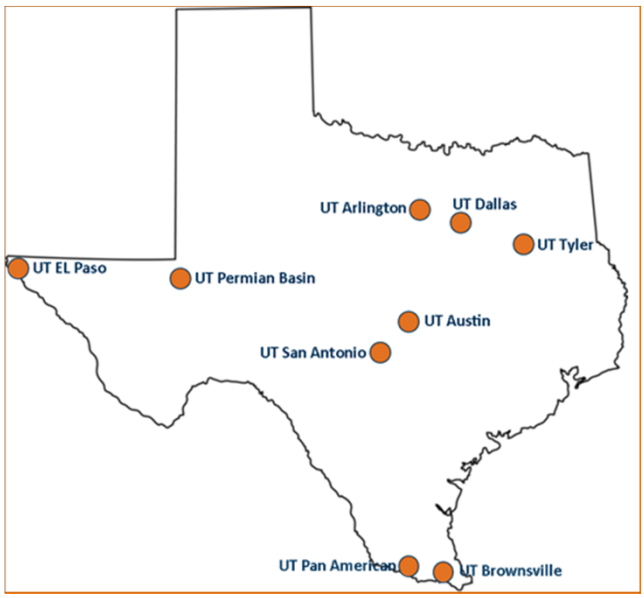
The University of Texas System



Texas Water Development Board

Sustainable Water Research for Texas

The University of Texas at El Paso

April 29, 2015

UTEP Research Centers

Center for Environmental Resources Management

Mission: provide university-wide leadership and coordination for environmentally-related research, education, and outreach activities. Priority areas for CERM include:

- Environmental health
- Water quantity and quality
- Desert and wetland ecology
- Air quality
- Renewable energy

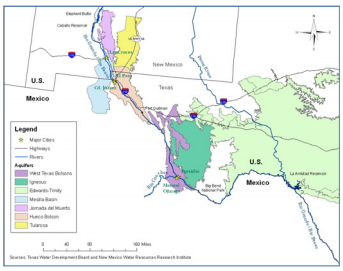
UTEP Research Centers

Center for Inland Desalination Systems

Mission: CIDS will advance the science, technology, and commercialization of inland desalination and innovative water treatment.

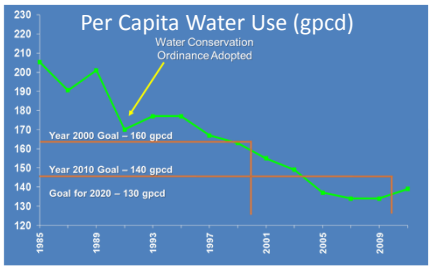
Sustainable Water Resources

- Irrigated agriculture and growing population in a desert river basin facing climate change:
- **How can sufficient water supplies be achieved and managed sustainably?**
- Integrated modeling among: hydrogeologists, climatologists, ag scientists, engineers, enconomists, anthropologists
- **Stakeholders collaboratively propose potential solutions that will be modeled and piloted**



Water Conservation

- EPWU has strategically invested in a conservation campaign for over two decades
- **Over 250 billion gallons and $460 million of deferred capital**
- Ongoing rate structure analyses



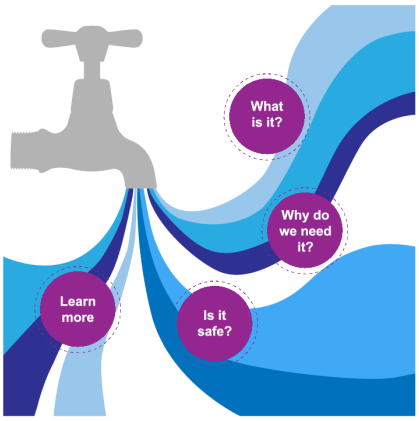
Indirect Potable Reuse

Fred Hervey Water Reclamation Plant (since 1985)

- 12 MGD of **wastewater treated to drinking water**:
  - primary, secondary, biological nitrogen removal
  - lime softening, sand filtration, ozonation, biologically activated carbon filtration, chlorination
- **Aquifer recharge** (Hueco Bolson)
- Analyses of constituents of emerging concern

Direct Potable Reuse

- **Advanced Purified Water**
  - First full-scale direct potable reuse plant in the U.S.
  - Secondary effluent treated by:
    - Biological nitrogen removal
    - Ozonation
    - Membrane Filtration
    - Reverse Osmosis
    - UV-Peroxide AOP
    - GAC Filtration
    - Chlorination
  - Piloting under construction

