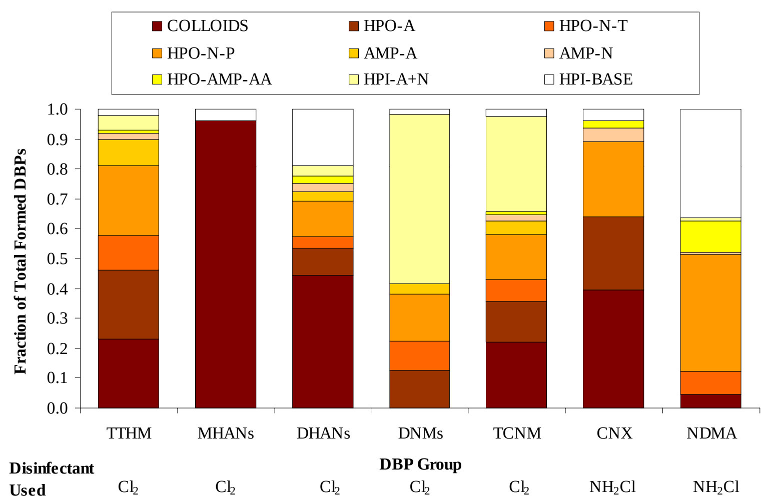

Saguaro Lake Fractionation
Fraction
EtAc subfraction
ACN/H_2O subfraction
Concentration (mg/L)
2.5
2
1.5
1
0.5
0
C:N = 8.1
C:N = 9.4
C:N = 68.
C:N = 42.2
C:N = 14.2
C:N = 20.7
C:N = 15.9
Colloids
Hydrophobic Base/Neutral
Hydrophobic Acid
Amphiphilic Base/Neutral
Amphiphilic Acid
Amino Acid
Hydrophilic Acid plus Neutral
Hydrophilic Base
Fraction

Coagulation of DOM Fractions



- Acid fractions are well removed, known to reduced regulated DBPs
- Colloids are the only Org-N enriched fraction removed

DBP Reconstruction Formation



- Isolate responsible for DBP formation varies with degree of halogenation
- HPI-B (1.8% DON) produces ~35 % of the total NDMA

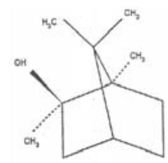
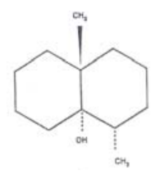
Factors affecting DOC removal

- Disinfection trends have been away from pre-disinfection with chlorine
- Trend has been towards continuous addition of PAC, instead of seasonal
- Coagulation trends have been towards higher doses and conversion to ferric
- Filtration trends have been towards using GAC instead of anthracite and not chlorinating filters
- Several plants now have GAC contactors

To GAC or not

Common Algal T&O Compounds

- Taste threshold ~ 10 ng/L
- Chlorine residual can "mask" odors
- T&O is a worldwide issue affecting the publics "confidence" in drinking waters, regulated

Parameter	MIB (2-methyisoborneol)	Geosmin
Full Name	(1-R-exo)-1,2,7,7-tetramethyl bucyclo-[2,2,1]-heptan-2-o1	tran-1, 10-dimethyl-trans-9-decalol
Molecular Formula	$C_{11}H_{20}O$	$C_{12}H_{22}O$
Molecular Weight	168 g-mole^{-1}	182 g-mole^{-1}
Boiling Point	197 °C	165 °C
Aqueous Solubility	195 mg/L	150 mg/L
K_{ow}	3.13	3.7
Henry's Law Constant	5.76×10^{-5} atm m^3-mole^{-1}	6.66×10^{-5} atm m^3-mole^{-1}
Structure		

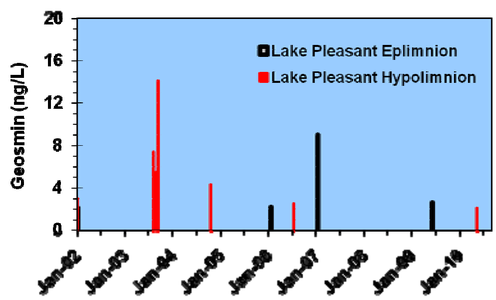
Source: (Pirbazari et al. 1992)

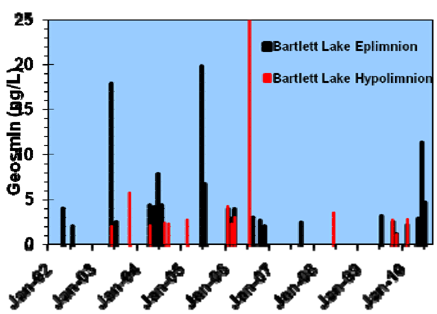
The effect of water source and chlorine and chloramine odorants in drinking water on earthy and musty odour intensity
Jane Curren, Zhengping Wang, Jose Matud, Erin D. Mackey and Mel Suffet

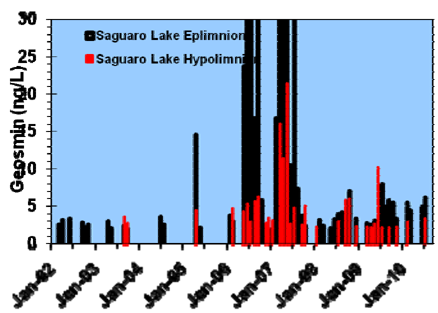
The Journal of Water Supply: Research and Technology – AQUA
Had a special issue on taste and odors in December 2009

European reassessment of MIB and geosmin perception in drinking water
P. Piriou, R. Devesa, M. De Lalande and K. Glucina

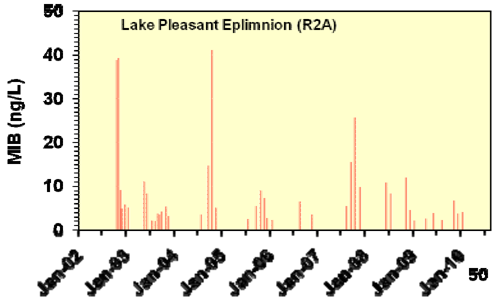
Geosmin Data

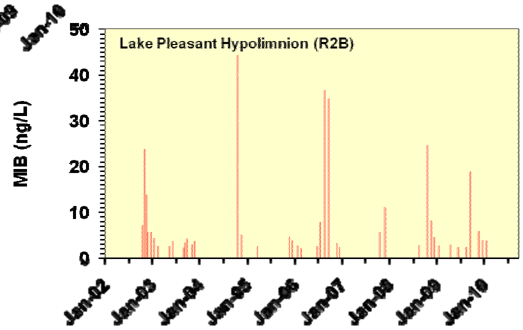






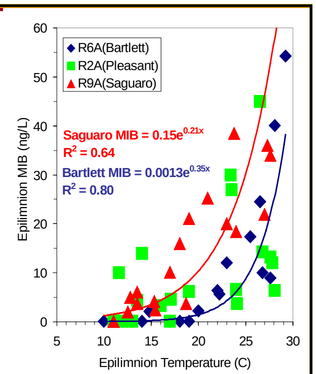
MIB Data – Lake Pleasant

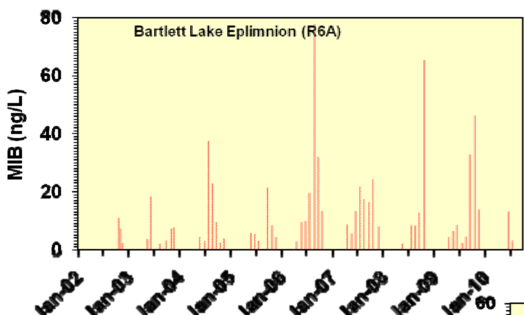


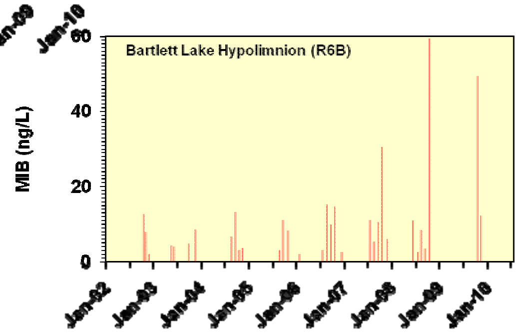


8/30/10 Levels:
- MIB < 2ng/L
- Geosmin < 2 ng/L
- Cyclocitral = 4 ng/L

MIB Data – Bartlett Lake

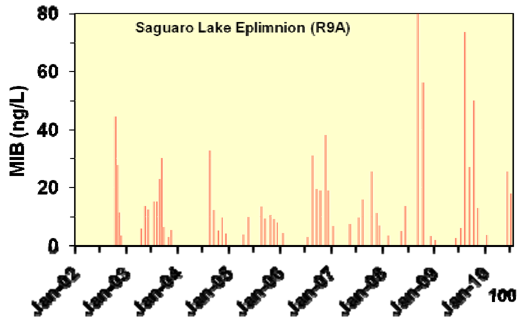






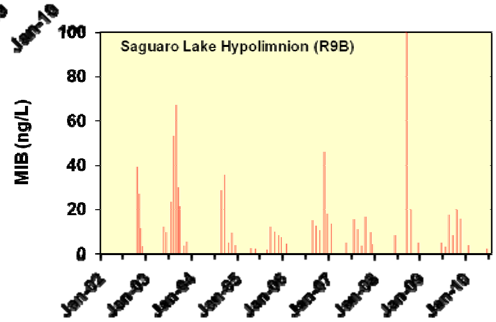
8/30/10 Levels:
- MIB = 2ng/L
- Geosmin < 2 ng/L
- Cyclocitral < 2 ng/L

