Regional Water Quality Issues:
Algae and Associated Drinking Water Challenges

Workshop – October 2008

A Cooperative Research and Implementation Program
Arizona State University (Tempe, AZ)
Paul Westerhoff, Chao-An Chiu, Jun Wang, Pierre Herckes, Rolf Halden, and Marisa Masles

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

10 YEAR Anniversary

Developing a Taste and Odor Control Program for the City of Phoenix

Collaborators:
Arizona State University
City of Phoenix
Salt River Project
Central Arizona Project
Larry Baker, Paul Westerhoff and Milt Sommerfeld
Arizona State University

Agenda

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

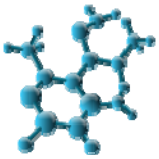
8:30	Refreshments
8:45	Introductions
9:00	Project scope & goals
9:15	Overview of water quality trends for Taste and Odor Compounds & other key water quality that affects drinking water
9:35	Understanding "where our turbidity comes from"
Break	
10:00	Pharmaceutical occurrence in source waters
10:20	Characterization of NOM & DBP formation
10:40	Removal of NOM from different source waters by Granular Activated Carbon
11:00	Future directions & discussion

Project Goals

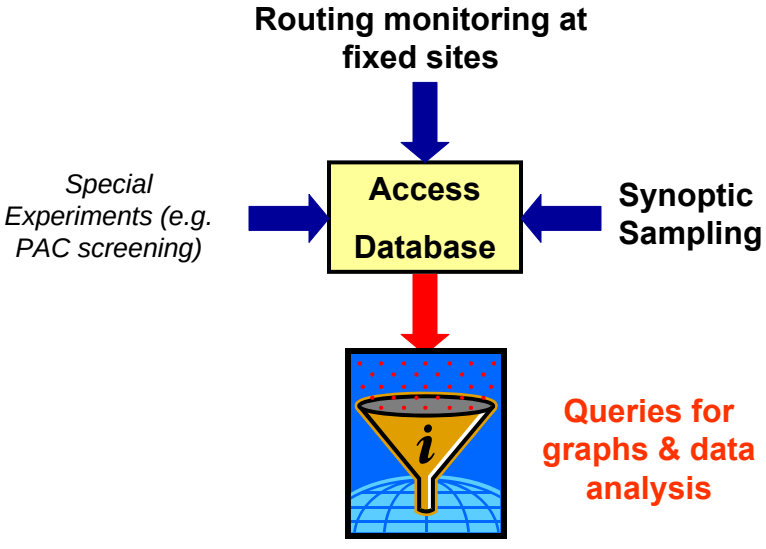
- Collect consistent database for non-regulated water constituents in central Arizona drinking water systems that cross jurisdictional boundaries
- Conduct research that improves our understanding of algal activity and hydrologic conditions on taste and odor production and organic matter
- Communicate watershed-wide water quality data and disseminate information on water quality/treatment to aid the local water systems
- Leverage funding from multiple local cities and agencies for water quality and treatment research projects

Focus for 2008

- Continued monitoring of course
- Endocrine disruptor, pharmaceuticals & personal care product occurrence
- Organic matter characterization
- Ability to remove organic matter & DBP precursors by granular activated carbon
- Analysis of sources of turbidity in our waters



Long-Term Database Is Becoming a Powerful Tool



Benefits

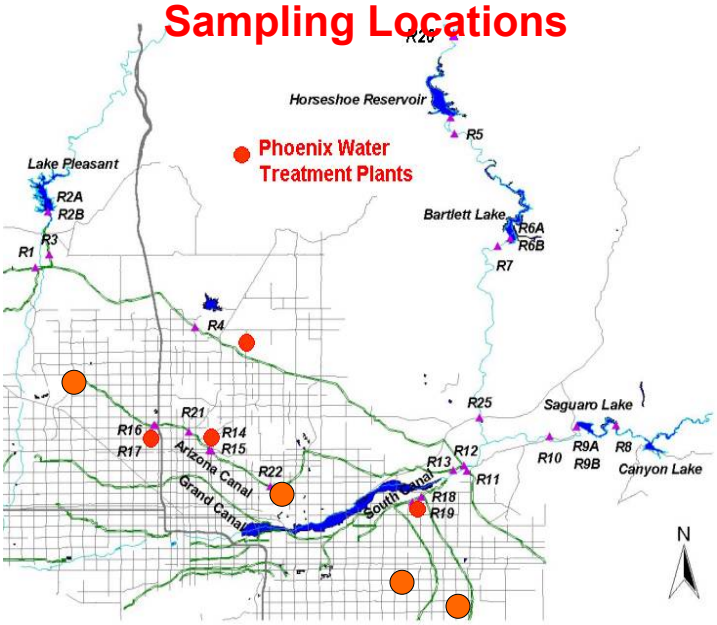
- Leveraged the funding with at least 8:1 external funding. Recent projects include:
  - AwwaRF / MPI/ ASU ($165K) – implant algae control
  - AwwaRF/ MWD/ASU /Yale ($450K) – N-DBPs
  - AwwaRF / ASU – Organic chloramines ($150K)
  - WERF / ASU – organic colloids ($100K)
  - SRP / ASU – DBP Project + Molecular Probes + EDC occurrence ($150K)
- Provides visibility to outside world that water municipalities in central Arizona are progressive and working collectively to understand and improve water quality
- Development of analytical and experimental skills to assist cities/consultants on regional issues
- ASU maintains ability to serve as independent third party for PAC testing
- We provide donuts and bagels at meetings

Overview of Water Quality

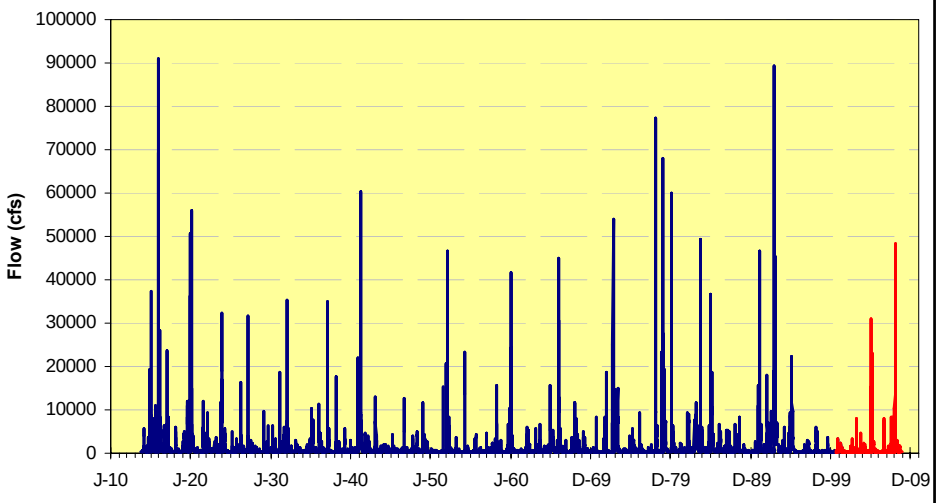
in 2008

relative to other years

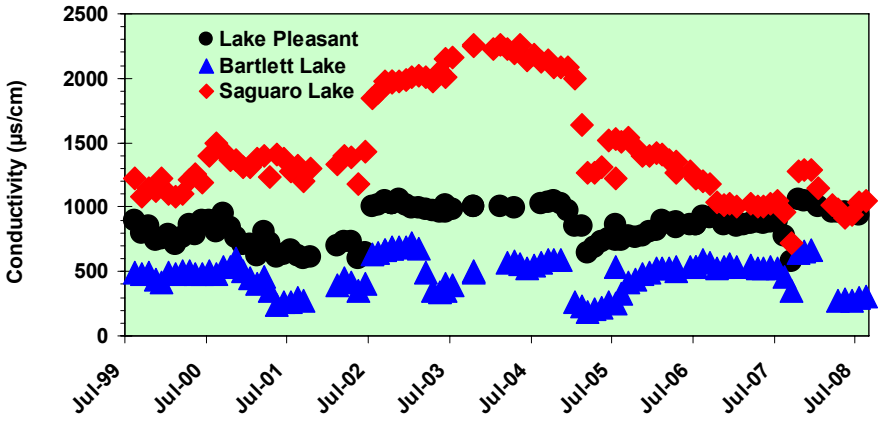
Sampling Locations



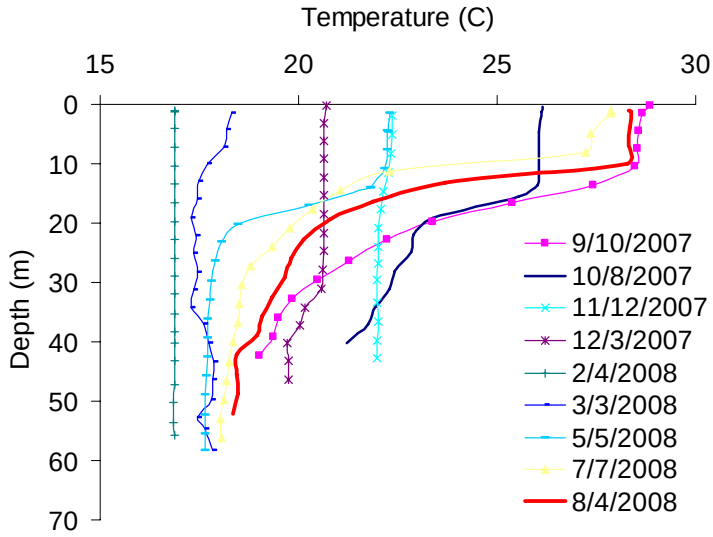
Project is spanning dry-wet years
Salt River Above Roosevelt



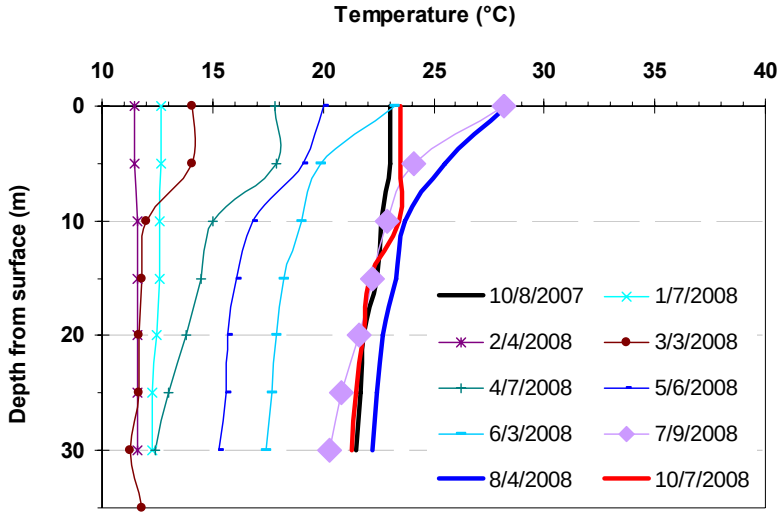
Hydrology Affects Water Quality (conductance can affect algal dominance)