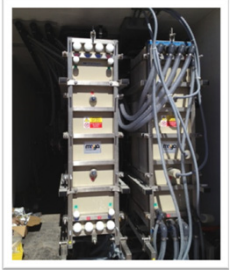


Brackish Groundwater Desalination

- Kay Bailey Hutchison Desalination Plant
  - 27.5 MGD total product (15 MGD permeate)
  - Two-stage RO
  - 83% recovery
  - Deep-well injection
- **Ongoing research and development of advanced concentrate treatment systems**

Zero Discharge Desalination (ZDD)

- Demonstrated at KBH (El Paso) and BGNDRF (Alamogordo)
- NF/RO and Electrodialysis Metathesis
- **Recovery: 97-99%**
- Energy: 6-7 kWh/kgal
- Potentially recoverable salts: $CaSO_4$, $Mg(OH)_2$, NaCl



Concentrate Enhanced Recovery RO

- Demonstrated at EPWU KBH (El Paso) and BGNDRF (Alamogordo)
- Seawater RO with high cross-flow and short cycle periods
- High silica treatment
- **Recovery: 95-97%**

Water & Wastewater for Colonias

- Focus groups for social sustainability
- Point of Use (POU) treatment for drinking water
- Community organization for development of long-term water and wastewater infrastructure

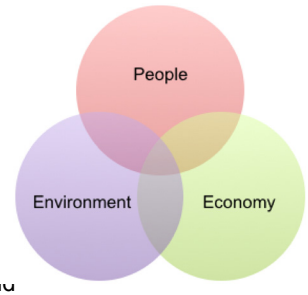
Water Research at UT Arlington

UNIVERSITY OF TEXAS ARLINGTON

The UTA Urban Water Institute

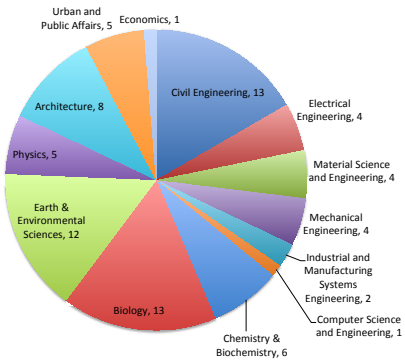
Located at the University of Texas at Arlington in the heart of the Dallas-Fort Worth Metrople
Water Institute has for mission to transf
challenges into opportunities for North
to develop innovative triple-bottom-line
solutions that encompass the economy
environment. Its goals are to

1. Bring together interdisciplinary educ
   researchers, agencies, industries ar
2. Innovate and educate in multidiscipl
   and sustainable solutions for water and energy, and
3. Help build public-private partnerships



The UTA Urban Water Institute

At The University of Texas at Arlington, about 80 faculty members are involved on various aspects of water research. These faculty members are associated with almost all UTA colleges and schools, including the College of Engineering - Departments of Civil Engineering, Electrical Engineering, Material Science and Engineering, Aerospace and Mechanical Engineering, Industrial and Manufacturing Systems Engineering, and Computer Science and Engineering - College of Sciences, - Department of Earth Sciences, Physics, Chemistry and Bio-Chemistry, and Biology, College of Business, School of Urban and Public Affairs, and School of Architecture.



Director: Jean-Pierre Bardet; bardet@uta.edu 817-271-6586

Collaborative Laboratories for Environmental Analysis and Remediation (CLEAR)

http://clear.uta.edu

Primary Research Areas:

- Exploring the relationship between unconventional drilling (hydraulic fracturing, waste handling, etc.) and groundwater quality.
- Development and testing of advanced remediation strategies for water decontamination.

UNIVERSITY OF TEXAS ARLINGTON

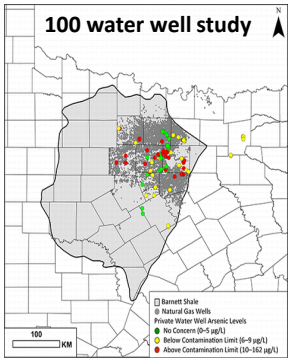
C.L.E.A.R.
Collaborative Laboratories for Environmental Analysis and Remediation

Contact: Kevin A. Schug, Ph.D., Shimadzu Distinguished Professor of Analytical Chemistry, CLEAR Director (kschug@uta.edu)

Groundwater Quality

C.L.E.A.R.
Collaborative Laboratories for Environmental Analysis and Remediation

Barnett Shale, 2011



29 of the 91 samples collected with active extraction areas contained elevated levels of arsenic (>10 µg/L)

Fontenot, B. E., et al. *Environ. Sci. Tech.* **2013,** *47,* 10032-10040

Advanced Analytical Methods and Use of Instrumentation in Shimadzu Center for Advanced Analytical Chemistry (www.uta.edu/scaac) for measuring metals, ions (Dasgupta lab, UTA), organics, and general water quality.

Most recent efforts:

Analytical characterization of wastewater from unconventional drilling: Thacker et al., *Water* **2015**, *7*, 1568-1579.