MIB Data – Saguaro Lake



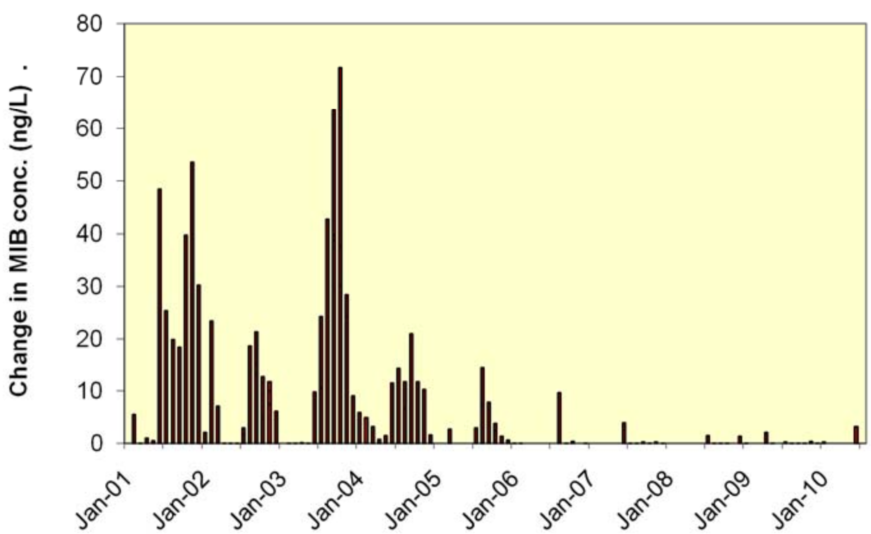
8/30/10 Levels:

- MIB = 50ng/L (15)
- Geosmin = 6 ng/L
- Cyclocitral < 2 ng/L

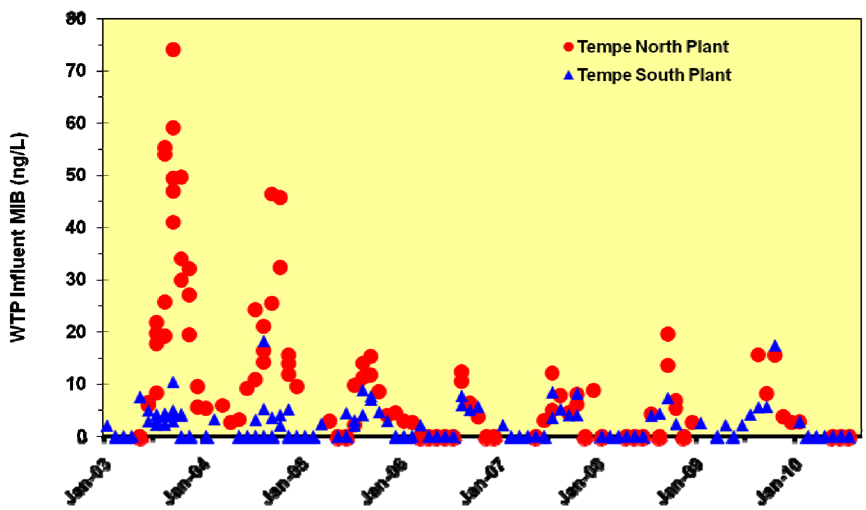


Cells die and settle into darkness

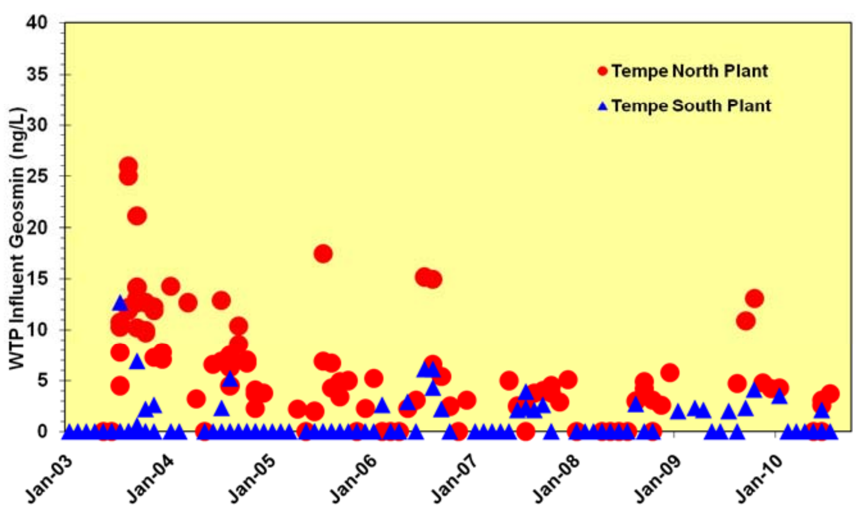
MIB Growth in AZ canal from below X-Con to DV Inlet



MIB levels higher in AZ Canal system compared against South Canal system

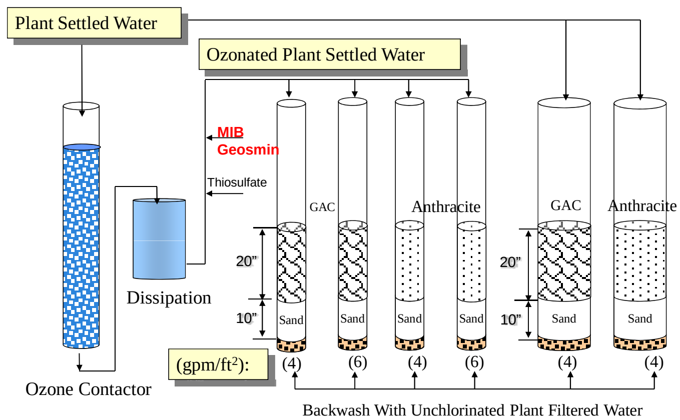


Geosmin Trends

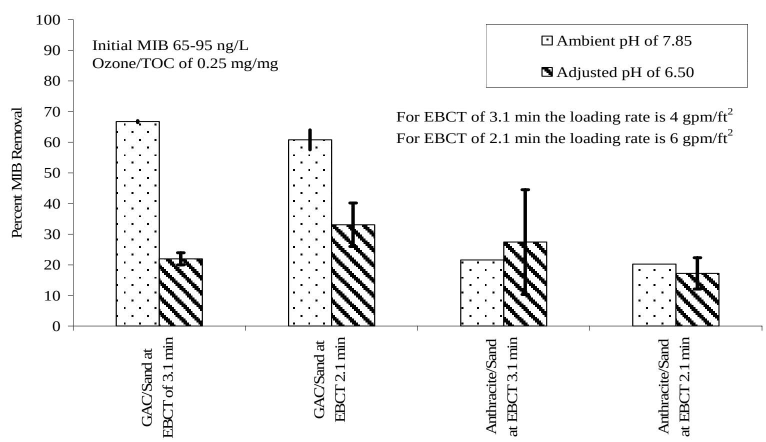


Does Biological Filtration Remove T&O?

Westerhoff, P., Summers, R.S., Chowdhury, Z., Kommineni, S. "Ozone-enhanced biofiltration for geosmin and MIB removal", Final Report (#90175), AwwaRF, Denver, CO, 188 pp. (2005)

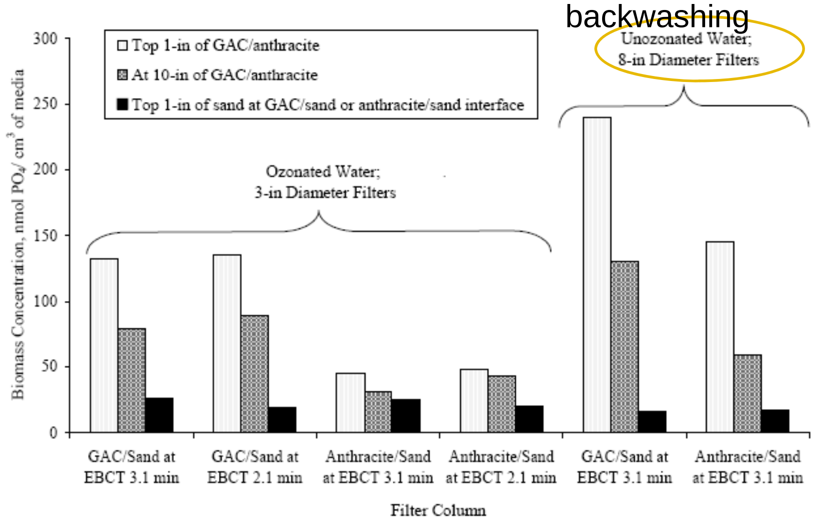


Shifts in water quality affected MIB Removal



Biomass Density varies with depth

Due to less efficient backwashing



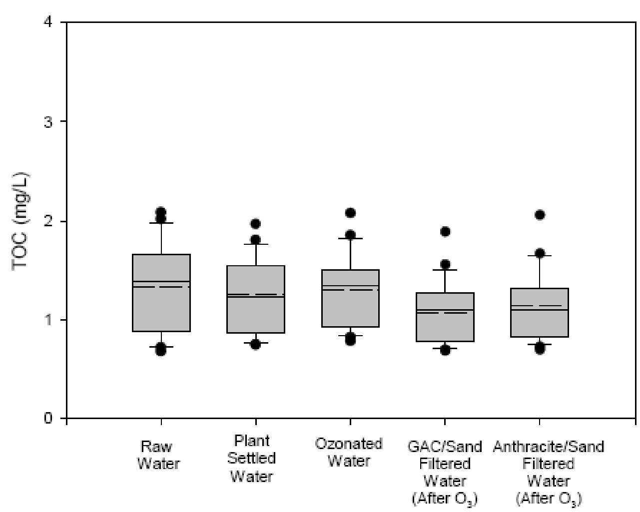


Figure 5.6 TOCs measured for raw, plant settled, ozonated settled and pilot filtered waters (Chandler pilot plant). The solid line within the box indicates the median and the dashed line indicates average. The whiskers indicate 10th and 90th percentile and the circles (beyond the whiskers) indicate outliers.