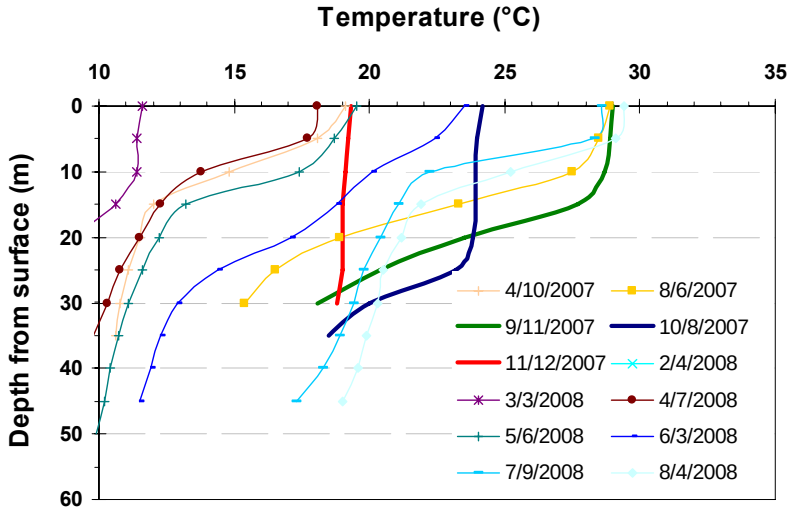
Thermal stratification of lakes affect water quality released from them (Lake Pleasant)



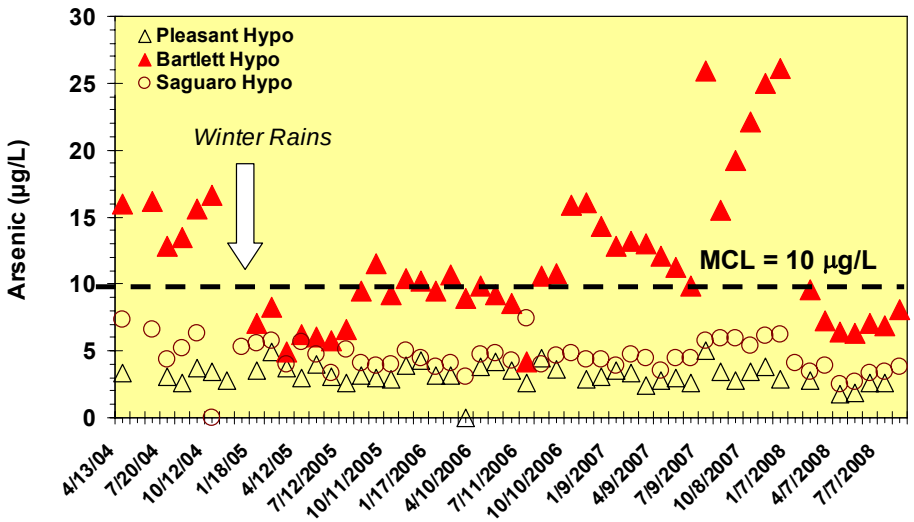
Saguaro Lake is only weakly stratified



Bartlett Lake

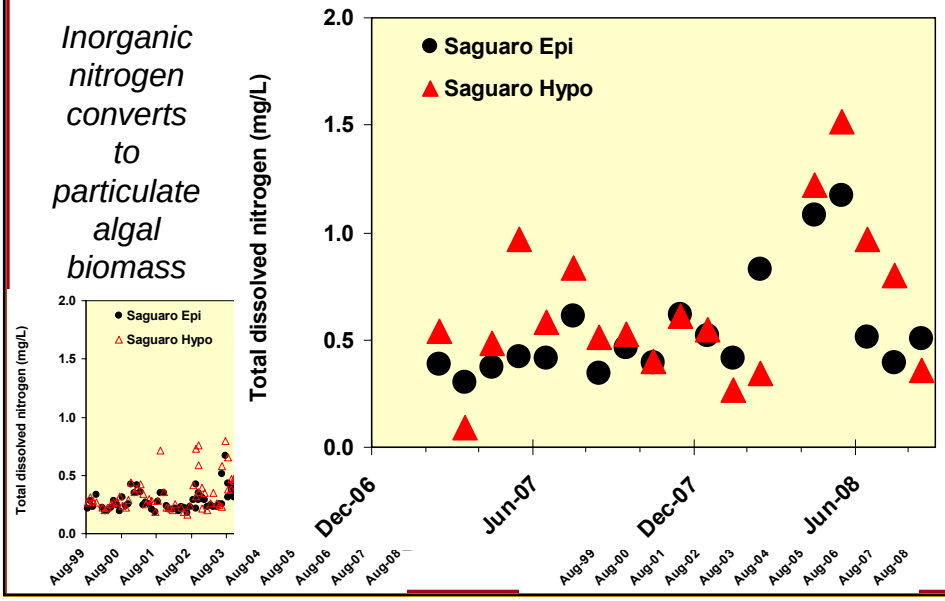


Arsenic Levels Vary in Sources and in response to climatic influences

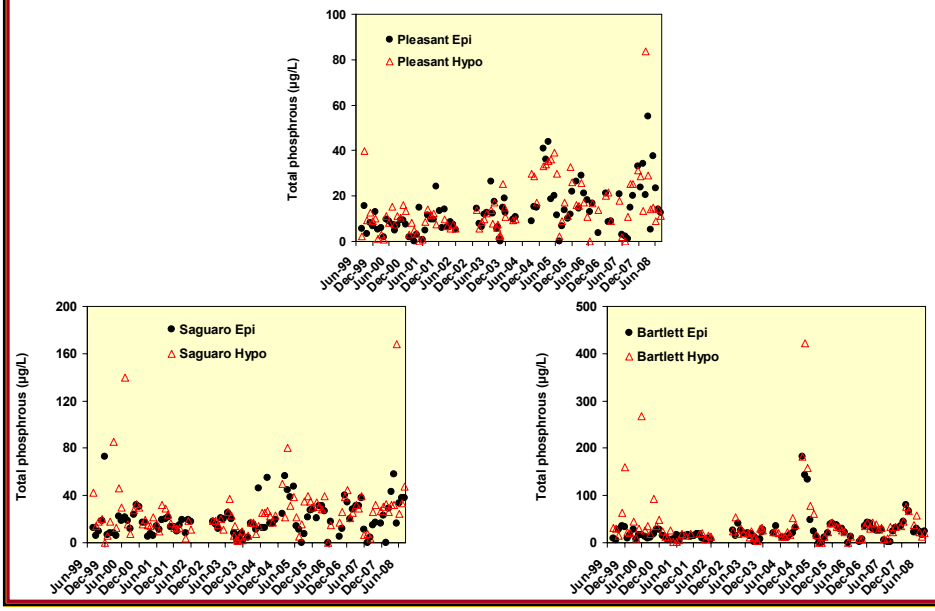


Dissolved Nitrogen Trends in Reservoirs

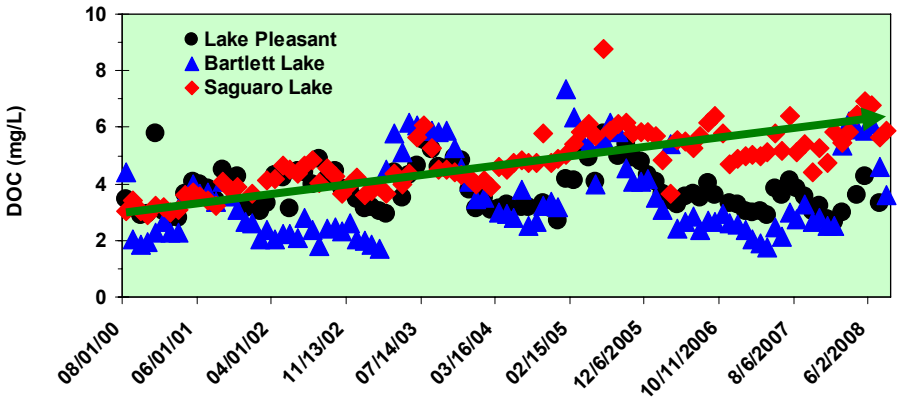
Inorganic nitrogen converts to particulate algal biomass