Extended water quality study (550 water wells) in the Barnett Shale: *Submitted for publication, 3/2015*.

Time course evaluation of the onset of unconventional oil extraction in the Cline Shale on water quality: *Submitted for publication 3/2015*.

Remediation Efforts

C.L.E.A.R.
Collaborative Laboratories for Environmental Analysis and Remediation

Active Degradation (Academic Affiliates)

- Extremophile enzymes (Pierce lab, UTA)
- Nanoparticle-assisted heterogeneous catalysis (Dias lab, UTA)
- Organocatalytic oxidation (Foss lab, UTA)

Passive Filtration (Industrial Affiliates)

- American Water Recycling (El Paso) – Graphene technology
- Asahi Kasei (California/Japan) – Advanced membrane technology

Drug Disposal Process

- US Patent Filed (Kevin Schug/UT Arlington)
- Licensed to MK Disposal Technologies

UNIVERSITY OF TEXAS ARLINGTON

Flood control

- High-resolution flash flood forecasting in large urban areas (NSF – DJ Seo)
- Hydrologic ensemble forecasting (NOAA/NWS - DJ Seo)
- Hydrologic analysis and design for Fort Worth Floodway (TRWD – N. Fang)

Water quality, municipal solid waste management

- In-situ sensing for detection of biological toxins in harmful algal blooms (NSF, NIH – H. Choi)
- Groundwater quality, wastewater remediation (K. Schug)
- Golden algae in Texas reservoirs (TPWD, J. Grover)
- Real-time watershed and river water quality forecasting (NIER – DJ Seo)
- Design and optimization of leachate recirculation in municipal solid waste (S. Hossain)

19

UNIVERSITY OF TEXAS ARLINGTON

Water supply

- Medium- to long-range ensemble streamflow and drought forecasting and decision support (NOAA/CPO – DJ Seo)
- Hydraulic fracturing and its impact on water resources (M. Hu)

Water supply and distribution systems, infrastructure

- Application of monochloramine to control biological growths in pumps and pipes (TRWD – A. Kruzic)
- Epidemiology of urban water distribution systems (JP Bardet)
- Performance of earthfill dams and prevention of surficial failures (USACE – A. Puppala)

GIS and remote sensing

- High-resolution mapping of elevation, vegetation and surface water (J. Lee)

20

WIT
Water Institute of Texas

UTSA
The University of Texas at San Antonio™

Water Research Expertise and Interest

UTSA The University of Texas at San Antonio™

Water Institute of Texas (WIT)

- Conduct research on the various factors related to water sustainability and their effect on the health and economic development of Texas and the Southern USA
- Multi-disciplinary collaborative institute that fosters partnerships with public and private water agencies in South Texas
- Promotes a coordinated and interdisciplinary approach to analyzing specific water related technical, socioeconomic and policy issues

The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249

UTSA The University of Texas at San Antonio™

Research Expertise and Interest

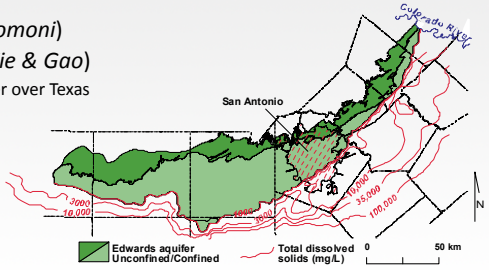
- Water resources development in the Eagle Ford Shale region (*Sharif*)
- Remote sensing precipitation products for Texas (*Sharif and Xie*)
- Physically-based, distributed-parameter runoff modeling and recharge estimation for Texas catchments and aquifers (*Sharif*)
- Flood forecasting and modeling in Texas (*Sharif*)
- Stormwater Management and Control (*Giacomoni & Shipley*)
  - Application of Low Impact Development (LID) and Best Management Practices (BMPs)
- Enhanced membrane treatment of desalination brines (*Johnson and Shipley*)
- Utilizing Plant Root Transport Pathways for Water Desalination and Subsurface Distribution (*Johnson*)
- Water Quality Monitoring (*Shipley, Johnson & Gao*)
- Novel Technologies for Water Treatment and Pollution Control (*Shipley*)
- Comparing and contrasting the success of market-based, acquisition policies (e.g. City of San Antonio's Edwards Aquifer Protection Program), as effective means of protecting quality and quantity of aquifer recharge (*Romero*)