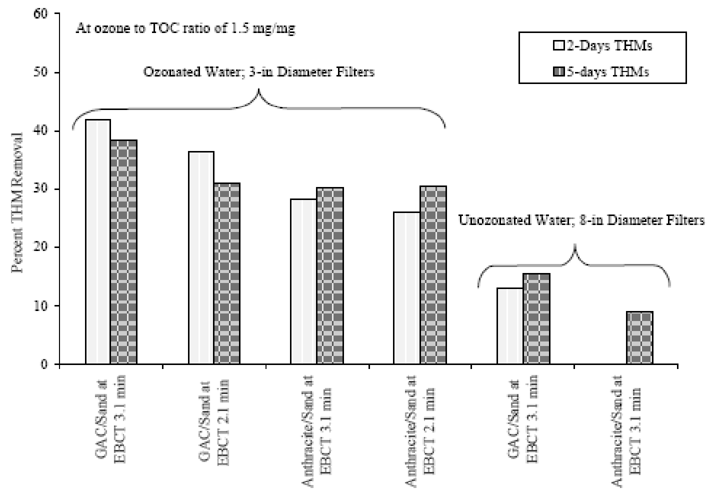
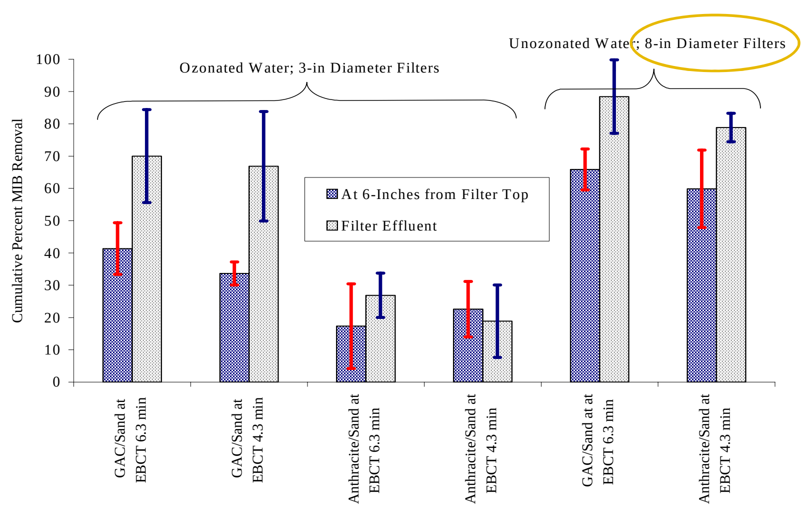


Figure 5.9 THM precursor removals in filters that received ozonated (at ozone/TOC of 1.5 mg/mg) and unozonated settled waters (Chandler pilot plant)

GAC have higher removals (data is normalized to biomass concentrations)



Longer EBCTs improved removal (not all data shown)

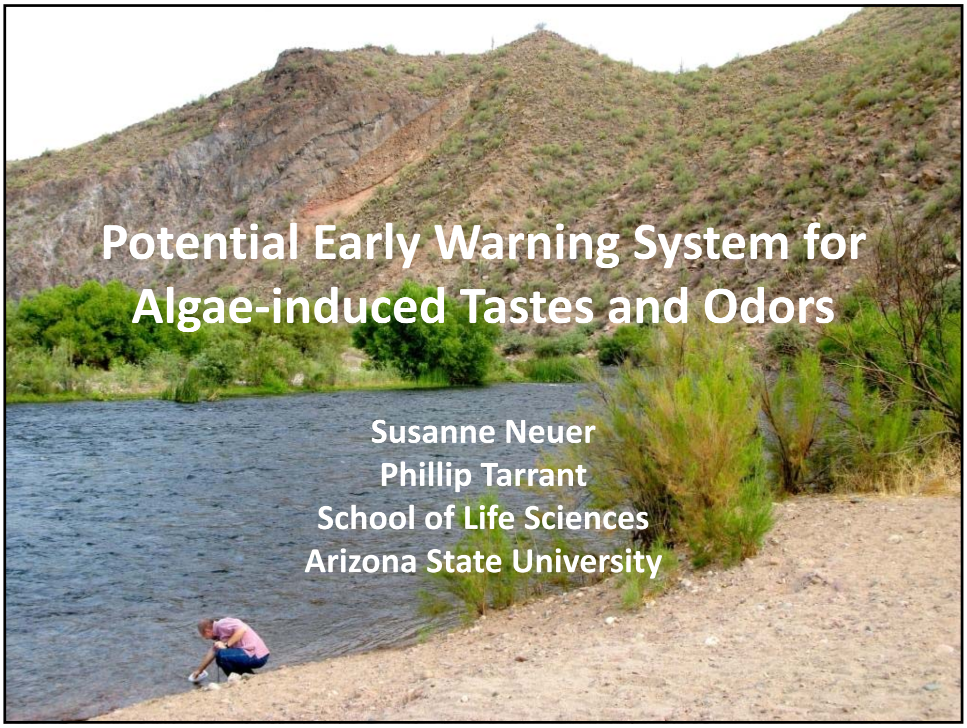
Quiz

- Why is MIB higher this week at these WTPs compared to 2 weeks ago?

Location	MIB on 8/30	MIB on 9/15
24th Street WTP Raw Treated	 7 4	 13 5
Tempe North WTP Raw Treated	 7 3	 17 5
Tempe South WTP Raw Treated	 4 3	 7 3

T&O Trends

- Saguaro Lake has consistently produced highest levels of T&O
- Verde River can produce T&O below Bartlett Reservoir
- Minimal production of T&O in canals over past ~ 5 years
- Prior > 50 ng/L MIB or geosmin could form in canals



Technology Investigation

- AWWA (Water Research Foundation) sponsored project.
- Intended to test the potential of new technology to identify the presence of taste and odor causing organisms and provide early warning.

Methods

- Field samples collected August – October 2009
- Three primary sampling sites supplemented by secondary sites (Westerhoff program)
- Epifluoresence cell counts of filtered samples
- FlowCam semi-automated particle counts
- MIB and geosmin laboratory analysis

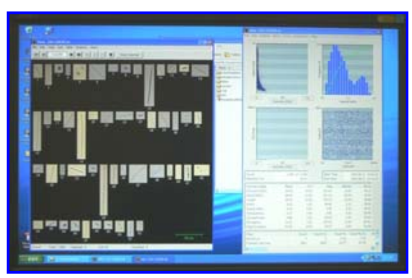
Sampling Sites

Digital Analysis

- Flow cytometry combined with digital imaging and software parameter analysis.
- New processes compared with existing microscopy methods.

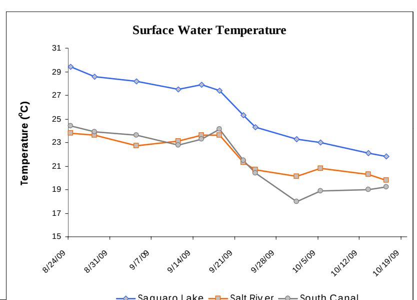
FlowCAM® System

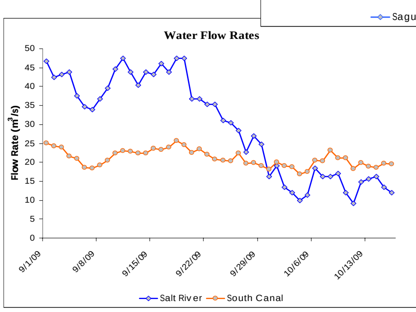
- Fluid Imaging Technologies Inc.
- Processes samples by drawing water through a laser monitored flow chamber.
- Laser triggers photo-multiplier tubes (>650 nm and 575 nm).
- Fluorescing particles are then imaged with a digital camera.
- Visualspreadsheet™ software processes and categorizes particles based on multiple parameters.

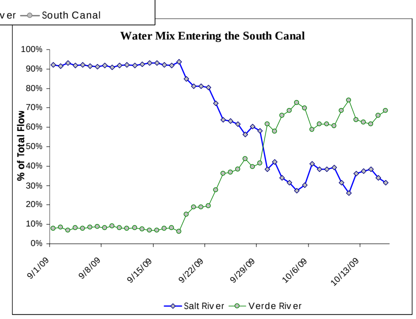


FlowCAM® System

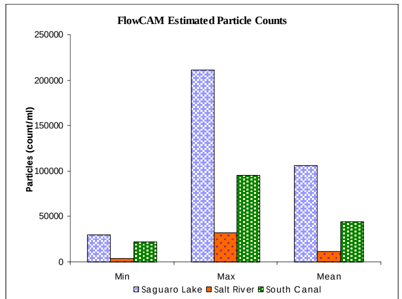
Environmental Conditions

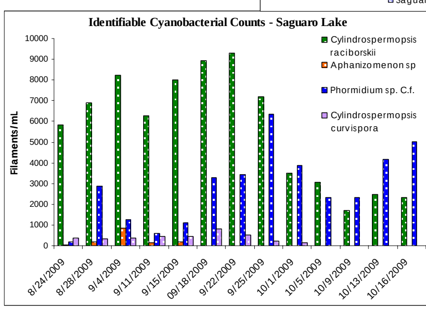


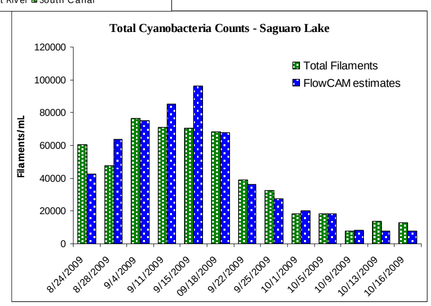




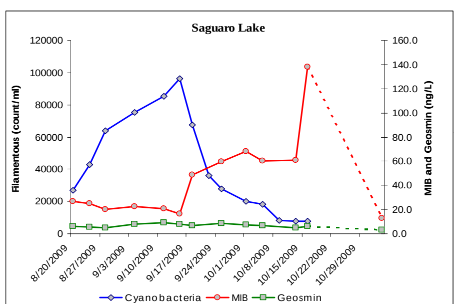
Results

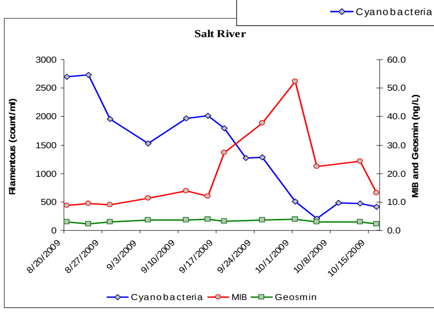


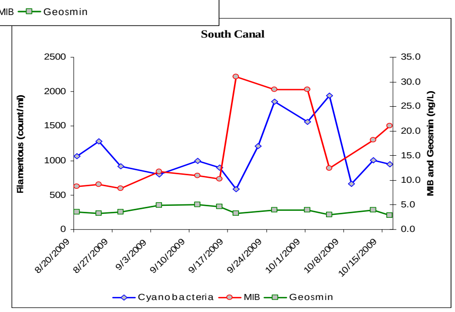




Results







Conclusions

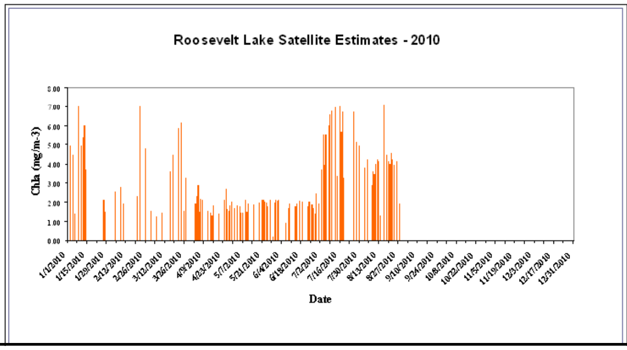
- MIB and geosmin releases are influenced by several factors
- Organism interaction, nutrients and environmental conditions may combine to produce toxins
- Good agreement between microscopy and particle analyzer
- Tracking cyanobacteria populations may provide early warning of MIB and geosmin peaks