Total Phosphorous

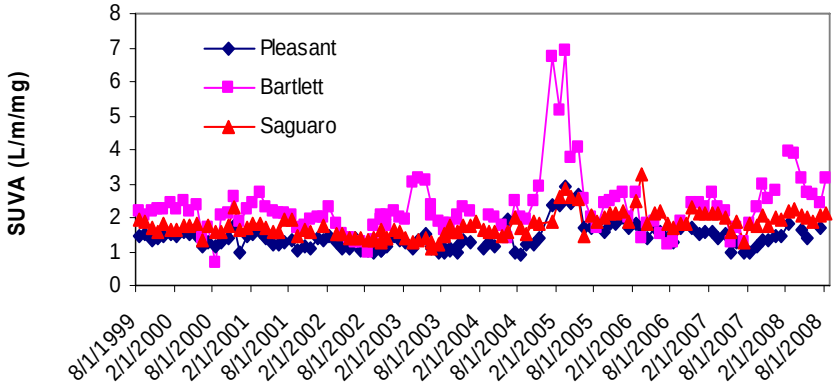


Up-stream reservoirs attenuate DOC

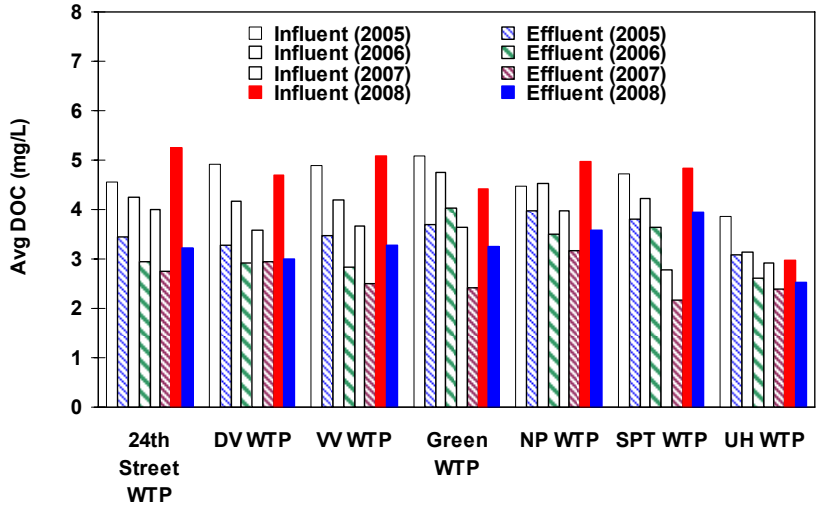


Saguaro Lake DOC increasing by
0.37 mg/L per year

Specific UV Absorbance at 254 nm
SUVA = UVA / DOC

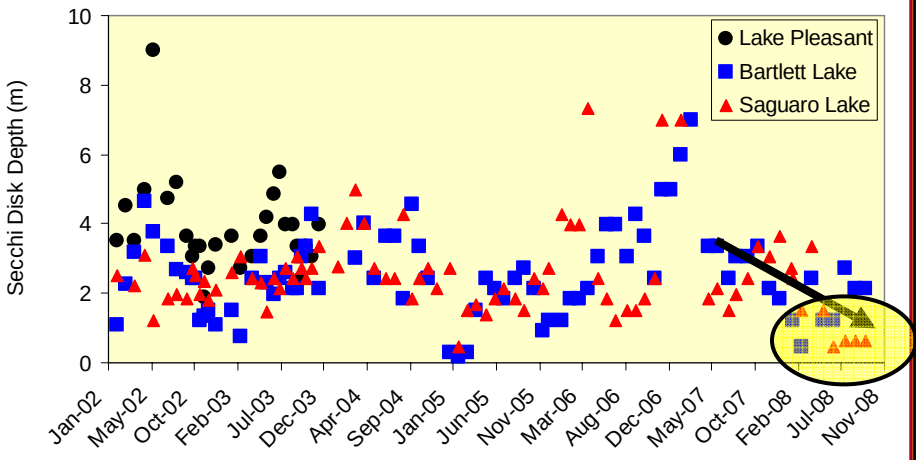


DOC Removal by WTP

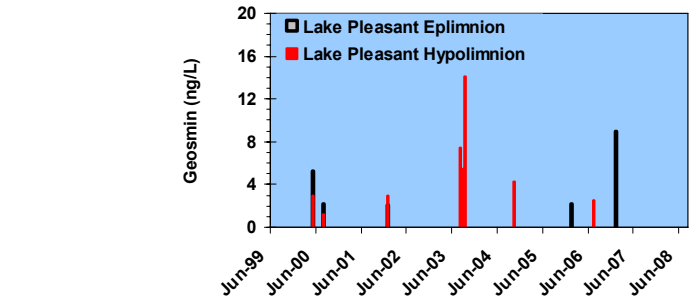


DOC % removal has increased over time

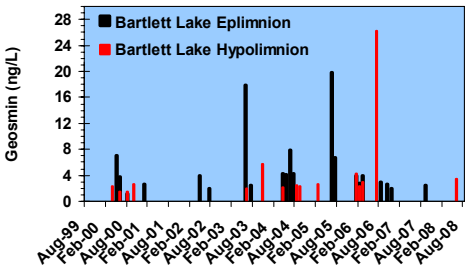
Secchi Disk Depth Influenced by Inorganic Suspended Sediment and/or Organic Biomass

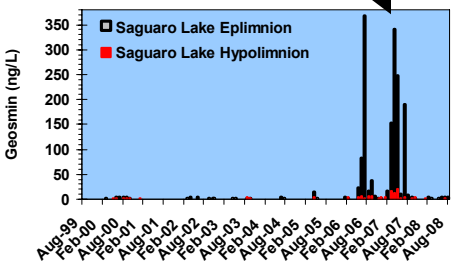


Geosmin Data

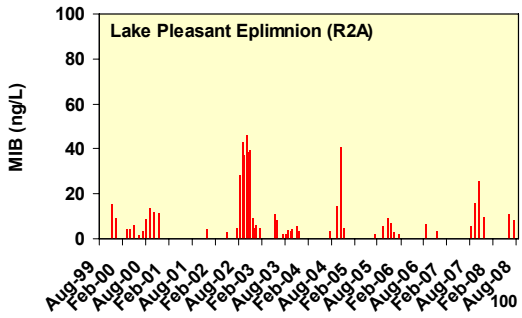


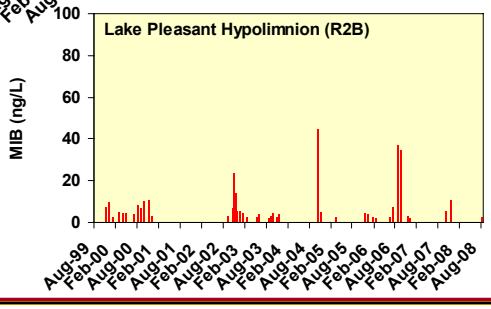
Huge Geosmin peaks in 2007 pre-April & mid-summer only in upper part of water column



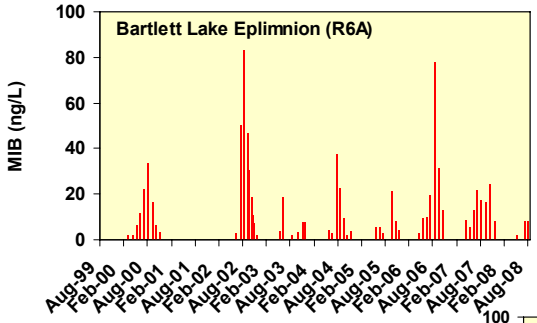


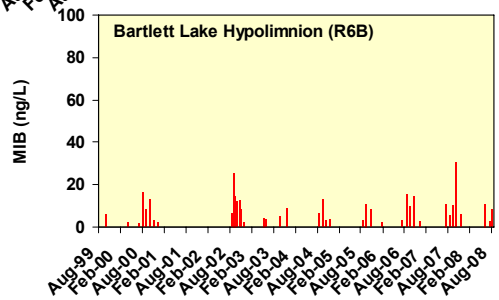
MIB Data – Lake Pleasant



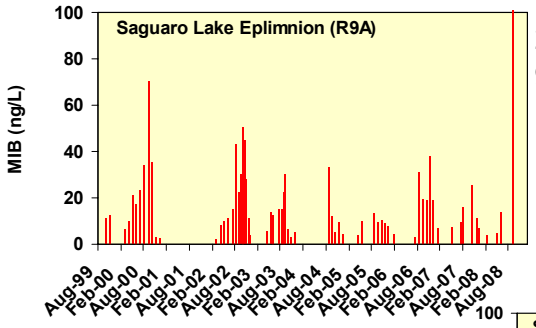


MIB Data – Bartlett Lake



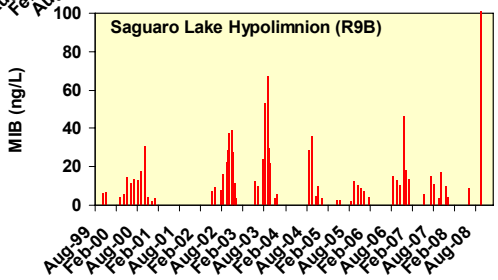


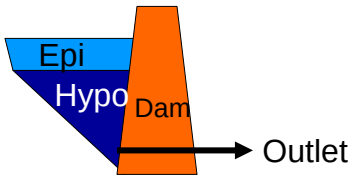
MIB Data – Saguaro Lake



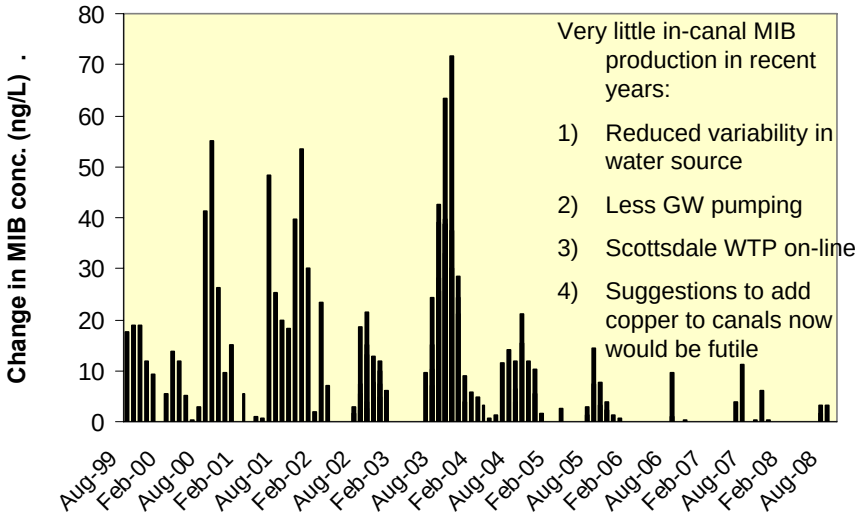
250 ng/L on 9/8/08

135 ng/L on 9/8/08

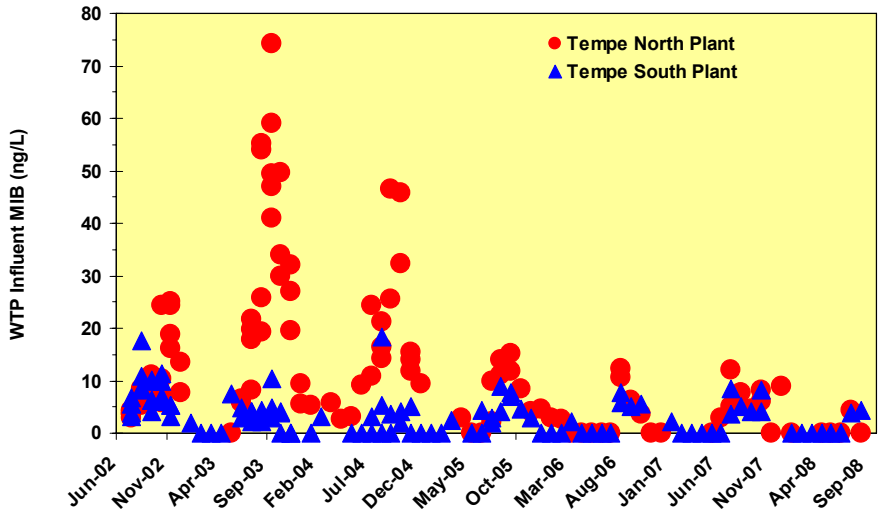




MIB Growth in Arizona canal from below X-Con to DV Inlet



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



Summary of General Water Quality & Operations

- "Normal" winter rains and above average moonsoons appear to have increased nutrient levels in some reservoirs
- Very high MIB production in Saguaro Lake; offset by SRP switching to Verde River in September
- Reservoirs are quite productive (low secchi disc = high algae) but conditions may not be favoring establishment of MIB producing algae
- DOC levels in Saguaro Lake have increased constantly over past 8 years (0.37 mg/L/year)
- EL NIÑO/SOUTHERN OSCILLATION (ENSO) neutral conditions are predicted through the Northern Hemisphere into Spring 2009 & "normal" weather conditions predicted by NOAA

When it Rains

Where does turbidity come from in our waters?

Turbidity

- Turbidity affects WTP operations (chemical dosing, solids loading & pathogen indictors)
- Turbidity response has been a focus for several cities in 2007-08
- Two turbidity events occur:
  - long-duration events resulting from upland runoff during winter or spring; Verde River reservoirs overflow
  - short-term events resulting from moonsoon events in the summer (focus of this study)

Critical Question

- Where does runoff carrying turbidity originate from that enters the SRP canals?
- What type of early warning program could be implemented?

