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

MCL = 10 μg/L
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%

Colloids
- Dialysis
- XAD-1
- XAD-4

Hydrophobics
- Acids
- Neutrals

Amphiphilics
- Acids
- Neutrals

Hydrophilics
- Acids & Neutrals
- Bases
- Not Adsorbed
- MSC-1H

Terpenoids
- Proteins
- Amphoterics
- Terpenoids
- Proteins

Saguaro Lake Fractionation

- Fraction I (Ethyl acetate subfraction)
- Fraction II (ACN/H2O subfraction)

Concentration (mg/L)

- Colloids
- Hydrophobic Base/Neutral
- Hydrophobic Acid
- Amphiphilic Base/Neutral
- Amphiphilic Acid
- Amino Acid
- Hydrophilic Acid
- 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 public's "confidence" in drinking waters.

The effect of water source and chlorine and chloramine odors on drinking water on earthy and musty odour intensity.

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

Geosmin Data

Source: Pibazari et al. 1992

European reassessment of MIB and geosmin perception in drinking water
P. Pirhola, R. Devosa, M. De Luhind and K. Ghilini

Graphs showing geosmin and MIB levels in different lakes.
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 = 50 ng/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?


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Shifts in water quality affected MIB Removal

- Initial MIB 65-95 ng/L
- Ozone/TOC of 0.25 mg/mg

- Ambient pH of 7.85
- Adjusted pH of 6.50

For EBCT of 3.1 min the loading rate is 4 gpm/ft²
For EBCT of 2.1 min the loading rate is 6 gpm/ft²

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GAC/Sand at EBCT of 3.1 min
GAC/Sand at EBCT 2.1 min
Anthracite/Sand at EBCT 3.1 min
Anthracite/Sand at EBCT 2.1 min
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.
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?

<table>
<thead>
<tr>
<th>Location</th>
<th>MIB on 8/30</th>
<th>MIB on 9/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>24th Street WTP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Treated</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Tempe North WTP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Treated</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Tempe South WTP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Treated</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

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
Potential Early Warning System for Algae-induced Tastes and Odors

Susanne Neuer
Phillip Tarrant
School of Life Sciences
Arizona State University

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
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.
- Visualspreadsheets™ software processes and categorizes particles based on multiple parameters.
FlowCAM® System

Environmental Conditions

Surface Water Temperature

Water Flow Rates

Water Mix Entering the South Canal
Results

FlowCAM Estimated Particle Counts

Identifiable Cyanobacterial Counts - Saguaro Lake

Total Cyanobacterial Counts - Saguaro Lake

Salt River

South Canal

Saguaro Lake

Results

Saguaro Lake

Salt River

South Canal
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


- 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/](http://neuer.lab.asu.edu/) click on “Data”
Potential Influences of Climate Change on Arizona Water Supply

Andrew Ellis

Regional Water Quality Workshop
September 17, 2010
Phoenix, Arizona

Historical Trends: Air Temperature

1901-2005
+0.08 to +0.2°C/decade
• increase through early 1940s
• slight decrease through 1970s

1979-2005
+0.1 to +0.5°C/decade
• monotonic, positive trend since early 1980s
Historical Time Series: Colorado River Basin Air Temperature

Mean Annual Air Temperature, 1895-2006

18.0 16.0 14.0 12.0 10.0 8.0 6.0 4.0

1901-2005
+0.12 degC/decade
p-value < 0.01
1977-2006: +0.35 degC/decade
p-value < 0.01