Acknowledgements

- Project funding – American Water Works Association (AWWA)
- FlowCam loan, training and support – Fluid Imaging Technologies
- Chemical analyses – Paul Westerhoff, ASU

Update on Satellite work in Neuer lab

- Tarrant P., J. Amacher and S. Neuer. 2010. Assessing the potential of MERIS and MODIS data for monitoring total suspended matter in small and intermediate sized lakes and reservoirs. Water Resources Research. *In press*.
- Master's thesis (Shikha Gupta): " The application of MERIS full resolution data to estimate algal blooms in central Arizona reservoirs"
- **http://neuer.lab.asu.edu/ click on "Data"**



Potential Influences of Climate Change on Arizona Water Supply

Andrew Ellis

ASU School of Geographical Sciences & Urban Planning

Regional Water Quality Workshop

September 17, 2010

Phoenix, Arizona

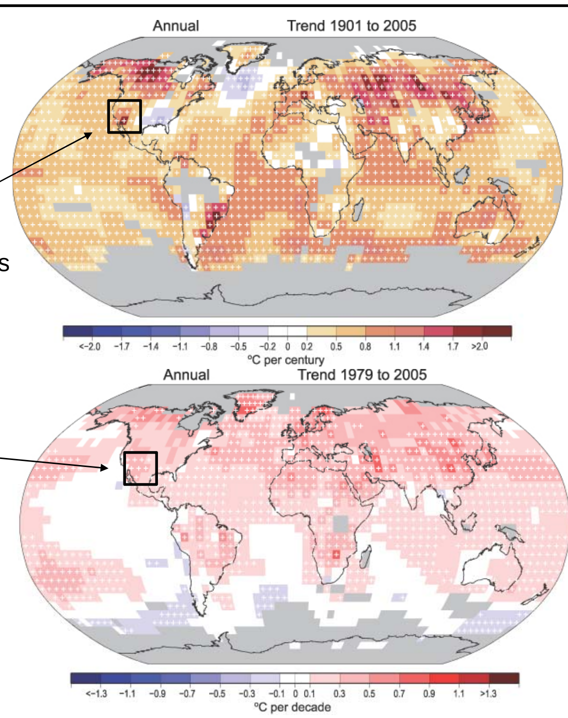
Historical Trends: Air Temperature

1901-2005
+0.08 to +0.2ºC/decade

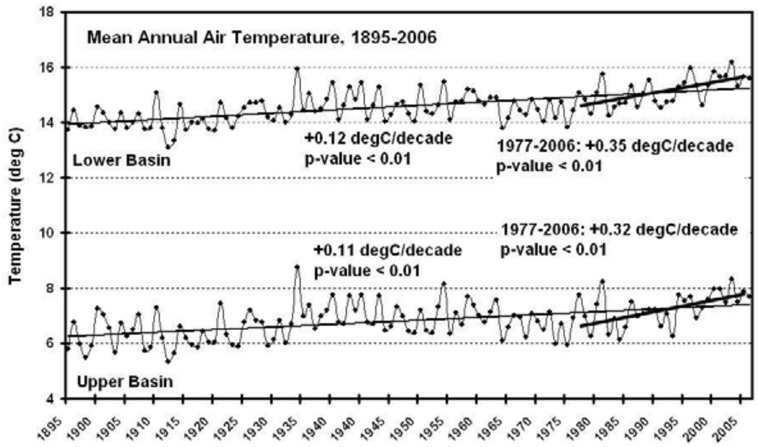
• increase through early 1940s
• slight decrease through 1970s

1979-2005
+0.1 to +0.5ºC/decade

• monotonic, positive trend since early 1980s

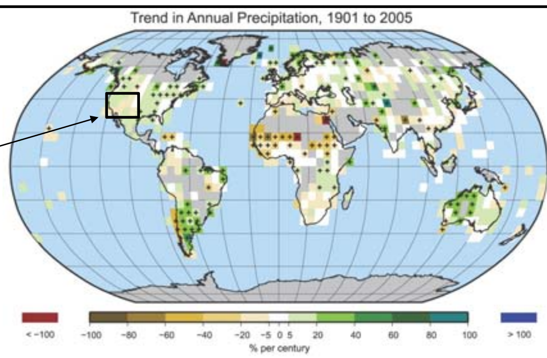


Historical Time Series: Colorado River Basin Air Temperature



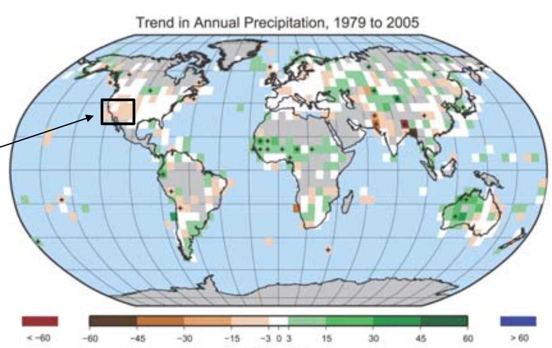
Historical Trends: Precipitation

1901-2005
+2 to -2% per decade

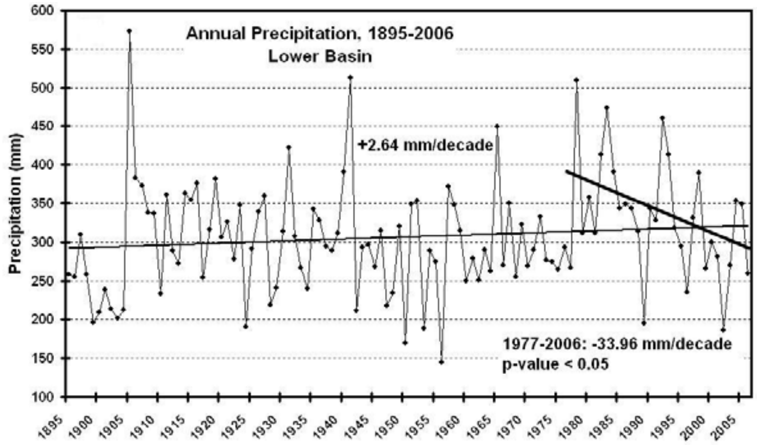


No significant long-term trend

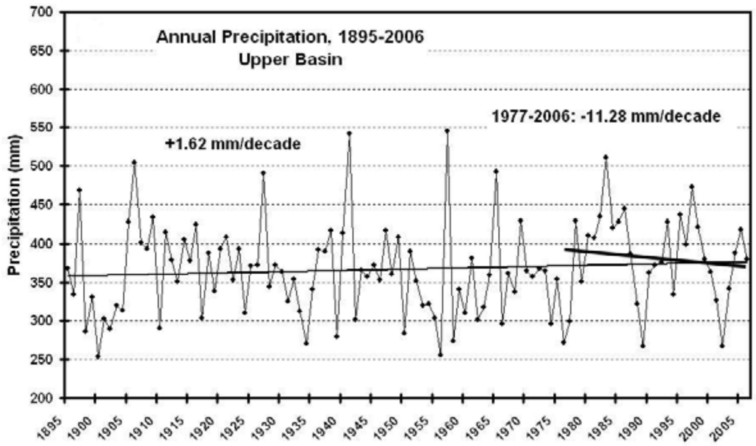
1979-2005
-3 to -15% per decade



Historical Time Series: Lower Colorado River Basin Precipitation

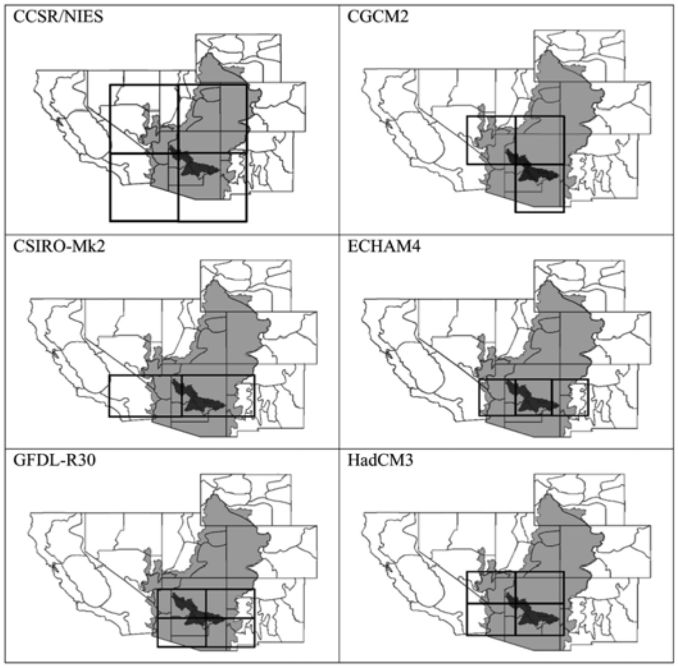


Historical Time Series: Upper Colorado River Basin Precipitation

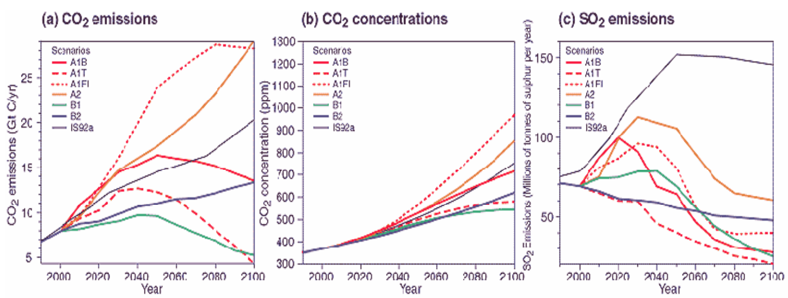


Global Climate Models (GCMs)