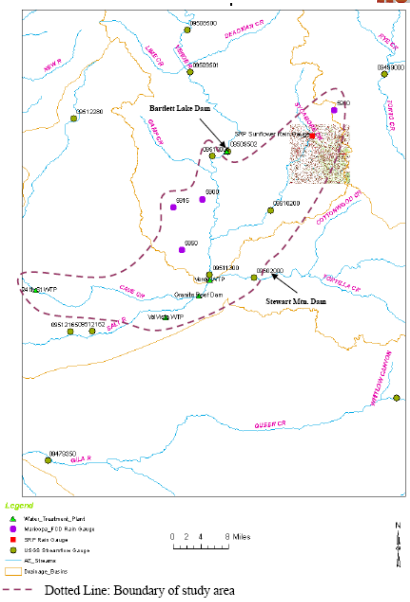


Figure 2.1 Map of the Study Area

We focused on several major events

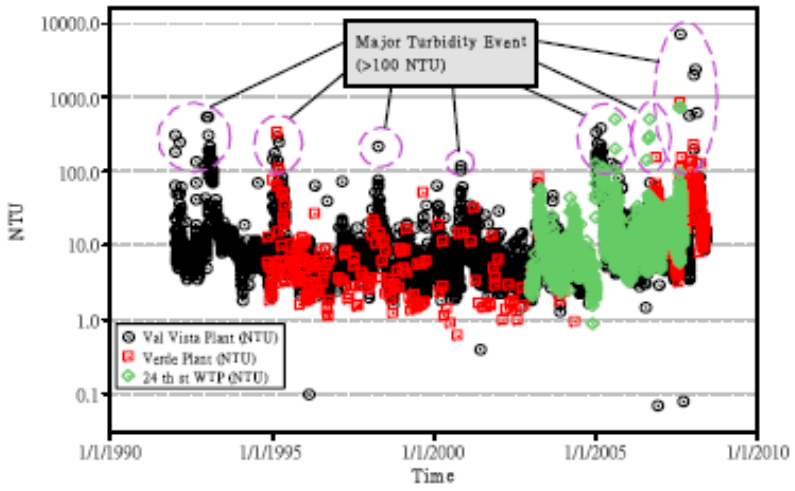


Figure 3.13 Turbidity (NTU) vs. Time at Local WTPs

Three sub-watersheds identified

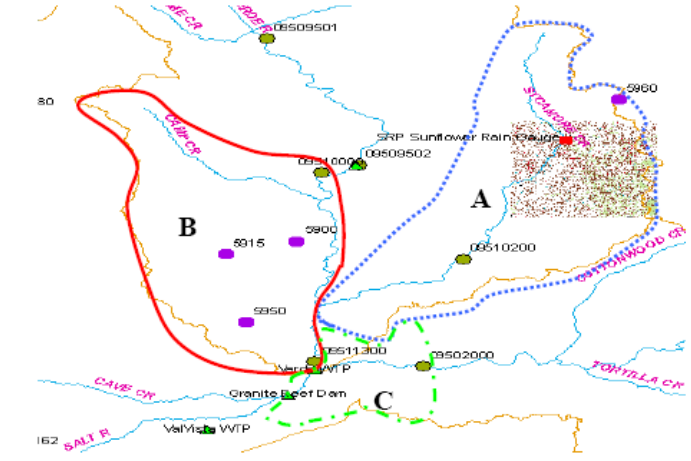


Figure 3.1 Map of Watershed Area for Salt and Verde River Flow Balance

Hydrologic Insights

- **Added flow between on the Salt River below Stewart Mountain Dam and the confluence with the Verde River:**
  - **Contribution of runoff from this sub-watershed is small compared with Sycamore Creek or Camp Creek watersheds**
  - **Contribution towards turbidity was negligible**
- **Added flow between on the Verde River below Bartlett Dam and confluence with Salt River:**
  - **A water balance in the Lower Verde River using USGS gauging stations can be "closed"**
  - **Sycamore Creek produces roughly 2.5 times more runoff volume than Camp Creek watershed**
  - **Less than 5% of rainfall volume in sub-watersheds actually enters the Verde River (only during higher flow events)**
  - **These sub watersheds are dominate source of turbidity during rain events**

July 2008 Event & Sampling

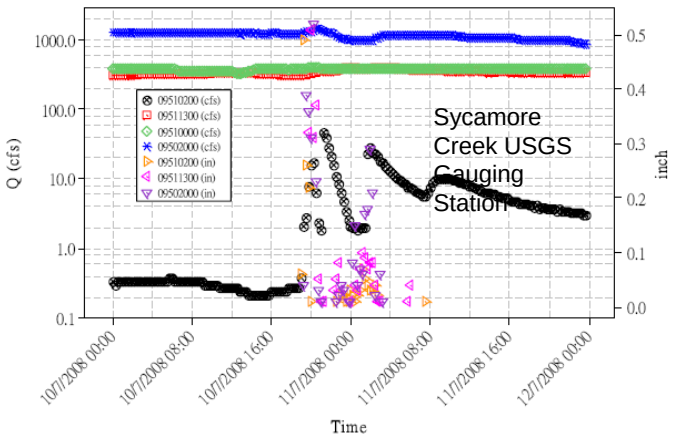


Figure 4.2 15 Minute Interval Plot of Rainfall and Discharge vs. Time on July 10 Storm Event

Precipitation occurs before runoff

(0.5 inch of rainfall 1 hour before discharge recorded)

USGS Gauging Stations

- 09510000 VERDE RIVER BLW BARTLETT DAM, AZ.
- 09510200 SYCAMORE CREEK NEAR FORT MCDOWELL, AZ.
- 09511300 VERDE RIVER NEAR SCOTTSDALE, AZ.
- 09502000 SALT RIVER BLW STEWART MOUNTAIN DAM, AZ.

Turbidity at WTP lagged peak Sycamore River discharge by only 2 hours at Midnight (*more warning time is needed*)

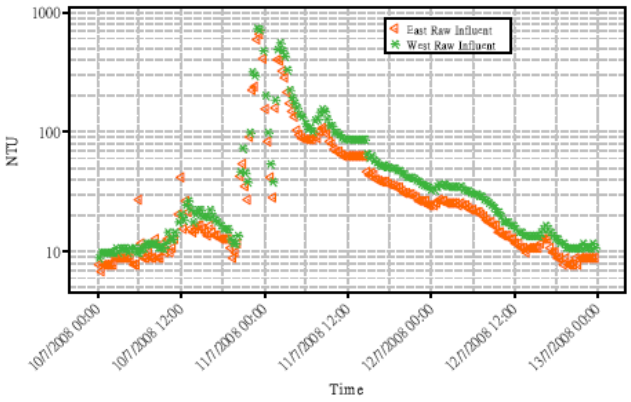


Figure 4.3. Turbidity Raw Data at Val Vista WTP on July 10 Storm Event

Turbidity contained 70% fixed and 30% volatile (organic) suspended solids

Doppler Radar Data

http://www.wrh.noaa.gov/psr/weather/radar.php

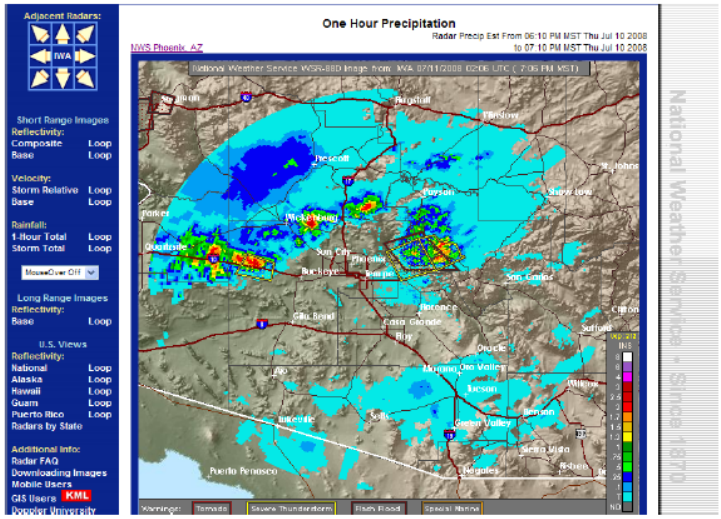
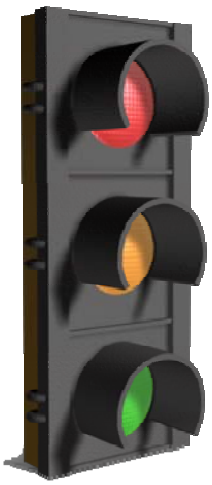


Figure 5.1. Hourly Rainfall Data from National Weather Services at the Phoenix National Doppler Site (KIWA)

Multi-tier Turbidity Warning System

- **Green light** = normal conditions
- **Yellow Light** = Doppler radar indicates clouds building in lower Verde River watershed; start monitoring streamflows on Sycamore Creek and Verde River
- Orange light = precipitation is recorded at stations
- **Red Light** = Ratio of flows exceeds 1.1 for Verde River at Beeline Highway relative to Verde River below Bartlett Lake (09511300 and 09510200). Confirm with on-line turbidity meters. Indicates elevated turbidity will arrive at WTPs within a few hours.

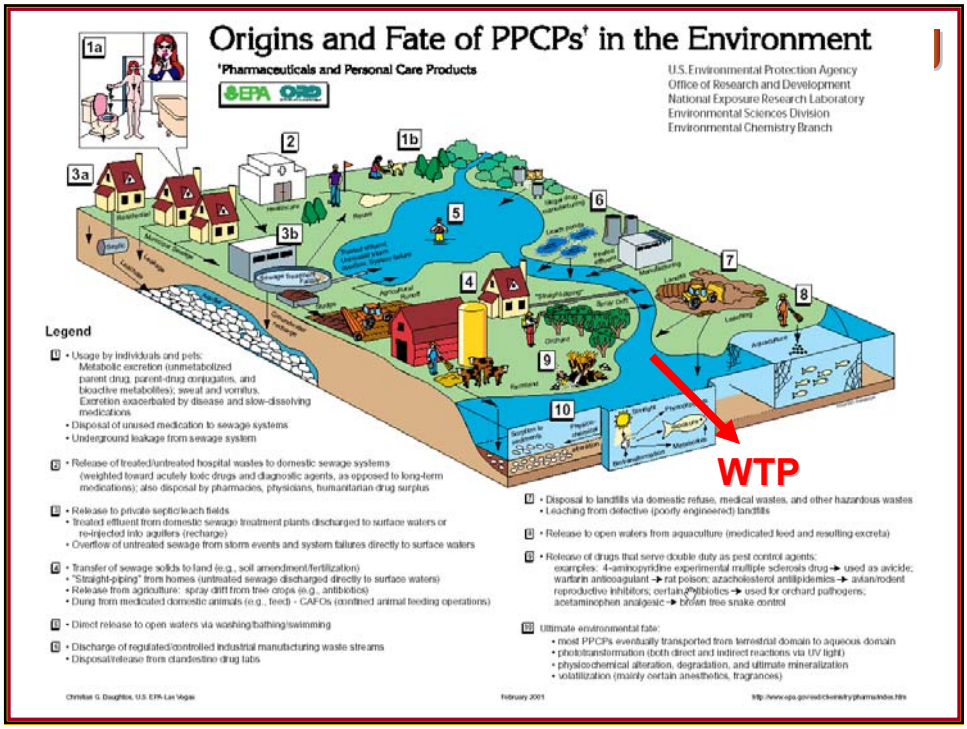


10 minute Break

Associated Press investigation:

Pharmaceuticals found in drinking water
A vast array of pharmaceuticals including antibiotics, anti-convulsants, mood stabilizers and sex hormones have been found in the drinking water supplies of at least 41 million Americans, an Associated Press investigation shows.

March 2008



"No substance is a poison by itself. It is the dose that makes a substance a poison..."