The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249

UTSA The University of Texas at San Antonio™

Research Expertise and Interest

- Aquifer Storage and Recovery (*Dutton*)
- Desalination of Edwards Brackish Water (*Dutton & Gao*)
- Water Resources Systems Analysis (*Giacomoni*)
- Effect of aquifer heterogeneity on long-term change of desalination make-up water composition (*Dutton & Gao*)
- Drought Management/ Climate change (*Giacomoni*)
  - Adaptive Demand Management
  - Water Conservation
  - Land/Water Nexus
- Sanitary Sewer Overflows (SSOs) (*Giacomoni*)
- Quantitative Rainfall Measurements (*Xie & Gao*)
  - To better understand the availability of water over Texas



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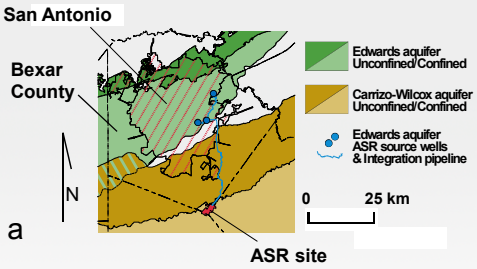
UTSA The University of Texas at San Antonio™

Aquifer Storage and Recovery

(Dutton in collaboration with SAWS)

- Volume of Edwards water in storage in Carrizo aquifer
- Technique for mapping mixing interface between Edwards and Carrizo waters
- Calibration of nuclear magnetic resonance geophysical logs for mapping hydraulic conductivity at a well-field scale
- Monitoring strategy for tracking mixing interface movement



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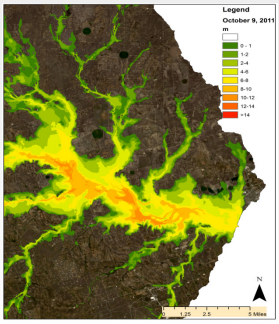
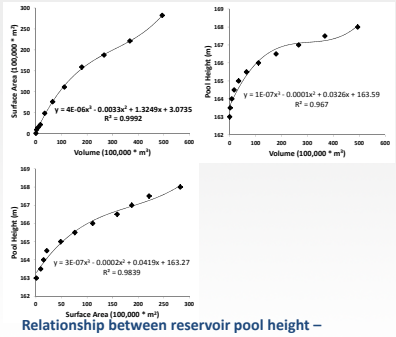
Water resources development in the Eagle Ford Shale region: Crystal City Case Study

(Sharif)

- Study the flood potential near Crystal City and delineate flood plains
- Prepare the hydrologic data for a feasibility study of a dam near Crystal City



Inundation map from October 9, 2011 event



Relationship between reservoir pool height – volume – and surface area derived from TIN

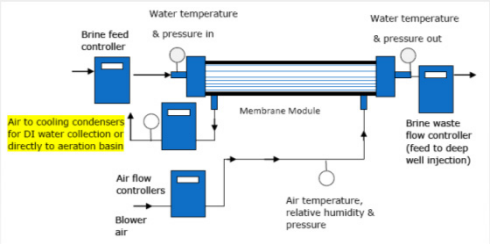
The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249

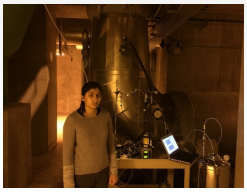
UTSA The University of Texas at San Antonio™

Enhanced membrane treatment of desalination brines

(Johnson and Shipley in collaboration with SAWS)

- focuses on membrane evaporation processes to reduce desalination brine volume
- investigates the potential of coupling membrane evaporation with waste heat generated from activated sludge aeration blower





Work supported by US Bureau of Reclamation

The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249

Water Research at UT Rio Grande Valley

UTRGV

UTB and UTPA

Research at UTB

- Arroyo Colorado Bacterial Source Tracking (2013-2015)
  - TSSWCB grant with five major partners ($350,000)
    - TWRI – Texas Water Resources Institute
    - TIAER – Texas Institute for Applied Environmental Research
    - ACWP – Arroyo Partnership
    - Texas A&M University
    - UTB – University of Texas at Brownsville ($70,000)
      - Local Coordination (presence in the watershed)
      - Collection of in-stream bacterial count samples for enumeration and DNA sequencing
      - Goal: Link E. coli and Enterococcus bacteria water column concentrations to their constituent source
        - » Human, avian, bovine, etc.
        - » Assist in more efficient water quality policy formulation

Research at UTB

- Brownsville Area Resaca Watershed Characterization (just awarded – 2014- 2016)
  - EPA grant with four major partners ($450,000)
    - TWRI – Texas Water Resources Institute
    - TIAER – Texas Institute for Applied Environmental Research
    - ACWP – Arroyo Partnership
    - UTB – University of Texas at Brownsville ($100,000)
      - Local Coordination (presence in the watershed)
      - Water quality data gap analysis and collection of additional data to fill gaps
      - Goal: Characterize watershed boundaries, potential sources of pollution, outreach / community stakeholder input on impairment mitigation measures.