- coarse resolution
- downscaling
- 24 GCMs worldwide

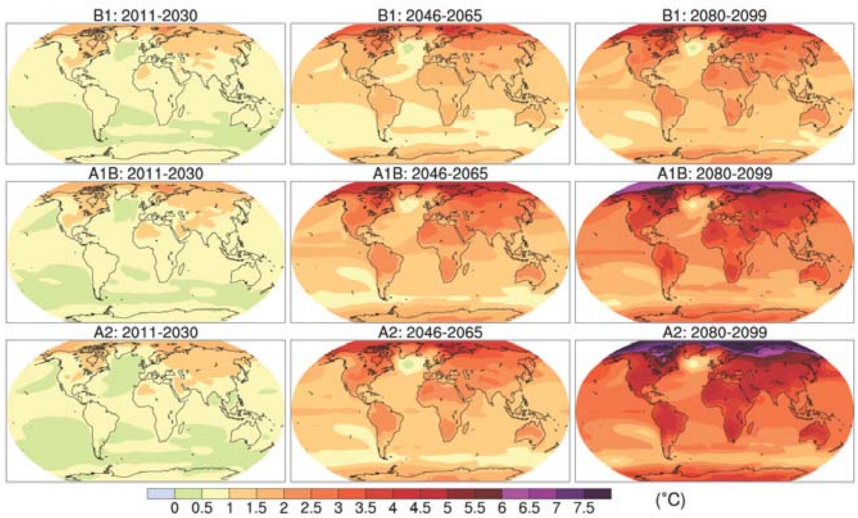


Intergovernmental Panel on Climate Change Greenhouse Gas Scenarios



4 families of GHG "storylines" (40 total) – no likelihood probabilities

Intergovernmental Panel on Climate Change
GCM-GHG Air Temperature Projections

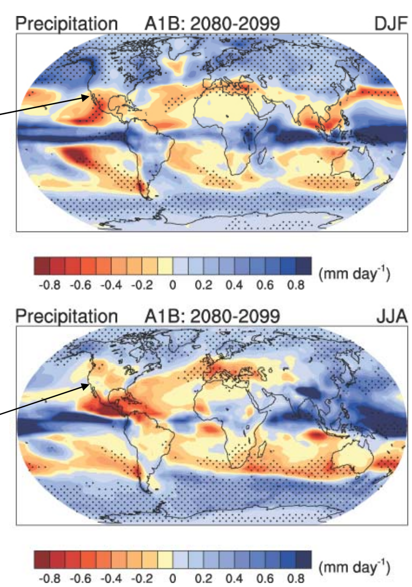


Year 2020
+0.5 to +1.5°C

Year 2055
+1.5 to +3°C

Year 2089
+2.5 to +5°C

Intergovernmental Panel on Climate Change
GCM-GHG Precipitation Projections



Winter: 0 – 27 mm decline

Precipitation decrease “likely” in both winter and summer: more than 66% of GCM-GHG simulations

Summer: 0 – 10 mm decline

Intergovernmental Panel on Climate Change GCM-GHG Climate Projections Downscaled to Colorado River Basin

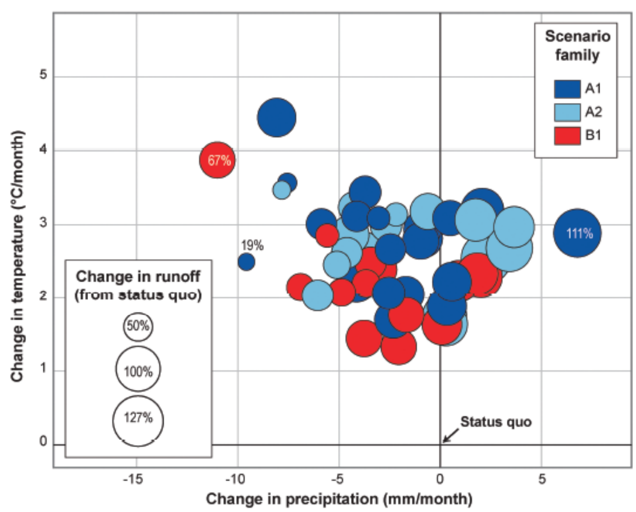
- Over last 25 years, at least at least 9 major studies of the potential impacts of future climate change on runoff within the Colorado River Basin
- All suggest a trend to less runoff in the future in response to warmer and drier conditions, the certainty of which is based on increased evapotranspiration from warming

TABLE 5-1. Projected Changes in Colorado River Basin Runoff or Streamflow in the Mid-21st Century from Recent Studies

Study	*GCMs (runs)*	*Spatial Scale*	*Temperature*	*Precipitation*	*Year*	*Runoff (Flow)*	*Risk Estimate*
Christensen et al. 2004	1 (3)	VIC model grid (~8 mi)	+3.1°F	-6%	2040–69	-18%	Yes
Milly 2005, replotted by P.C.D. Milly	12 (24) (~100–300 mi)	GCM grids —	—		2041–60	-10 to -20% 96% model agreement	No
Hoerling and Eischeid 2006	18 (42)	NCDC Climate Division	+5.0°F	~0%	2035–60	-45%	No
Christensen and Lettenmaier 2007	11 (22)	VIC model grid (~8 mi)	+4.5°F (+1.8 to +5.0)	-1% (-21% to +13%)	2040–69	-6% (-40% to +18%)	Yes
Seager et al. 2007*	19 (49)	GCM grids (~100–300 mi)	—	—	2050	-16% (-8% to -25%)	No
McCabe and Wolock 2008	—	USGS HUC8 units (~25–65 mi)	Assumed +3.6°F	0%	—	-17 %	Yes
Barnett and Pierce 2008*	—	—	—	—	2057	Assumed -10% to -30%	Yes

Intergovernmental Panel on Climate Change GCM-GHG Climate Projections Downscaled to Salt/Verde Basins

- 2040-2069 conditions v. 1961-90
- 50 GCM-GHG combinations
- 19-123% of historical average
- mean = 66% of historical average
- historical 30-year runoff means: 82-118%



Summary: Potential Impacts of Climate Change on Surface Water Supply

- Region has warmed over the past century; rapidly in recent decades
- Regional precipitation has changed little over the past century; recent drought of early 2000s evidenced in a trend back to long-term mean
- Regional climate projected to warm during remainder of 21^{st} century – little uncertainty
- Much uncertainty in projected precipitation during rest of the century – majority of GCM-GHG combinations suggest less precipitation
- Virtually all local-to-regional hydrologic projections (GCM → downscaling → hydrologic modeling) indicate less runoff (-10% to -20%), but with a large range of potential outcomes (+23% to –45%)
- Level of certainty in runoff projections associated with warming…yet we know that runoff is largely controlled by precipitation…and runoff on many regional basins has not declined in recent decades despite the significant warming

Potential Influences of Climate Change on Arizona Water Supply

Andrew Ellis

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ASU School of Geographical Sciences & Urban Planning

Regional Water Quality Workshop

September 17, 2010

Phoenix, Arizona

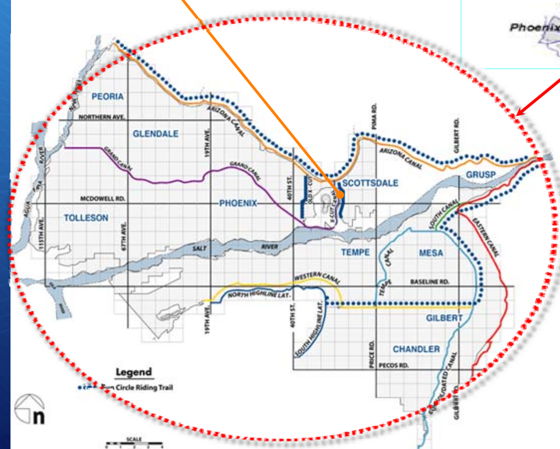
Optimizing Source Waters for Disinfection By-Product Control

Presented by: Jacelyn Rice

Background

- Meeting DBP's during summer months
- Salt River Source Water accessed for hydropower generation
- Seasonal changes
- Frequently higher NOM concentration in Salt River (compared to Verde River)

City of Tempe JGM Water Treatment Plant



http://azorionconstruct.com/Projects.html http://www.racelab.com/CanalMap.gif http://www.watershedmonitor.com/pdf/lowvrgswws.pdf

Case Study Site

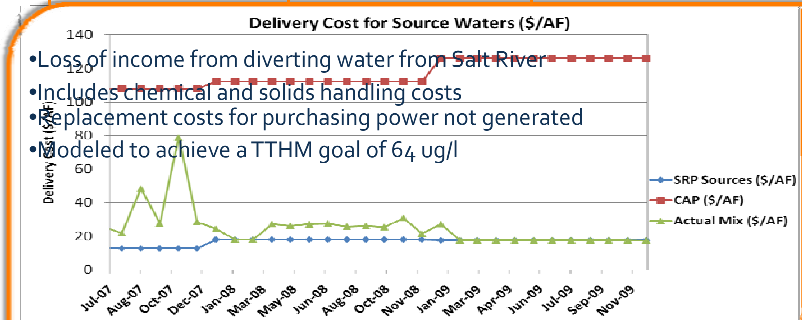
City of Tempe JGM Water Treatment Plant

- 50 MGD
- Arizona Canal Influent

Treatment Train:

Embedded Costs

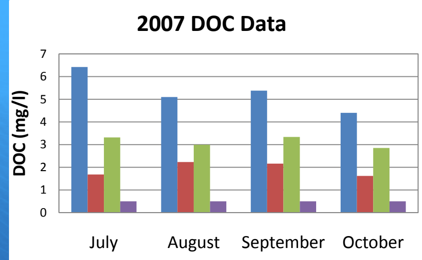
Delivery Cost + Treatment Cost + Off-set Hydro = Total Cost

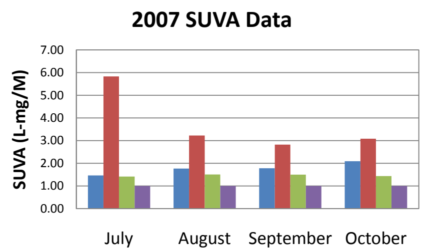


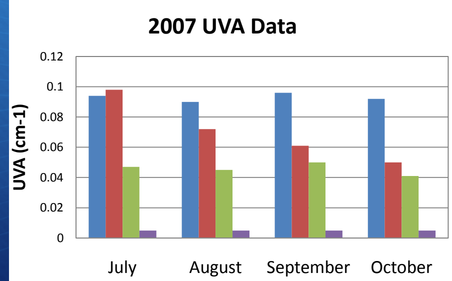
- Loss of income from diverting water from Salt River
- Includes chemical and solids handling costs
- Replacement costs for purchasing power not generated
- Modeled to achieve a TTHM goal of 64 ug/l