Paracelsus (1493-1541)

Pharmaceutical Risk Perspective

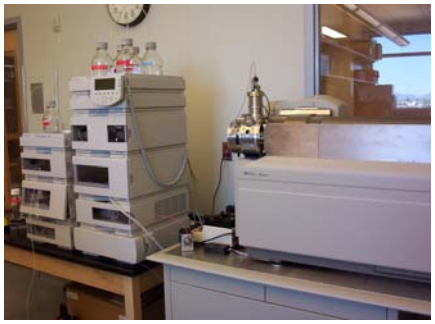
Compound	Max conc reported (ng/L) in surface water	Predicted No Effect Concentration (PNEC) (ng/L)	Liters of water/day → ADI[b]
Acetaminophen	10,000	5,000,000	2380
Albuterol	15[a]	410,000	13,067
Ciprofloxacin	30	230,000	3,733
Codeine	1000	290,000	140
Digoxin	130[a]	1,000	38
Fluoxetine	12	420,000	16,912
Gemfibrozil	790	800,000	4,873
Ibuprofen	1000	16,000,000	7,700
Metformin	150	9,100,000	28,933
Oxytetracycline	340	4,400,000	6,176
Sulfamethoxazole	1900	19,000,000	4,789
Warfarin	0.5a	23,000	22,400

[a] ND, ½ Reporting Limit [b] Assumes average weight of 70 kg and max conc reported

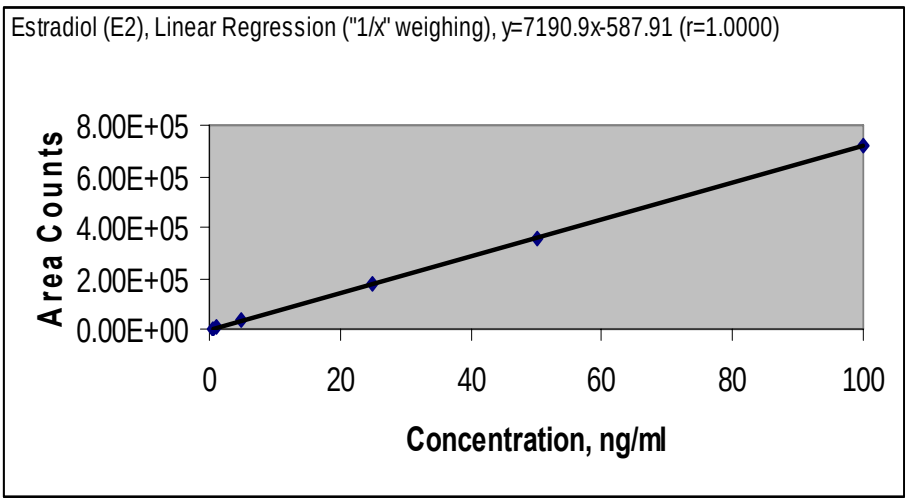
Reference: B.W. Schwab et al./ Regulatory Toxicology and Pharmacology 42 (2005) 296-312

Analytical Scheme

- Solid Phase extraction (Oasis HLB) @ ASU
- Analysis at Arizona Department of Health Services
- Method development support by a Arizona Water Institute grant

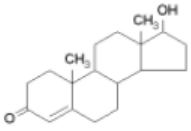


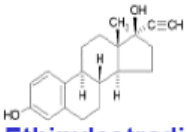
Calibration Curve for Estradiol

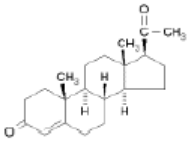


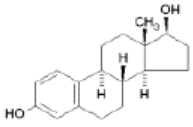
LC/MS/MS Compounds

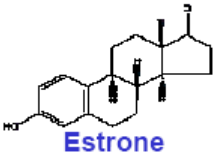
Steroids

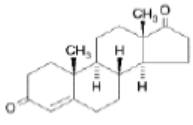

Testosterone

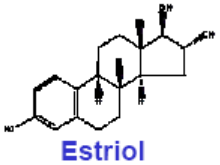

Ethinylestradiol


Progesterone

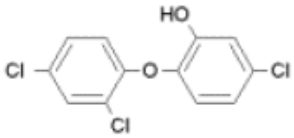

17β Estradiol


Estrone

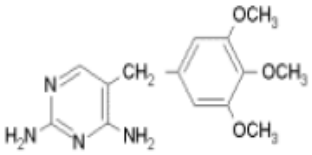

Androstenedione


Estriol

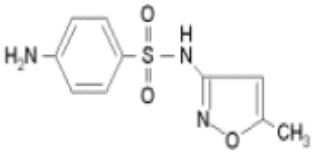
Antimicrobials



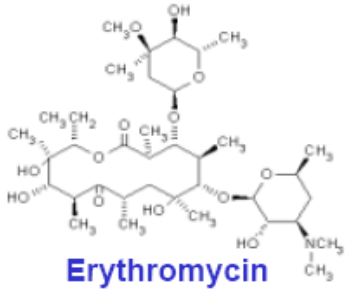
Triclosan



Trimethoprim

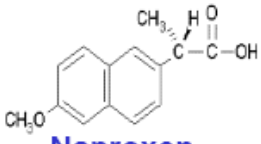


Sulfamethoxazole

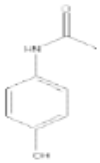


Erythromycin

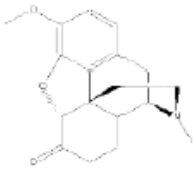
Analgesics



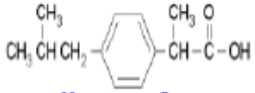
Naproxen



Acetaminophen



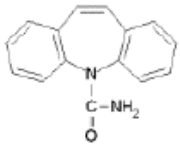
Hydrocodone

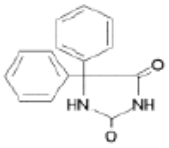


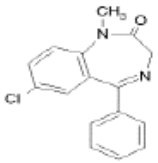
Ibuprofen

Diclofenac

Psychoactive


Carbamazepine


Dilantin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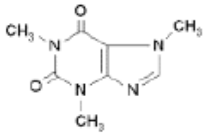
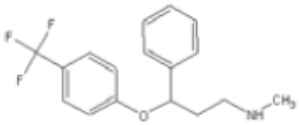
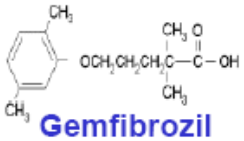
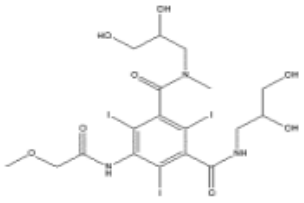

Caffeine

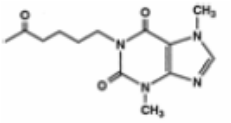

Fluoxetine


Meprobamate

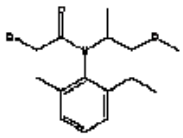
Others

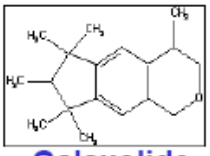

Gemfibrozil

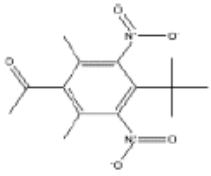

Iopromide

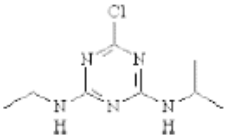

Pentoxifylline


TCEP


Metolachlor


Galaxolide


Musk Ketone


Atrazine

Arizona Potential EDC/PPCP Sources

- Colorado River
- Wastewater discharges into rivers and groundwater
- Leaking septic systems
- Houseboats & direct contact (recreation)

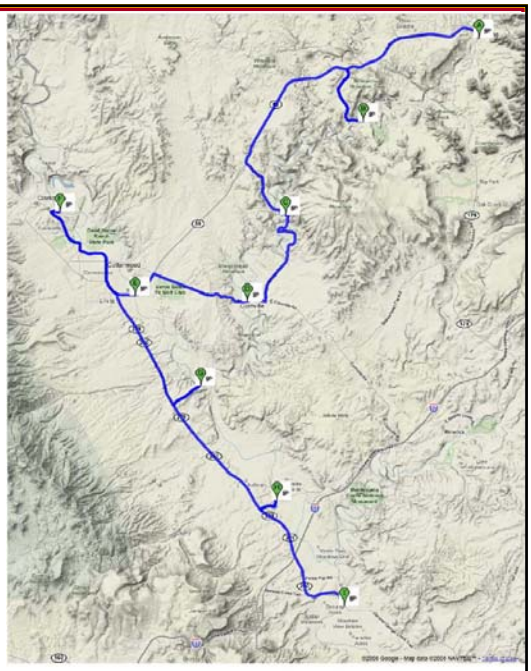
A Few Numbers

Source	< 2 ng/L & ≤ Blank	2 to 10 ng/L	10 to 20 ng/L	20 ng/L to 1 ug/L	> 1 ug/L
CAP Canal from Colorado River (SRP water a little lower)	Steroids Others	Caffeine Carbamazepine Meprobamate Naproxen Sucralose	Ibuprofen Diclofenac	None	None
Activated sludge WWTP with nitrification	Steroids Others	Fluoxetine	caffeine, cotinine, diuron, ibuprofen, naproxen	carbazepine, hydrocodone, meprobamate, sulfamethoxazole, DEET, Erythromycin, trimethoprim, primidone, dilantin, triclosan, diclofenac, sucralose	none
Raw wastewater	A few	None	Estrogens Fluoxetine	Testosterone, Progesterone, hydrocodone, meprobamate, pentoxifylline, DEET, erythromycin, trimethoprim, primidone, carbamazepine, dilantin, diclofenac	Ibuprofen, naproxen, triclosan, sucralose, acetominophen, caffeine, cotinine, oxybenzone, sulfamethoxazole

Occurrence of Chemotherapy Drugs

	Irinotecan	Tamoxifen	Daunorubicin	Ccl.phosphamide
Series 1				
Hospital A	<	4.44	<	<
Hospital B	<	<	<	<
Hospital D	<	<	<	<
Hospital E	<	30.1	<	<
WWTP Influent	<	1.34	<	<
WWTP Effluent	<	<	<	<
Series 2				
Hospital A	<	0.70	0.90	<
Hospital B	<	<	0.48	<
Hospital C	<	0.39	<	<
WWTP Influent	<	0.49	<	<
WWTP Effluent	<	<	<	<