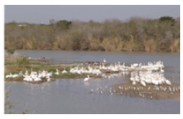
Research at UTB

- EFDC (Environmental Fluid Dynamics Code) Modeling for the Arroyo Colorado (2012-2015)
  - EPA grant with three major partners ($500,000)
    - TWRI – Texas Water Resources Institute
    - TIAER – Texas Institute for Applied Environmental Research
    - ACWP – Arroyo Partnership
    - UTB - University of Texas at Brownsville ($80,000 Share)
      - Education and Outreach
      - Local Coordination (presence in the watershed)
      - Water quality data collection for model calibration and validation

Dr. Frank J. Dirrigl Jr.
LRGV Biomonitoring Laboratory
Environmental & Earth Sciences Program

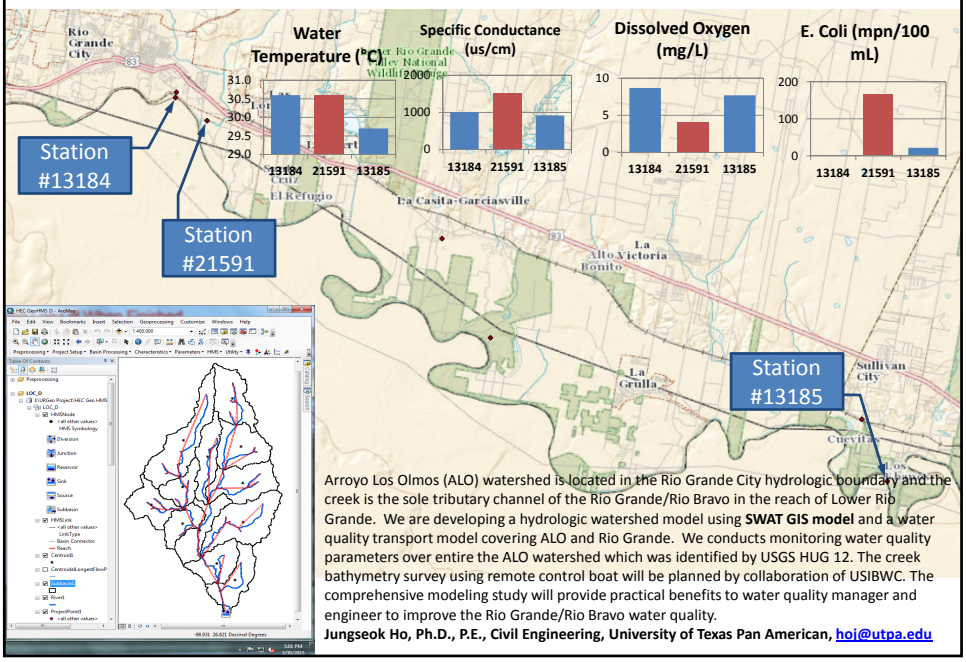
- Stormwater Quality Monitoring
- Irrigation Canal Water Quality Monitoring
- Evaluation of Best Management Practices (BMPs)
- Biomonitoring to Determine Ecosystem Health

Water Quality Sampling in the Arroyo Colorado and Brownsville Area Resacas



Jude A. Benavides, Ph.D.
Jaime Flores, Watershed Coordinator, TWRI
Monica Delgado, B.S. (Env Sci)
Guadalupe Garcia
Rachelle Maldonado
Juan Castaneda
Robert Figueroa-Downing
John Gray, B.S. (Env Sci)

Arroyo Los Olmos Watershed Hydrologic Modeling



Arroyo Los Olmos (ALO) watershed is located in the Rio Grande City hydrologic boundary and the creek is the sole tributary channel of the Rio Grande/Rio Bravo in the reach of Lower Rio Grande. We are developing a hydrologic watershed model using **SWAT GIS model** and a water quality transport model covering ALO and Rio Grande. We conducts monitoring water quality parameters over entire the ALO watershed which was identified by USGS HUG 12. The creek bathymetry survey using remote control boat will be planned by collaboration of USIBWC. The comprehensive modeling study will provide practical benefits to water quality manager and engineer to improve the Rio Grande/Rio Bravo water quality.

Jungseok Ho, Ph.D., P.E., Civil Engineering, University of Texas Pan American, hoj@utpa.edu

UT Tyler Current Water Conservation and Responsible Development Projects

- Key Faculty Involved:
  - Harmonie Hawley (Engineering)
  - Neil Ford (Biology)
  - Lance Williams (Biology)
  - Meryem Saygili (Economics)
  - Josh Banta (Biology)
  - John Placyk (Biology)
  - Thomas Guderjan (Anthropology)

- Key Project Areas:
  - The effects of water use and manipulation on endangered species.
  - Waterway interruption (bridge construction) effects on native aquatic organisms.
  - Hydrologic and hydraulic modeling of surface water in particular to estimate flow and stress effects on threatened habits.
  - Method development to determine the specific surface area of solid media. The main interest is to understand contaminant movement in groundwater and improved water remediation.
  - Geotechnical engineering advice, research, analysis and development support for oil and gas offshore development projects, which support offshore structures and pipelines.