Results

Water Quality Comparison



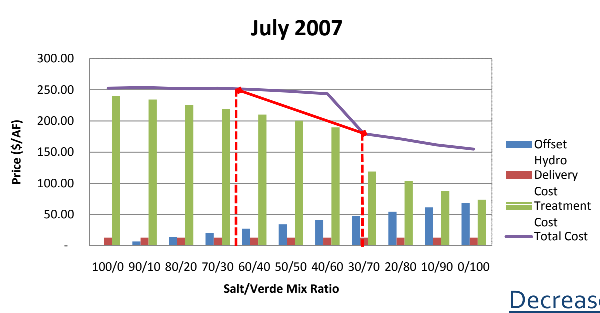




Legend:

- Salt River
- Verde River
- CAP Water
- Groundwater

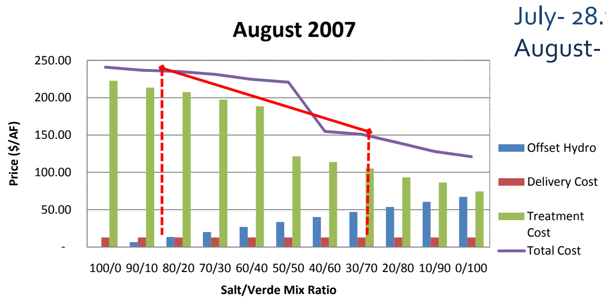
Water Treatment Costs Analysis



Decrease in Total Cost

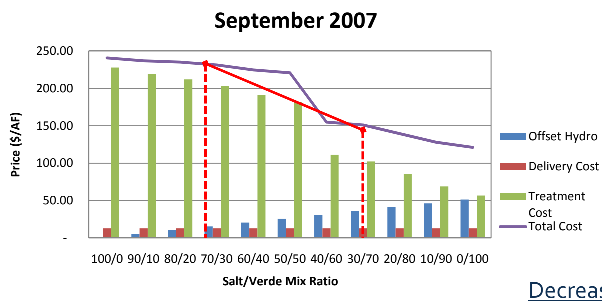
July- 28.7%

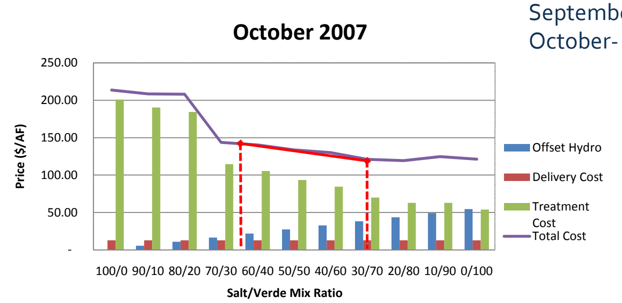
August- 49.9%



*Scenarios were ran to meet a TTHM Goal of 64 ug/l

Water Treatment Costs Analysis





Decrease in Total Cost:
September- 25.6%
October- 14.7%

*Scenarios were ran to meet a TTHM Goal of 64 ug/l

Cost Breakdown:

		DELIVERY COST		OFF-SET HYDRO		TREATMENT COST				TOTAL COST	
						Chemical		Solids Handling			
		$/AF	$/MG	$/AF	$/MG	$/AF	$/MG	$/AF	$/MG	$/AF	$/MG
July	Actual Mix	$12.86	$39.47	$-	$-	$67.59	$207.42	$135.17	$414.85	$251.57	$772.97
	Preferred Mix	$12.86	$39.47	$35.95	$110.33	$43.56	$133.68	$87.11	$267.35	$179.48	$550.82

- 29% decrease in total cost
- Solids and handling estimation

Conclusion

- Average Total Cost Savings (July-October 2007)
  - 30%
  - $82/AF
  - $154/MG
- Change in total cost vary greatly
  - DOC Concentrations
  - Difference in values between the two sources
- "Preferred" water is cost effective under these conditions:
  - DOC Range
    - Salt River: 4-7 mg/l
    - Verde River: 2-3.5 mg/l
  - Difference in Values
    - Verde at least 50% lower than Salt

Acknowledgements

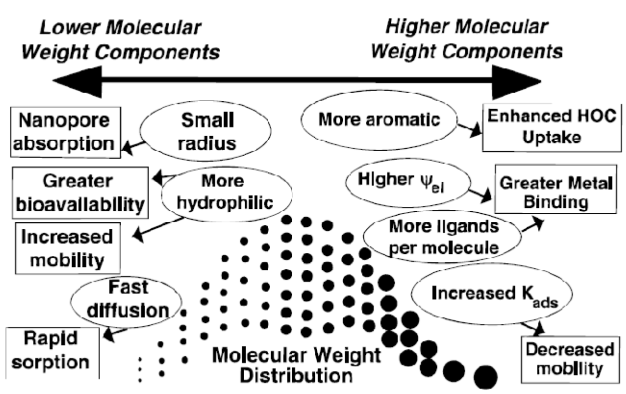
- Salt River Project
- City of Tempe for support at JGM Water Treatment Plant
- *Other partners that support the Regional Water Quality Project*

Strategies to remove and monitor organic matter

Chao-An Chiu

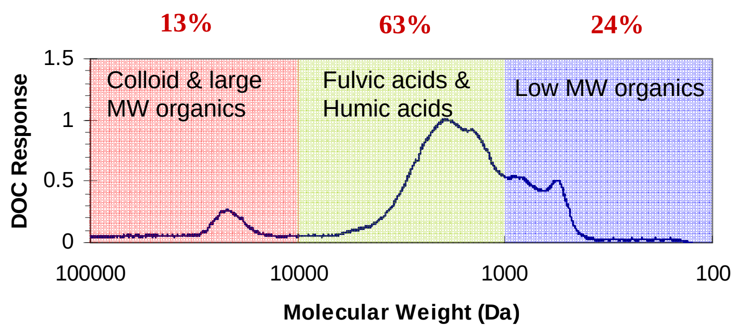
Background

Molecular Weight Distribution



Cabaniss, S. E., Zhou, Q., et al. (2000). A Log-Normal Distribution Model for the Molecular Weight of Aquatic Fulvic Acids. Environmental Science & Technology, 34(6): 1103-1109.

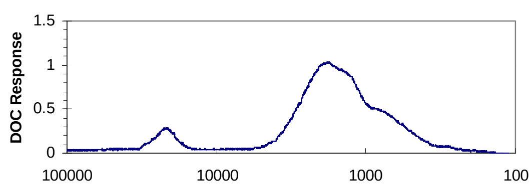
DOM MWD in Natural Water



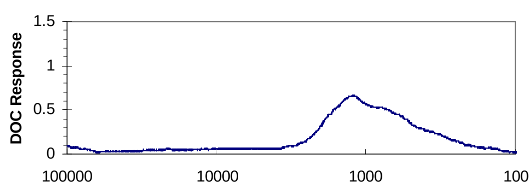
Medium and low-MW organic matter is the dominant component

DOM MWD in Drinking Water

WTP Influent



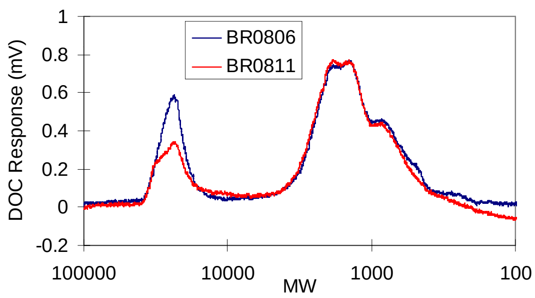
WTP Effluent



Drinking water treatment processes can effectively remove the high-MW organic matter

SEC-DOC for Raw Water Monitoring

Mesa Brown Road WTP: CAP Canal



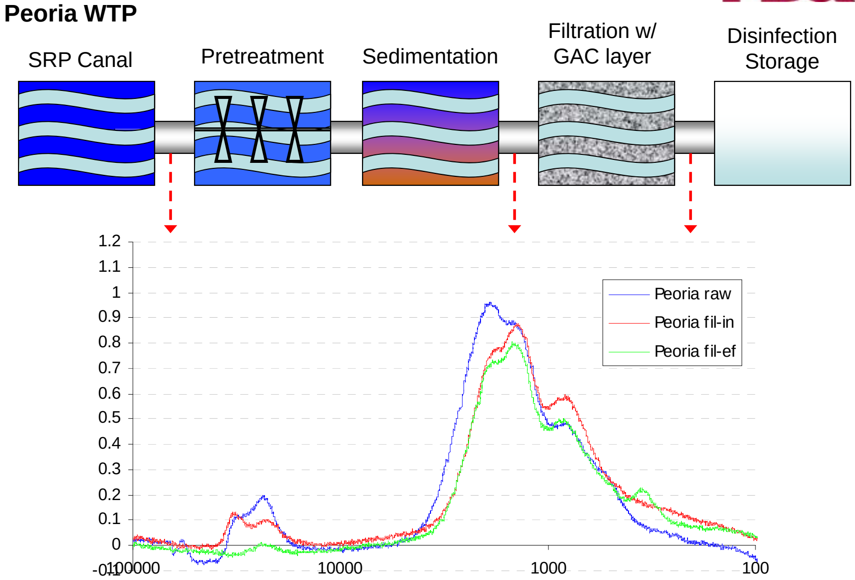
BR0806 TOC=4.4 mg/L

BR0811 TOC=3.7 mg/L

- ***SEC-DOC help to understand size distribution of raw waters in terms of facility operation.***