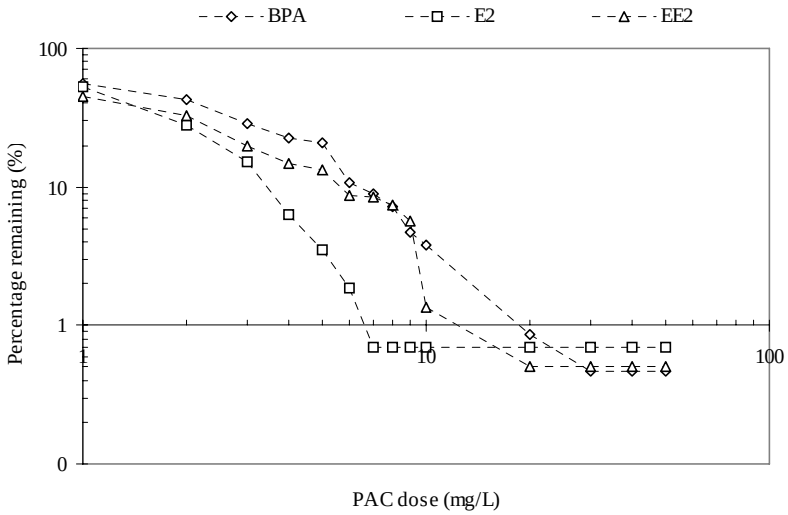
Sedona Area Sampling



The Challenge of ppt Data analysis

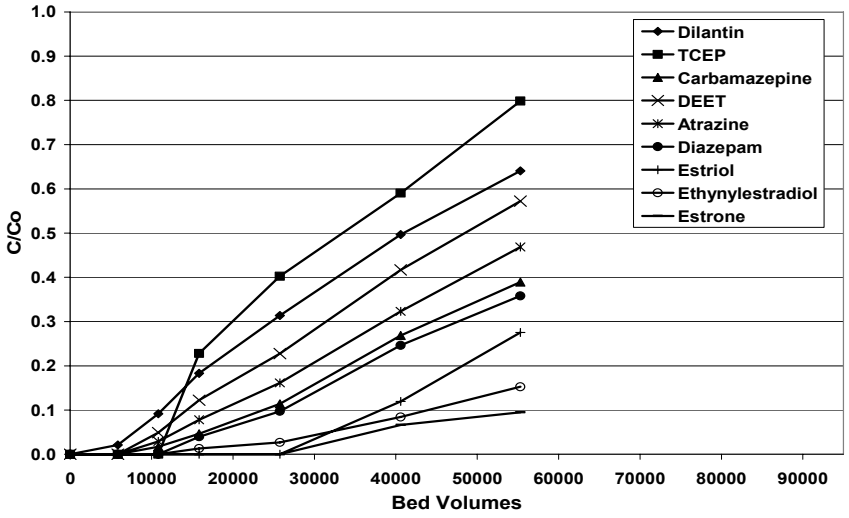
Sample Name	Caffeine	Ibuprofen	Triclosan	Sucralose
lab blank	1.41	ND	1.04	< 0
field blank	1.12	ND	0.97	< 0
Sedona A	3.95	ND	0.78	< 0
Sedona A Duplicate	5.71	1.29	1.34	< 0
Sedona B	9.33	1.40	2.03	< 0
Sedona C	6.68	2.21	1.04	1.36
Sedona D	6.95	ND	1.56	< 0
Verde E	18.20	3.85	0.90	< 0
Verde E (Duplicate)	22.10	4.22	1.13	< 0
Verde F	13.10	ND	1.51	< 0
Verde G	7.99	ND	2.23	< 0
Verde H	4.91	ND	1.07	< 0
Verde I	6.19	ND	1.16	< 0
Verde I (duplicate)	5.83	ND	0.68	< 0
Hwy 87 at Beeline	25.50	ND	1.04	< 0
Blue Point Bridge	6.07	1.31	0.72	0.60
WTP Raw water	9.49	ND	1.16	< 0
WTP Settled water	13.30	ND	0.66	0.97
WTP after chlorine	10.90	1.54	1.09	< 0
WWTP raw	51300.00	7380.00	1400.00	4060.00
WWTP treated	13.90	10.80	111.00	1010.00
WWTP treated - post UV	19.70	10.70	57.90	976.00

Effect of PAC (AC800) dose on BPA, E2, and EE2 removal in SRPW (contact time = 4 h)



Yoon et al.

GAC in Column Tests (RSSCTs)



Experiments by F. Cannon

Full-Scale Water Treatment Plants From Across the USA

From: Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes
[Project #2758]
by

Shane A. Snyder, Eric C. Wert, Hongxia Lei, Paul Westerhoff, and Yeomin Yoon

Raw Water Summary (ng/L)

	AVE	SD	Hits	Percent
DEET	10.8	7.9	18	100.0
Caffeine	26.6	19.9	17	94.4
TCEP	21.9	18.2	17	94.4
Dilantin	4.1	3.7	16	88.9
Carbamazepine	5.7	6.2	16	88.9
Sulfamethoxazole	17.8	15.6	15	83.3
Ibuprofen	7.3	7.6	15	83.3
Atrazine	153.8	225.1	14	77.8
Meprobamate	6.8	4.5	12	66.7
Iopromide	13.8	16.1	11	61.1
Naproxen	5.6	6.1	11	61.1
Gemfibrozil	6.1	4.1	11	61.1
Erythromycin-H_2O	2.7	0.8	8	44.4
Triclosan	1.7	0.9	5	27.8
Trimethoprim	2.3	0.1	4	22.2
Acetaminophen	3.6	4.0	4	22.2
Hydrocodone	1.9	0.0	2	11.1
Oxybenzone	1.3	0.4	2	11.1
Estrone	1.4	0.0	1	5.6
Testosterone	1.0	0.0	1	5.6
Androstenedione	1.9	0.0	1	5.6

Finished Water Summary (ng/L)

	AVE	SD	Hits	Percent
DEET	10.9	9.6	17	94.4
TCEP	9.9	5.6	16	88.9
Caffeine	27.7	24.7	15	83.3
Ibuprofen	10.4	11.2	14	77.8
Atrazine	117.8	179.2	13	72.2
Meprobamate	5.7	3.3	12	66.7
Dilantin	3.3	2.2	11	61.1
Iopromide	9.0	4.6	10	55.6
Carbamazepine	4.1	1.5	8	44.4
Gemfibrozil	5.2	3.3	4	22.2
Estrone	1.2	0.1	2	11.1
Acetaminophen	1.1	0.0	1	5.6
Erythromycin-H_2O	2.6	0.0	1	5.6
Sulfamethoxazole	2.1	0.0	1	5.6
Naproxen	1.0	0.0	1	5.6

Full-scale performance follows lab-scale predictions
Example – Conventional WTP with Cl_2

	Raw	Finished	% Removed	Predicted
Caffeine	31	20	35	18
Sulfamethoxazole	5.6	<1.0	>82	>99
Meprobamate	2.6	2.3	12	13
Dilantin	3.7	2.2	41	18
TCEP	42	5.8	86	4
Carbamazepine	1.2	<1.0	>17	25
DEET	17	16	6	15
Atrazine	457	431	6	4
Iopromide	6.6	7.8	0	25
Naproxen	1.8	<1.0	>44	>93
Ibuprofen	3.6	3.0	17	40
Gemfibrozil	1.7	<1.0	>41	75

Full-scale performance follows lab-scale predictions
Example – WTP with Ozone

	Raw	Finished	% Removal	Predicted
Caffeine	4.1	<1.0	>99	>99
Sulfamethoxazole	11	<1.0	>99	>99
Meprobamate	13	9.4	28	50
Dilantin	3.1	1.5	52	80
TCEP	5.0	6.5	0	10
Carbamazepine	3.5	<1.0	>99	>99
DEET	4.0	2.0	50	70
Atrazine	1.4	<1.0	>50	50
Estrone	1.4	<1.0	>50	>99
Testosterone	1.0	<1.0	>50	>99

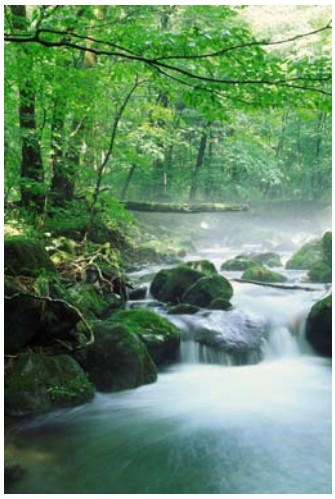
Summary of Selected Compounds
(X: 25-50% XX: 50-90% XXX: >90% Removal)

Analyte	Coag	PAC	Cl2	O3	UV
Iopromide		X	X	XX	XX
Meprobamate		X		XX	
Sulfamethoxazole		X	XXX	XXX	XXX
Gemfibrozil		X	X	XXX	
DEET		X	X	XX	
TCEP		X			
Galaxolide		XX	X	XX	?
Atrazine		XX		XX	XX
Carbamazepine		XX		XXX	
Ethynylestradiol		XX	XXX	XXX	XXX
Testosterone	X	XX	X	XXX	XX
Androstenedione	X	XX	X	XX(X)	XX
Benzo[a]pyrene	X	XX	XX	XX	?
Progesterone	X	XX	X	XX(X)	XX
Oxybenzone		XXX	XXX	XXX	XX
Pyrene		XXX	X	XXX	?

Shifting from Trace Organics to Bulk Organics

NOM Isolation & Characterization

- NOM is made of unique chemical groups (acids, neutrals, ..)
- Each group has different removal capabilities and ability to form DBPs
- This work with Carollo and Malcolm Pirnie helped them interpret trends in water sources and climatic events on NOM behaviour and treatment

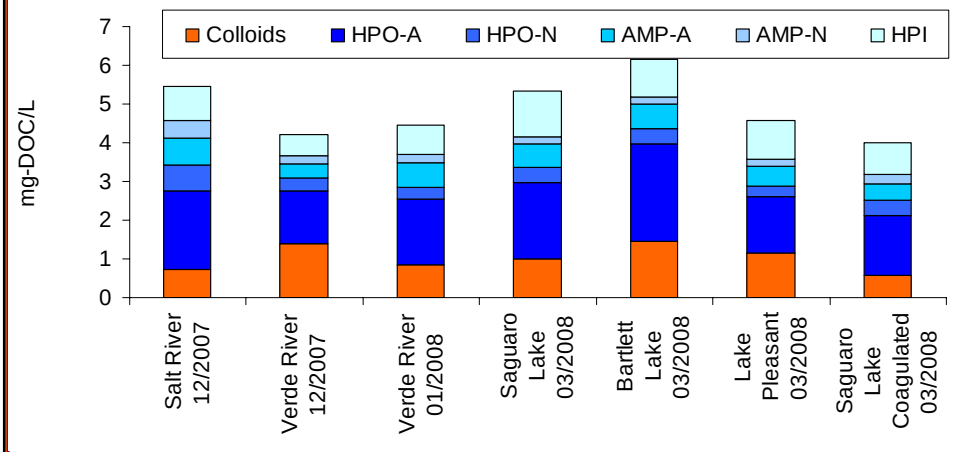


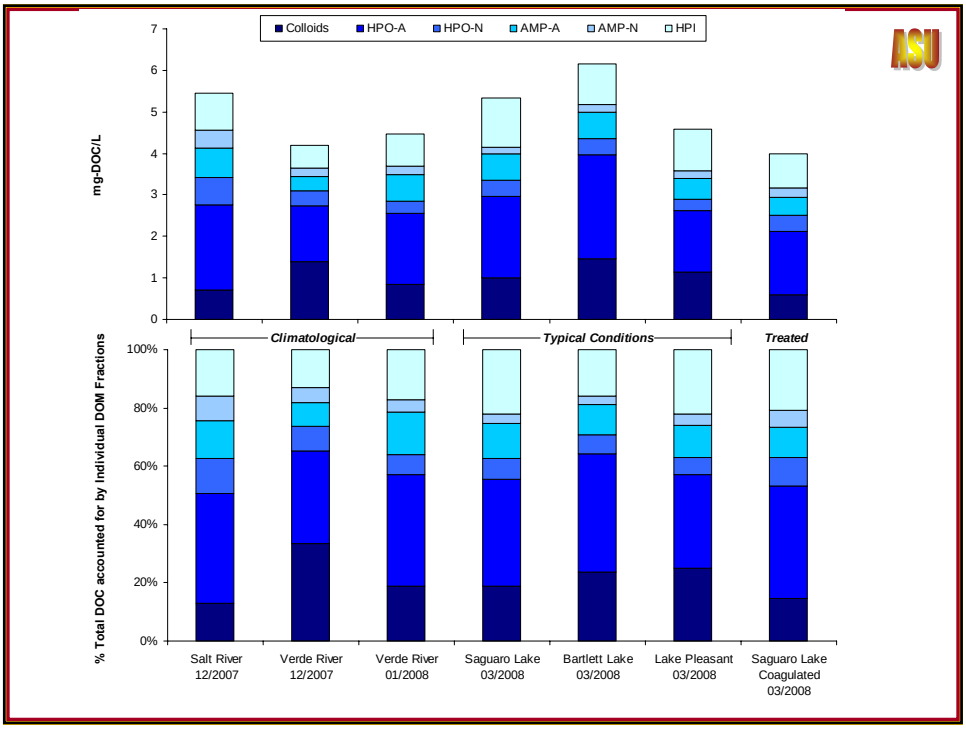
Sampling Locations & Time

Location	Sample	Date	Volume	pH	DOC	TDN	DON
			liters	--	mgC/L	mgN/L	mgN/L
Salt River	Climatological	12/2007	77.7	8.0	3.64	0.672	0.476
Verde River	Climatological	12/2007	76.2	8.2	5.49	1.98	0.720
Verde River	Climatological	1/2008	76.8	8.2	4.82	1.22	0.640
Saguaro Lake	Lake	3/2008	77.2	8.8	5.85	1.08	0.426
Bartlett Lake	Lake	3/2008	77.4	9.2	6.02	0.614	0.388
Lake Pleasant	Lake	3/2008	76.1	7.7	4.56	1.07	0.593
Saguaro Lake Coagulated	Treated Lake	3/2008	36.8	7.1	3.92	0.924	0.362