Project Spotlight: Big Thicket (Dr. Neil Ford, UT Tyler Biology)

Texas has over fifty species of unionid mussels in multiple river basins that often have isolated drainage into the Gulf of Mexico. The species composition in southeastern Texas differs significantly from that of central and western areas. Southeast Texas is also a region where the construction of reservoirs and smaller impoundments has been prevalent. The change in water flow downstream of dams has major impacts on mussel diversity and abundance. In addition, erosion from agricultural land, water pollution and commercial harvesting have likely been impacting the freshwater mussels of this area. However, the Neches and its tributaries above Beaumont receive some environmental protection from the lands of the Big Thicket National Preserve. Whether this has reduced the factors causing mussel declines elsewhere is unknown since mussel surveys in the area are very limited.

Specific Goals of the Project: Survey for mussels in larger streams and rivers of 4 units of the Big Thicket Nature Preserve with emphasis given to areas where habitat characteristics are appropriate for mussels.

Water Research at UT Austin

TEXAS
The University of Texas at Austin

Center for Research in Water Resources

The University of Texas at Austin
J.J. Pickle Research Center

The mission of CRWR is to:

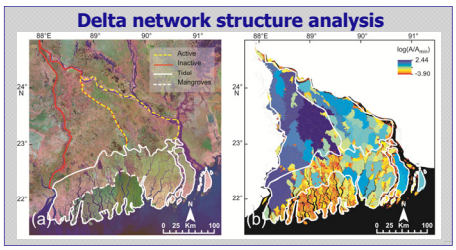
- serve as the central focus for environmental and water resources research at the University;
- communicate the results of its advanced research to government, industry, and other educational institutions;
- work with other agencies and institutions in Texas to solve the State's complex water problems:
- act as a regional center for water-related research, education, planning, and practical design;
- share relevant experience and provide support to graduate students of the University by involving them in applied research.

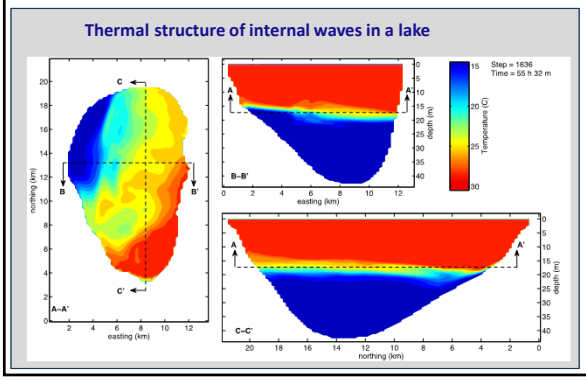
CRWR Researchers, Staff and Students

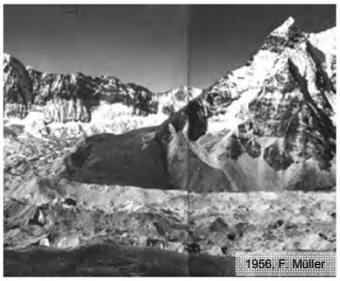
Long standing strengths in Water Treatment and Management

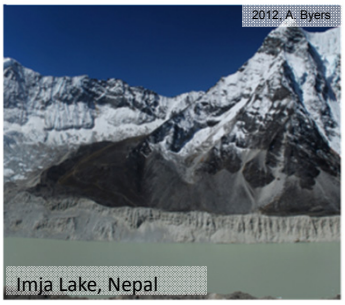
- 15 faculty
  - Plus 4 affiliates in the Jackson School of Geosciences
- 3 research scientists
- 9 research fellows (e.g., post-docs, research associates, etc.)
- ~80 graduate students
- 3.5 administrative staff
- 0.25 professional staff
- Average research funding of $4-5 million/yr

Regional Water Modeling





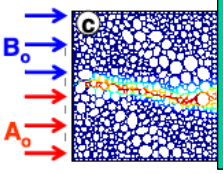




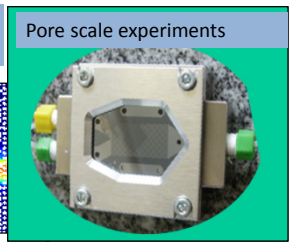
Reactive Transport in Porous Media

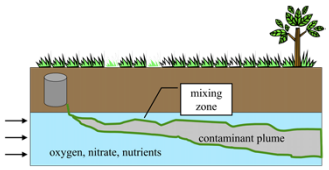
Applications to hazardous waste remediation & geological carbon sequestration