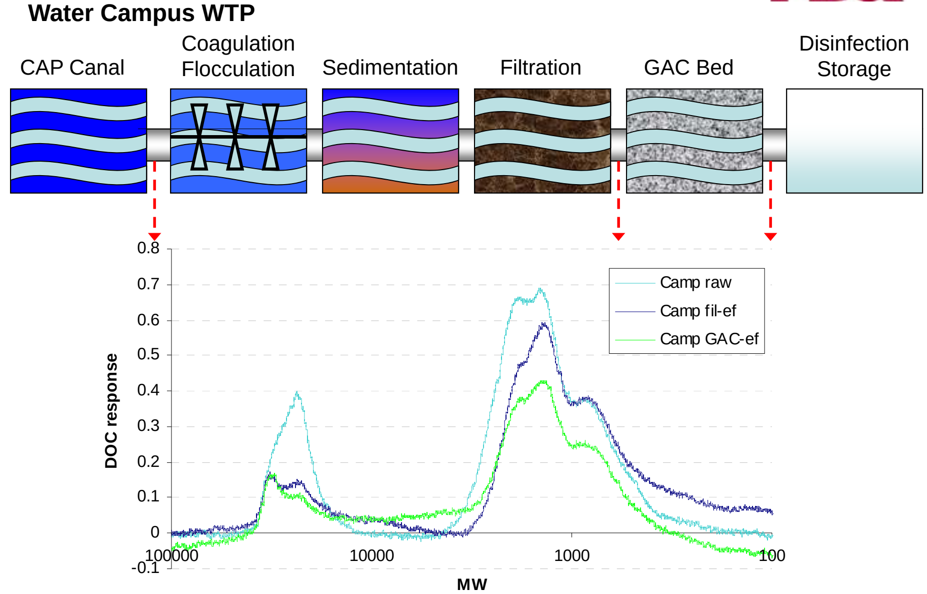
GAC filtration

Peoria WTP



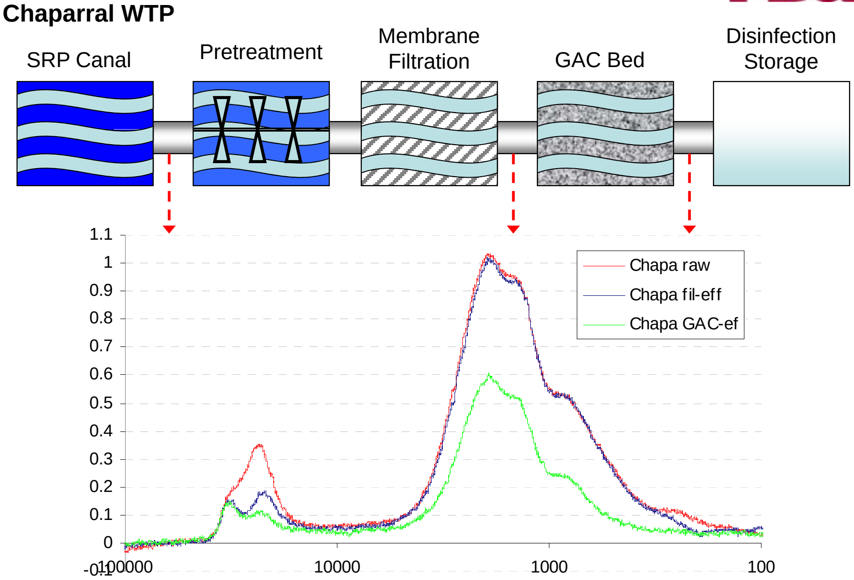
Deep Bed GAC adsorber with C/F/S

Water Campus WTP

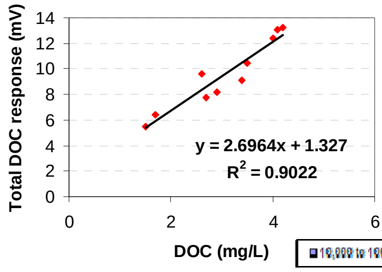


Deep Bed GAC adsorber without C/F/S

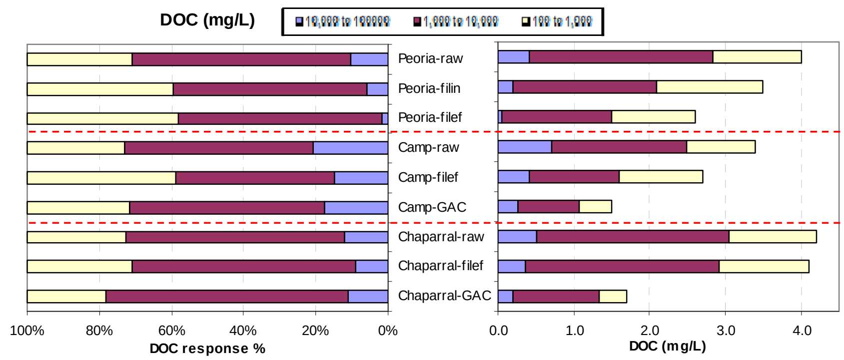
Chaparral WTP



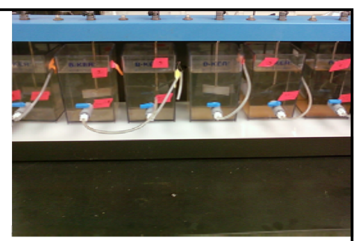
SEC-DOC Across Treatment Processes

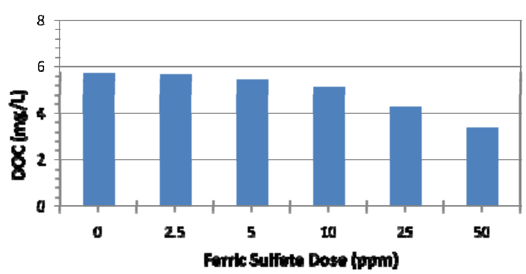


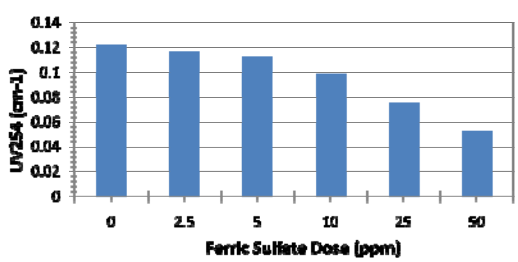
- *SEC-DOC results fit DOC concentrations well.*
- *Deep bed GAC can remove medium/low-MW organics.*

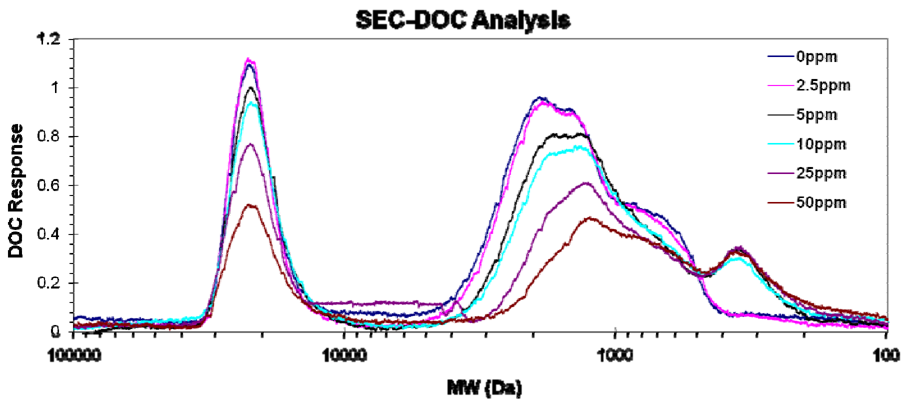


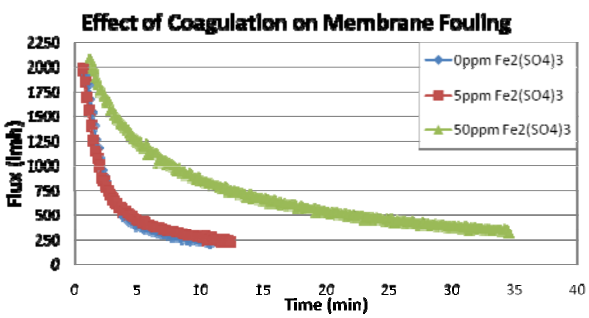
Jar Testing :
Chaparral WTP Raw Water
Coagulant: Ferric Sulfate (43%)

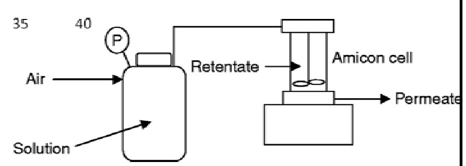


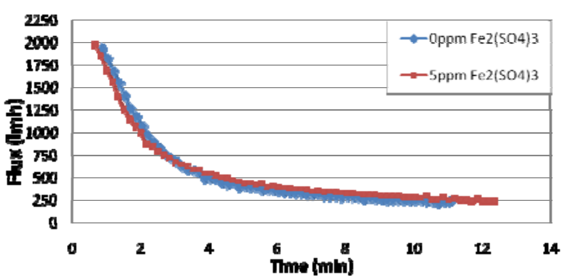





SEC-DOC Analysis
DOC Response
MW (Da)
1.2
1
0.8
0.6
0.4
0.2
0
100000
10000
1000
100
0ppm
2.5ppm
5ppm
10ppm
25ppm
50ppm


Effect of Coagulation on Membrane Fouling
Flux (lmh)
Time (min)
2250
2000
1750
1500
1250
1000
750
500
250
0
0
5
10
15
20
25
30
35
40
0ppm Fe2(SO4)3
5ppm Fe2(SO4)3
50ppm Fe2(SO4)3


P
Air
Solution
Retentate
Amicon cell
Permeate


Flux (lmh)
Time (min)
2250
2000
1750
1500
1250
1000
750
500
250
0
0
2
4
6
8
10
12
14
0ppm Fe2(SO4)3
5ppm Fe2(SO4)3

Summary of SEC-DOC for Organic Monitoring

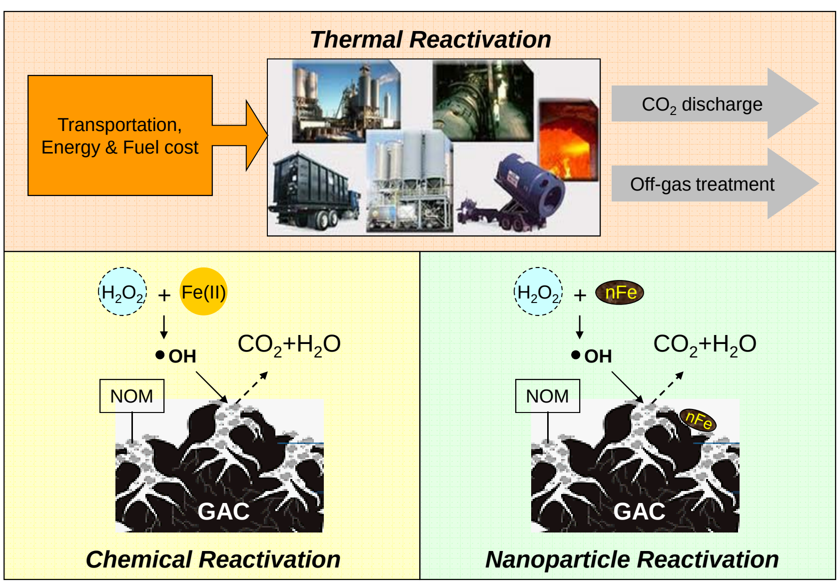
- SEC-DOC can be used to monitor change of molecular weight distribution of raw waters.
- SEC-DOC monitoring across water treatment processes can help to understand the MW removal preference along treatment train.
- Coagulation /sedimentation/ filtration remove colloids and large MW organics.
- GAC filtration removes colloids and large MW organics.
- Deep bed GAC adsorber removes HA, FA, and low-MW organics further.
- Coagulation could reduce membrane fouling by remove colloids and part of medium MW organics.