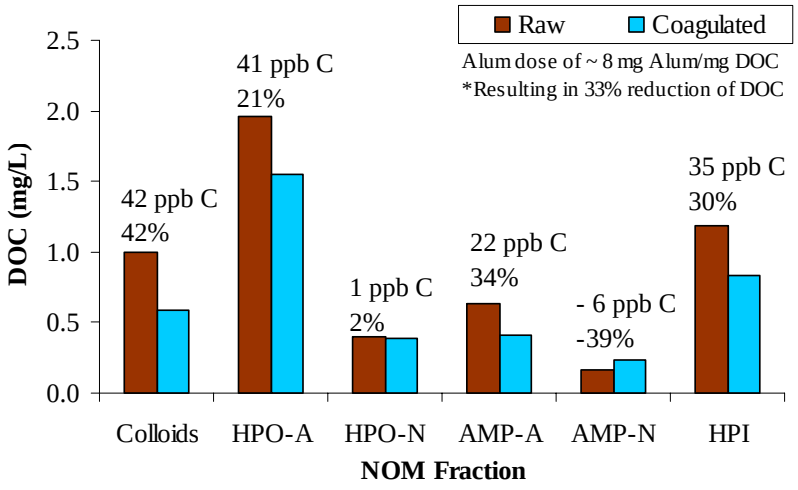
Carbon recovery during isolation averaged 95% (77%-145%)

Distribution of DOC in organic matter



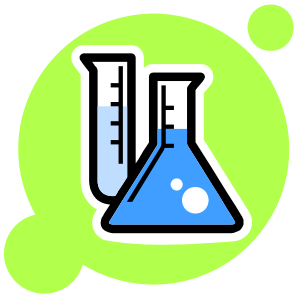


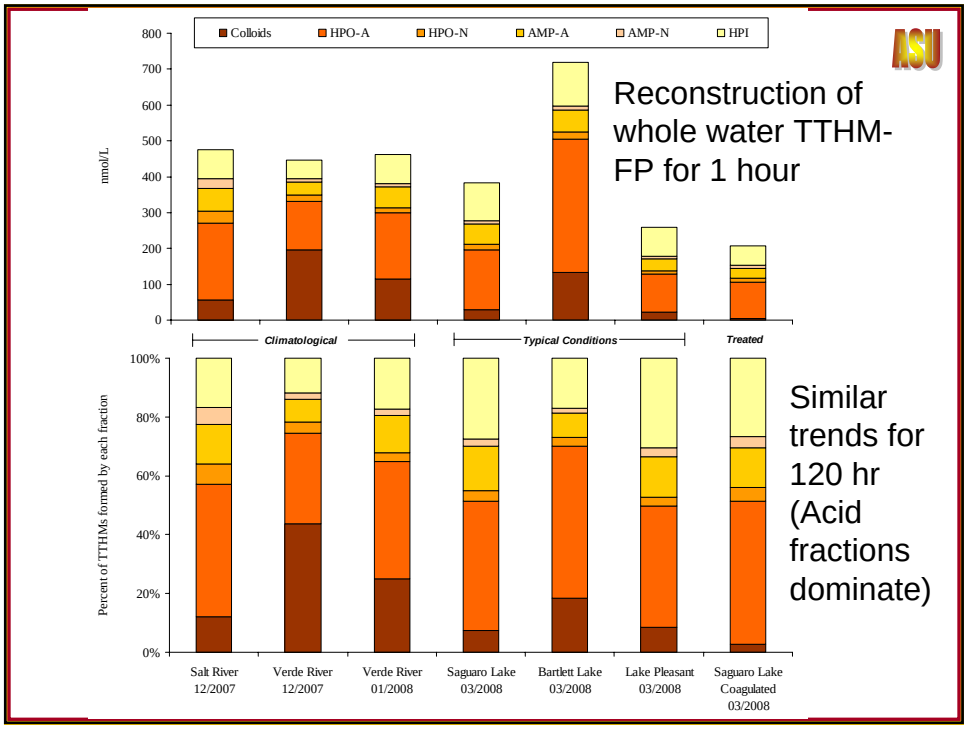
Effect of Coagulation on NOM distribution



Simulated Distribution System DBP formation testing

- Each NOM isolate was dissolved in water
- Each isolate was chlorinated under "typical" levels and incubated for 24 or 120 hours
- THM & HAA levels measured

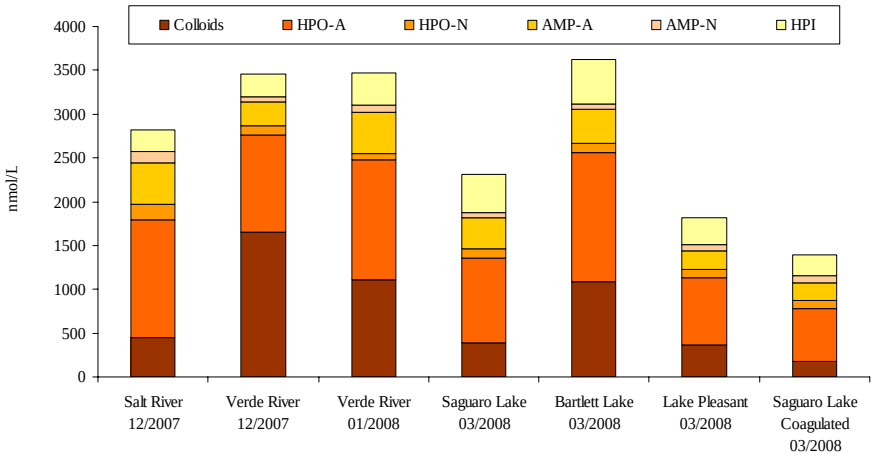




Reconstruction of whole water TTHM-FP for 1 hour

Similar trends for 120 hr (Acid fractions dominate)

120 hr HAA5 Formation Potential



Summary

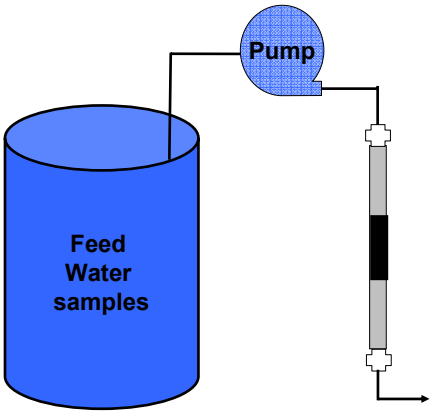
- No distinct difference was present between climatological, lake, or treated NOM pools
- The dominance (% of DOC in initial water) was as follows:
  - HPO-A > Colloids > HPI > AMP-A > HPO-N > AMP-N
- All NOM isolates form both TTHMs and HAAs but specific NOM isolates are more reactive than others.
  - HPO-A > Colloid > HPI > AMP-A > HPO-N > AMP-N
- Coagulation was observed to be better at removing colloids and acid fractions while not removing a notable portion of the neutrals.
- Higher SUVA NOM isolates react more rapidly to form TTHMs than lower SUVA NOM isolates.

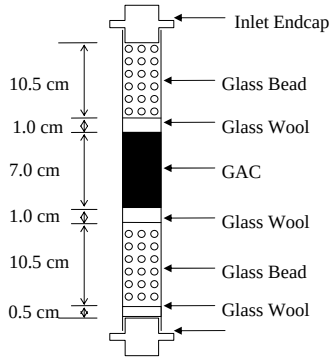
GAC to Remove Organics & DBP Precursors

DBP Precursors include:

- organic carbon
- bromide
- organic nitrogen

Schematic of RSSCTs set





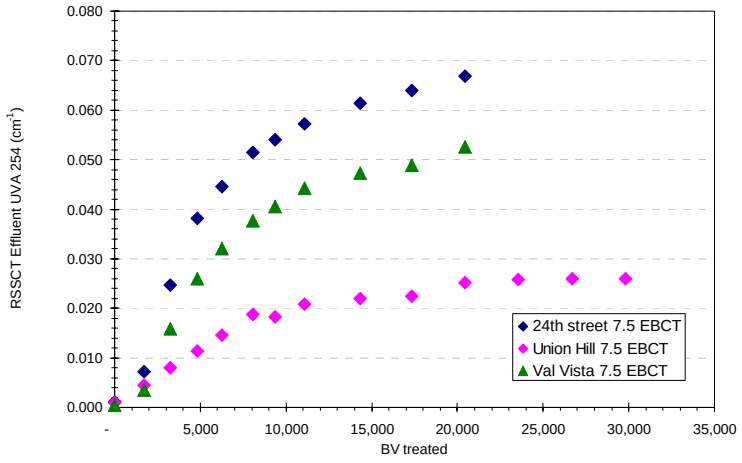
RSSCT Parameters

Parameter	Simulated Pilot Scale	RSSCT
EBCT (min)	7.5	0.46
Loading Rate (cm/min)	24.46	15.31
Particle Radius (cm)	0.08	0.005
Length of Media (cm)	121.92	7
GAC	Norit 8x20 mesh	140 x 170 mesh (0.009 to 0.0106 cm)

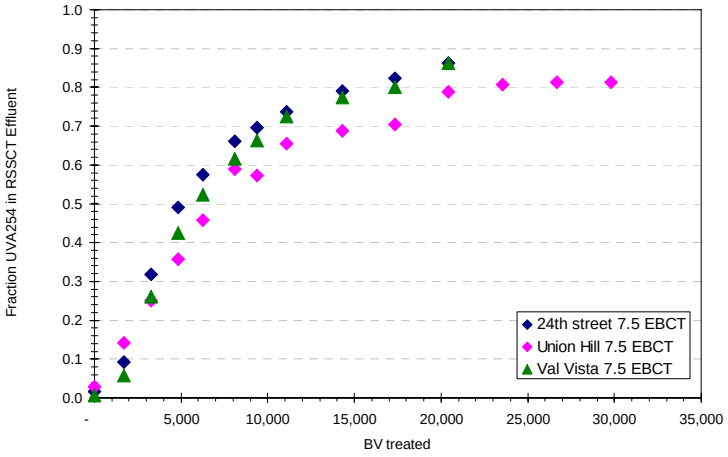
RSSCT Sampling and SDS testing

- Project conducted in cooperation with City of Phoenix, Carollo Engineers and Malcolm Pirnie Inc.
- Samples were collected every 12 hours in the first 3 days and then once per day during RSSCT test
- Parameters monitored: DOC, TDN and UV254.
- Simulated distribution system (SDS) test at 20%, 40%, 60% and 80% of UV254 breakthrough.
- 72 hours and 120 hours holding time for SDS (Analyzed by City of Phoenix)