Pore scale modeling



Pore scale experiments





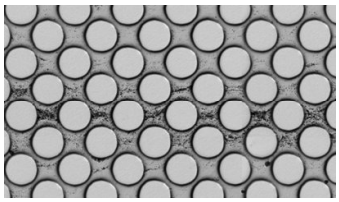
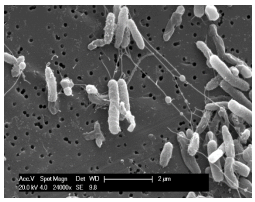


Image analysis of biomass growth and precipitation in model aquifers

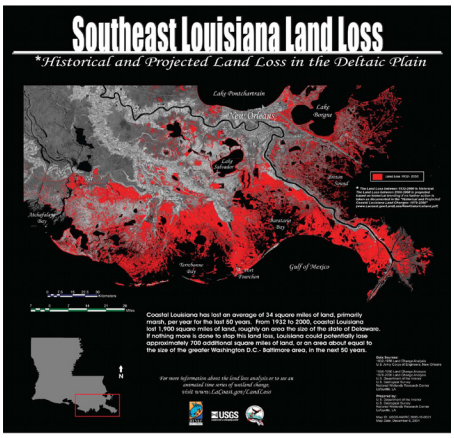


Coastal Restoration

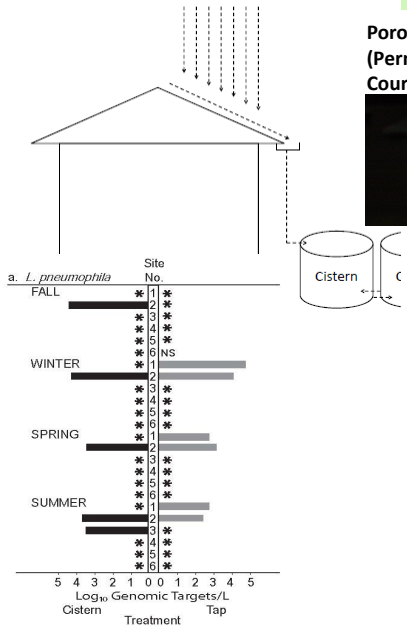
NSF-funded Delta Dynamics Collaboratory:

Field observatory and numerical modeling brings together five different disciplines in a multidisciplinary effort to recapture land mass

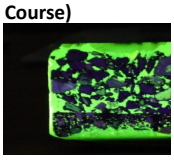
From Natural to Engineered Systems

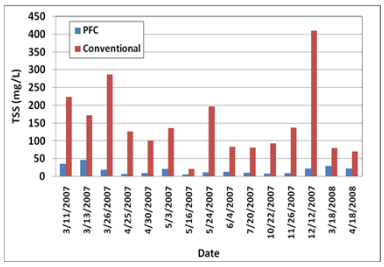


Rainwater, Greywater and Stormwater

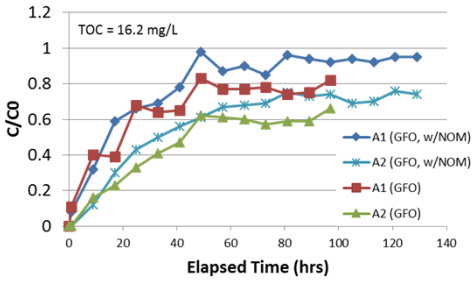


Porous Pavement (Permeable Friction Course)