In-situ GAC Regeneration Technique by nFe (prepared from Ferric chloride)

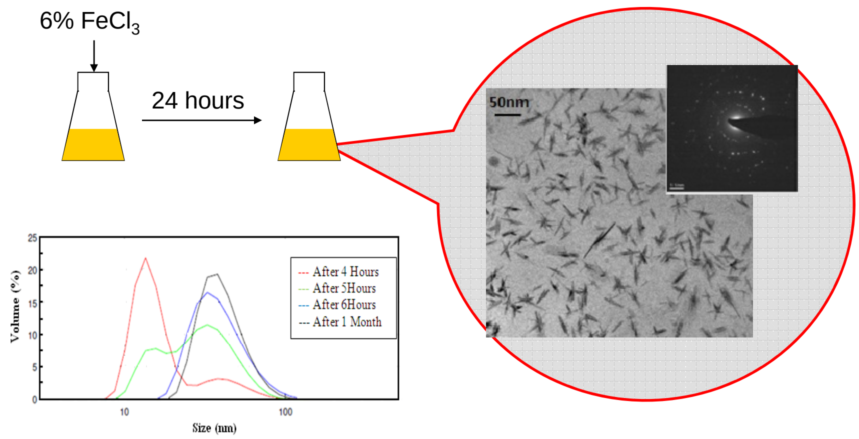
In-situ GAC Regeneration Technique

- GAC contactor needs to be replaced with virgin/regenerated GAC every 6~9 months.
- Traditional thermal-regeneration for spent-GAC is energy-consuming and lose ~10% of carbon during regeneration.
- Spent-GAC need to be transferred to regeneration facility by transportation.
- Sustainable and environment-friendly GAC regeneration technique can improve the applicability for drinking water treatment.

Spent-GAC Reactivation Technology

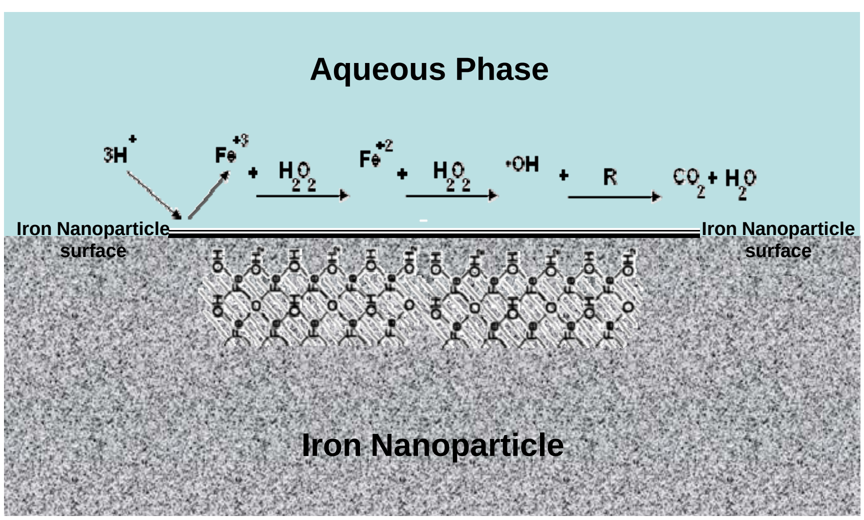


Iron-nanoparticles Preparation

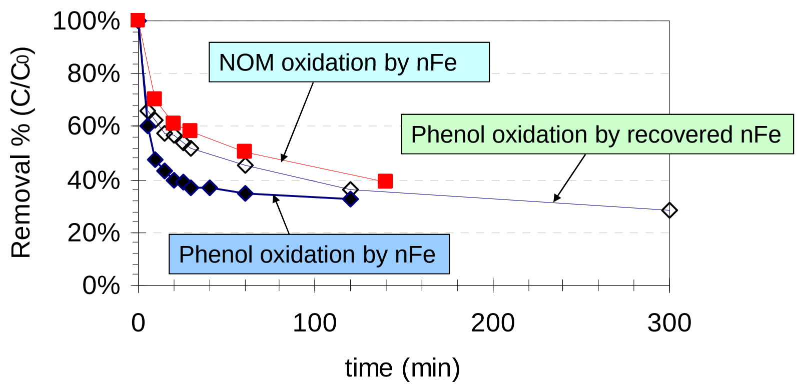


nFe: FeO(OH), ~55 nm, formed and stable after 6 hours of preparation and can last for months.

Fenton-like reaction for OC degradation

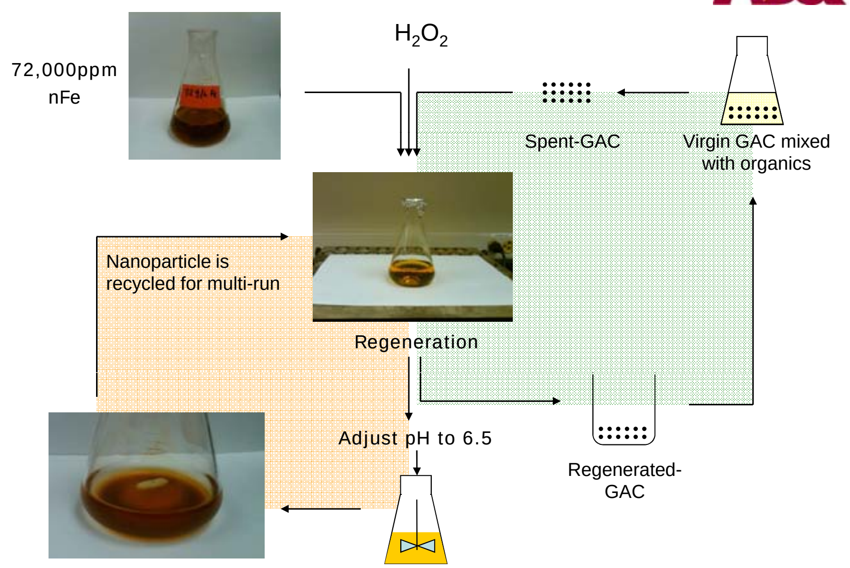


Test for Organic Degradation by nFe/H_2O_2

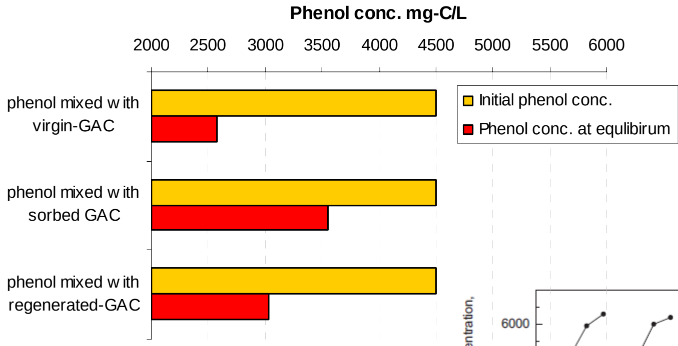


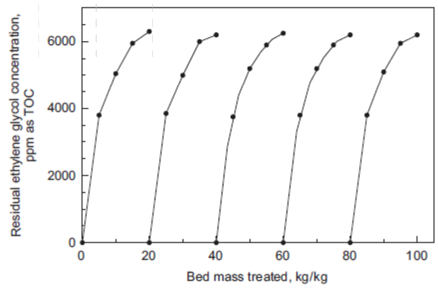
nFe can be used for phenol and NOM mineralization and recycled effectively for multi-run

Batch Test for Sorbed-GAC regeneration

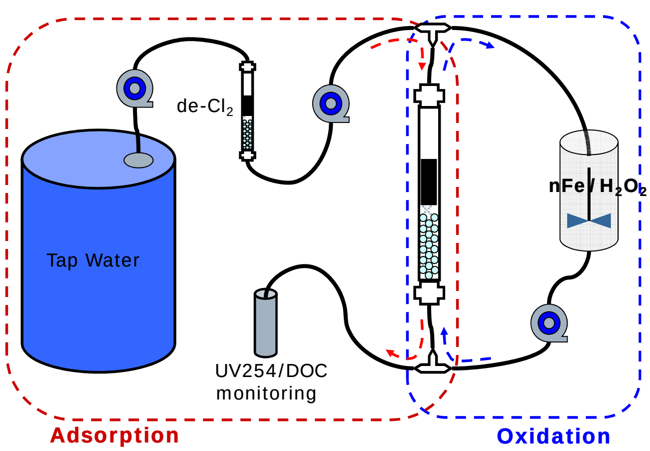


Batch Test for Sorbed-GAC regeneration





Column Test for Spent-GAC regeneration



Summary for nFe In-situ Regeneration

- Improve organic matters removal.
- Save energy and operation/maintenance cost
  - $5,663,000 of direct O&M cost for thermal regeneration (DSWA study).
- Reduce CO_2 discharge
  - Natural gas as fuel for Thermal regeneration: 30 M-lb/yr of GAC need 15 M-lb/yr of CH_4, produce 41 M-lb/yr CO_2 for Maricopa County (DSWA study) = CO_2 emission of 136 Camry.
- Compare with Fe(II)/H_2O_2:
  - Faster, easier to prepare, store, recovered, in-situ.