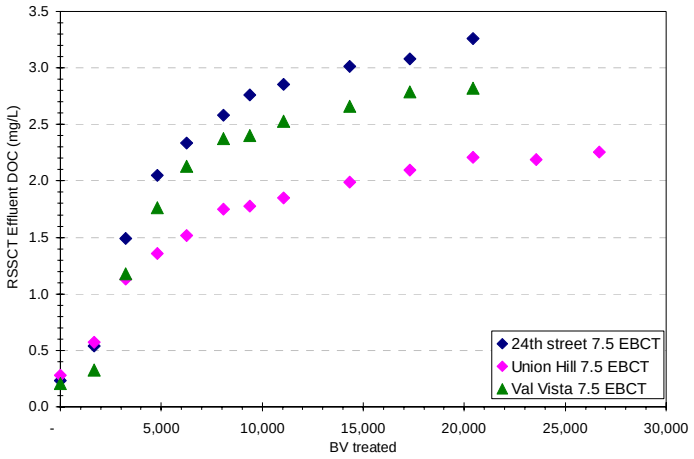
Organic Matter Breakthrough Curves



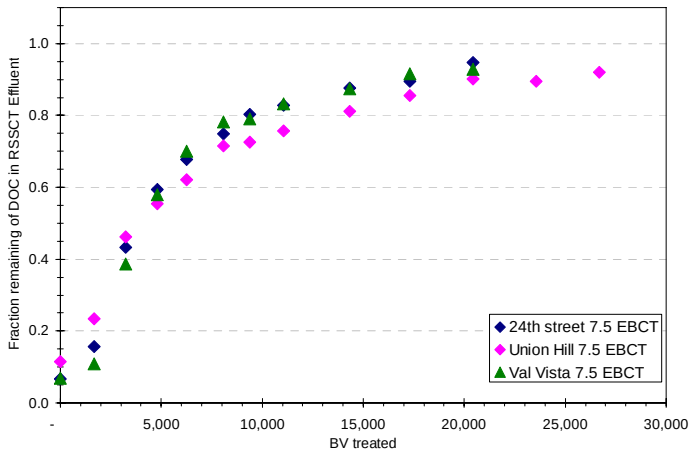
Normalized UVA breakthrough



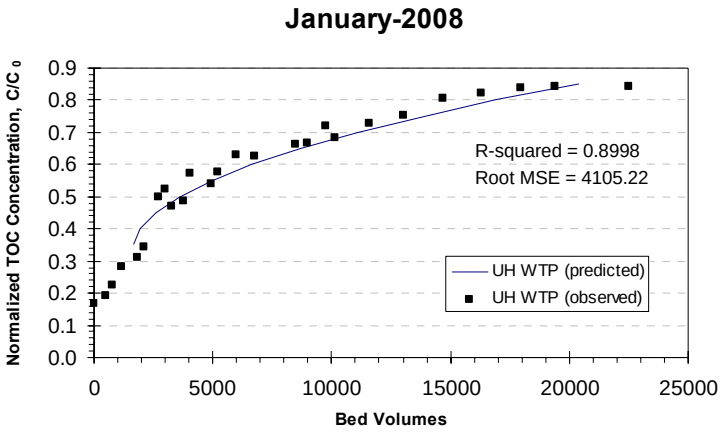
DOC Breakthrough



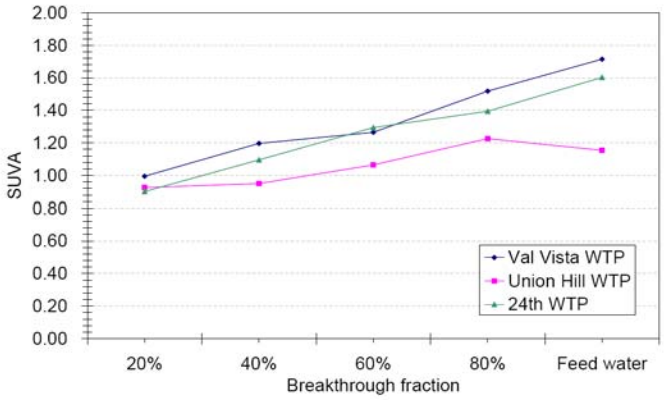
Normalized DOC Breakthrough



Modeling DOC Breakthrough

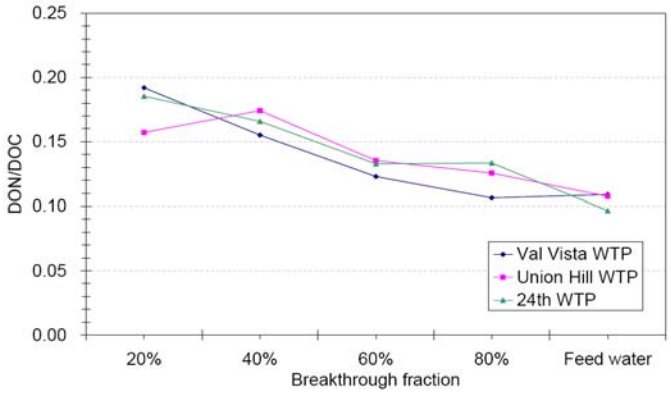


SUVA Breakthrough



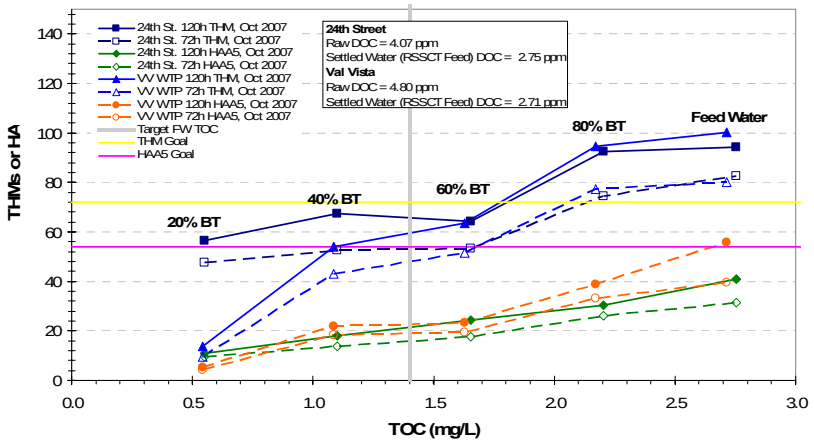
UVA material is preferentially removed fraction of organic matter

Organic nitrogen can form N-DBPs



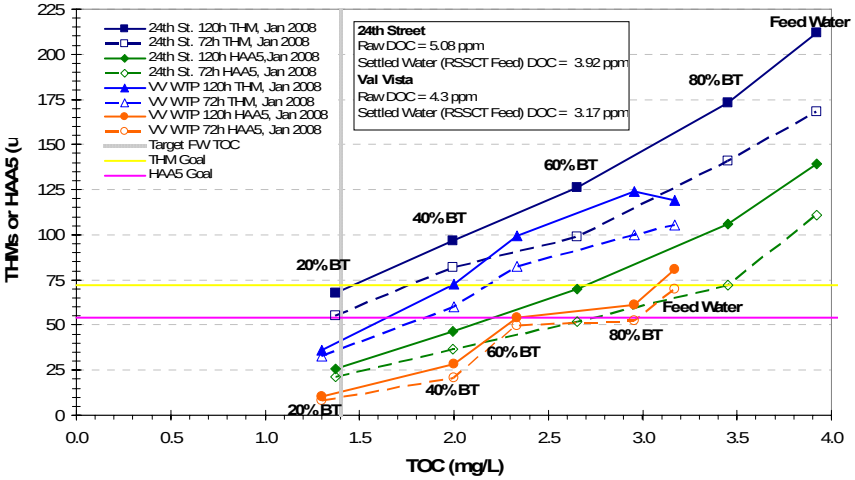
DOC is preferentially removed over DON
Both are part of the organic matter pool

SDS test results



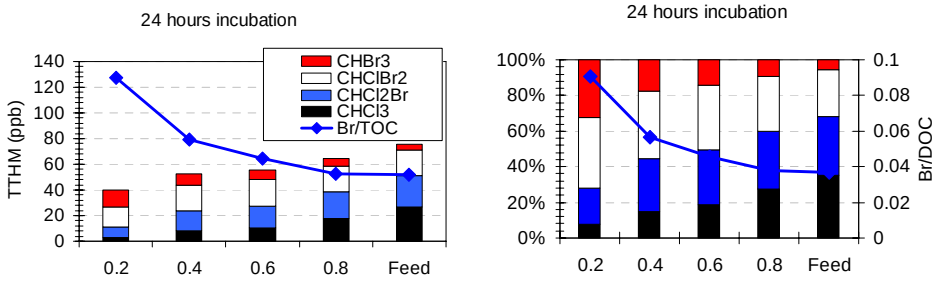
SDS testing of feed water and RSSCT effluent of October 24th Street WTP and Val Vista WTP water samples

Different month – different outcome



SDS testing of feed water and RSSCT effluent of January 24th Street WTP and Val Vista WTP water samples

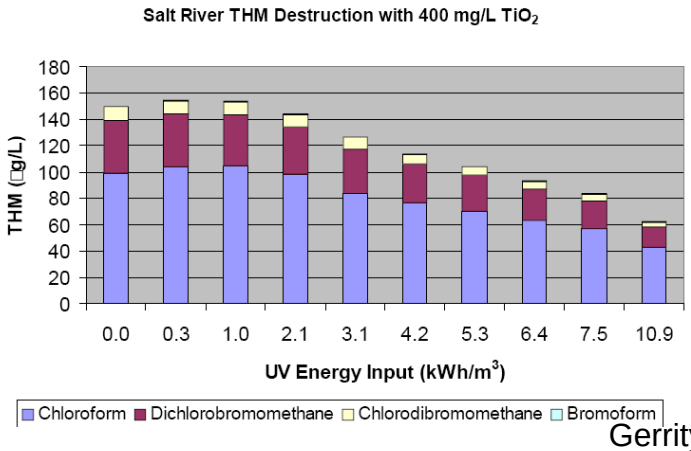
Br/DOC Ratio changes during GAC operation and affects DBP speciation



Granular activated carbon removes DOC initially, but not bromide, so THM formation shifts to a greater mass concentration of brominated THM species

Removal of DBPs after they form?

- Not an ideal approach
- Air stripping is viable for removing chlorinated THMs
- Photolysis is possible, but involves large energy input



Gerrity et al 2008

Future Directions & Discussion

- Where do you want to see our research go in 2009?
- Continued monitoring of EDC/PPCPs at potential "hot spot" locations
- Consideration of climate change on water quality
- Water-energy *nexus* issues related to water quality in central Arizona
- Characterization of organic colloid removal by different treatment trains
- As T&O levels increase be able to respond with key research needs