1977-2006: +0.11 degC/decade
p-value < 0.01

Historical Trends: Precipitation

1901-2005
+2 to -2% per decade

1979-2005
-3 to -15% per decade
No significant long-term trend
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  Year 2055  Year 2089
+0.5 to +1.5°C  +1.5 to +3°C  +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>
<thead>
<tr>
<th>Study</th>
<th>GCM(s) (runs)</th>
<th>Spatial scale</th>
<th>Temperature</th>
<th>Precipitation</th>
<th>Her</th>
<th>Runoff (Flow)</th>
<th>Risk Estimates</th>
</tr>
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<tbody>
<tr>
<td>Okirov et al., 2004</td>
<td>1 (3)</td>
<td>grid (~4 mi)</td>
<td>+3.1°F</td>
<td>-6%</td>
<td>2040-69</td>
<td>-18%</td>
<td>Yes</td>
</tr>
<tr>
<td>Kivalsy 2005, repl. by J. C. Halley</td>
<td>12 (5)</td>
<td>(-100-300 m)</td>
<td>--</td>
<td>--</td>
<td>2001-60</td>
<td>-31% to -55%</td>
<td>50% model agreement</td>
</tr>
<tr>
<td>Hoelting and Isschel 2006</td>
<td>18 (4)</td>
<td>NCAR Climate Glacier</td>
<td>+0.3°F</td>
<td>-0%</td>
<td>2075-2089</td>
<td>-7%</td>
<td>No</td>
</tr>
<tr>
<td>Okirov and Lathemanevar 2007</td>
<td>11 (27)</td>
<td>VEC model grid</td>
<td>+0.6°F</td>
<td>-5%</td>
<td>2060-69</td>
<td>-6%</td>
<td>19-123% of historical average</td>
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<tr>
<td>Siegel et al. 2007*</td>
<td>19 (45)</td>
<td>GCM grids</td>
<td>(-100-300 m)</td>
<td>--</td>
<td>2070</td>
<td>-51% (-8% to 25%)</td>
<td>No</td>
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<tr>
<td>Meehl and Walser 2008</td>
<td>--</td>
<td>USGS HUCs USGS</td>
<td>--</td>
<td>Assumed +5.0°F</td>
<td>2060-69</td>
<td>-17%</td>
<td>Assumed +30% to -30%</td>
</tr>
<tr>
<td>Heredia and Pierce 2008*</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Assumed --</td>
<td>2070</td>
<td>66%</td>
<td>11%</td>
</tr>
</tbody>
</table>

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%

Change in precipitation (mm/month)
Change in temperature (°C/mont)
Change in runoff (from status quo)
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 21st 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

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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)
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

- Includes chemical and solids handling costs
- Replacement costs for purchasing power not generated
- Modeled to achieve a TTHM goal of 64 ug/l

Delivery Cost for Source Waters ($/AF)

Results
Water Quality Comparison

2007 DOC Data

2007 SUVA Data

2007 UVA Data

Legend:
- Salt River
- Verde River
- CAP Water
- Groundwater

July August September October
DOC (mg/l) 2007 DOC Data

SUVA (L‐mg/M) 2007 SUVA Data

UVA (cm‐1) 2007 UVA Data

Price ($/AF)

Offset Hydro Delivery Cost Treatment Cost Total Cost

2007 Water Treatment Costs Analysis

July 2007

August 2007

Decrease in Total Cost
July- 28.7%
August- 49.9%

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

Cost Breakdown:

<table>
<thead>
<tr>
<th></th>
<th>DELIVERY COST</th>
<th>OFF-SET HYDRO</th>
<th>TREATMENT COST</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual Mix</td>
<td>$12.86</td>
<td>$39.47</td>
<td>$-</td>
<td>$-</td>
</tr>
<tr>
<td>Preferred Mix</td>
<td>$12.86</td>
<td>$39.47</td>
<td>$35.95</td>
<td>$110.33</td>
</tr>
</tbody>
</table>

- 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

DOM MWD in Natural Water

Medium and low-MW organic matter is the dominant component

DOM MWD in Drinking Water

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

SRP Canal  Pretreatment  Sedimentation  Filtration w/ GAC layer  Disinfection Storage

Peoria raw  Peoria fil-in  Peoria fil-ef
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.

![Graph showing SEC-DOC Across Treatment Processes](image)

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

- ![Graph showing DOC response to ferric sulfate dose](image)
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

Thermal Reactivation

Transportation, Energy & Fuel cost

CO₂ discharge

Off-gas treatment

Chemical Reactivation

NOM

GAC

NH₂O₂ + Fe(II) → OH⁻ + CO₂ + H₂O

Nanoparticle Reactivation

NOM

GAC

NH₂O₂ + HFe → OH⁻ + CO₂ + H₂O
Iron-nanoparticles Preparation

6% FeCl₃

24 hours

\( n\text{Fe}: \text{FeO(OH)}, \sim 55 \text{ nm}, \text{formed and stable after 6 hours of preparation and can last for months.} \)

Fenton-like reaction for OC degradation
**Test for Organic Degradation by nFe/H₂O₂**

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

**Batch Test for Sorbed-GAC regeneration**

- 72,000ppm nFe
- H₂O₂
- Virgin GAC mixed with organics
- Spent-GAC
- Nanoparticle is recycled for multi-run
- Adjust pH to 6.5
- Regenerated-GAC
Batch Test for Sorbed-GAC regeneration

![Graph showing phenol concentrations with virgin-GAC, sorbed-GAC, and regenerated-GAC](image)

Column Test for Spent-GAC regeneration

![Diagram showing water treatment process](image)
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 CO₂ discharge
  • Natural gas as fuel for Thermal regeneration:
    30 M-lb/yr of GAC need 15 M-lb/yr of CH₄, produce 41 M-lb/yr CO₂ for Maricopa County (DSWA study) = CO₂ emission of 136 Camry.

• Compare with Fe(II)/H₂O₂:
  • Faster, easier to prepare, store, recovered, in-situ.