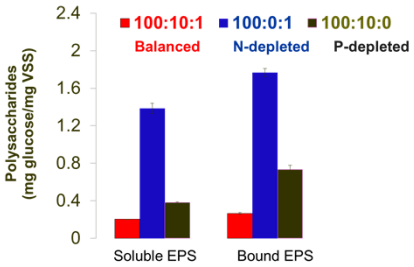


Iron Oxide Media, Influent Cu = 50ug/L

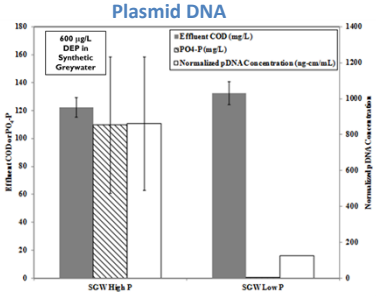


Nutrients in Wastewaters

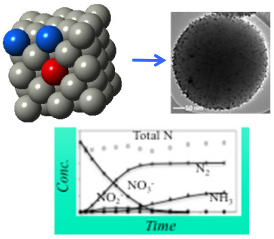
Extracellular Polysaccharides



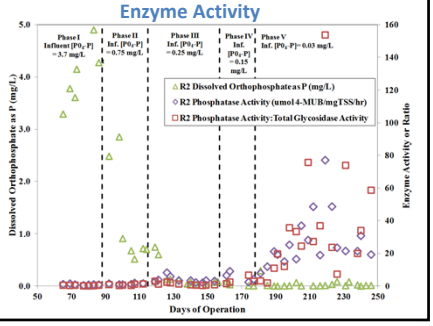
Plasmid DNA



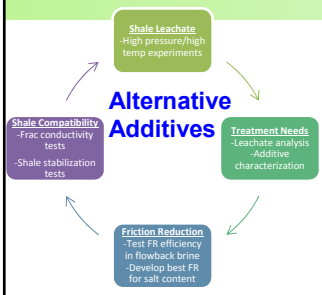
Catalysts for Nutrient Removal



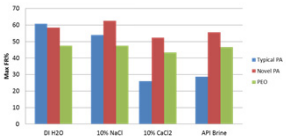
Enzyme Activity



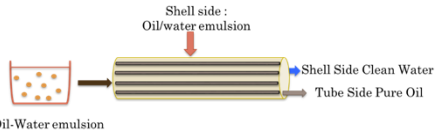
Hydraulic Fracturing and Produced Water Treatment and Reuse



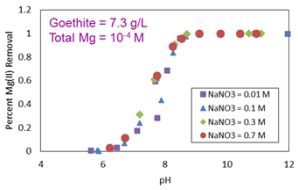
Alternative Additives

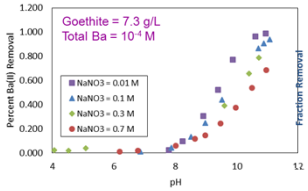


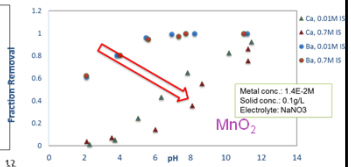
Hydrophobic Membranes for Oil Recovery



Evaluating Adsorbents for Selective Ion Removal in Saline Waters

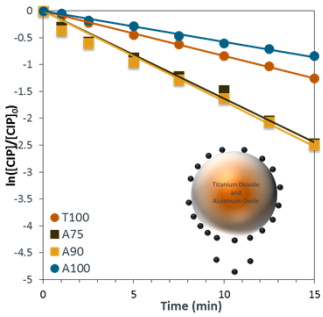




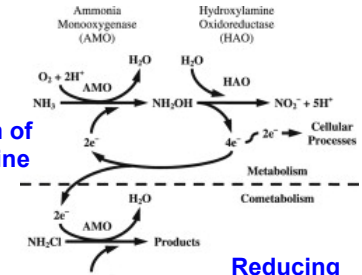


Treatment of PPCPs, DBPs and Emerging Contaminants

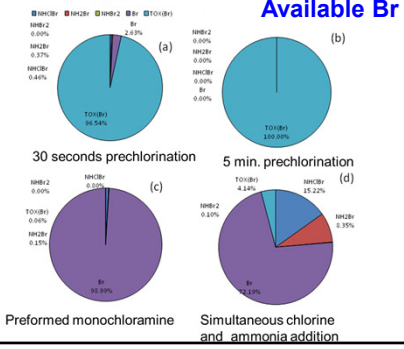
Photocatlysis of Ciproflaxacin



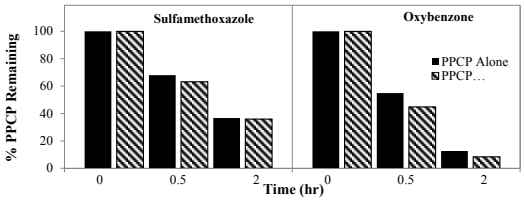
Cometabolism of Monochloramine



Reducing Available Br

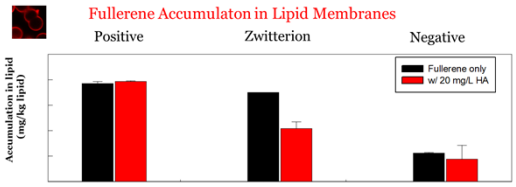


Enzyme Based Degradation



Nanoparticles

Fate and Transport



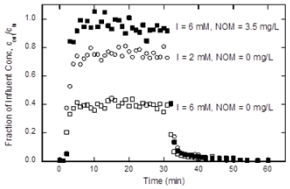
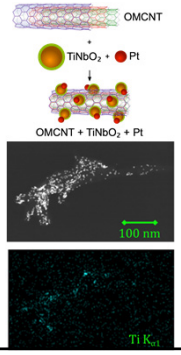
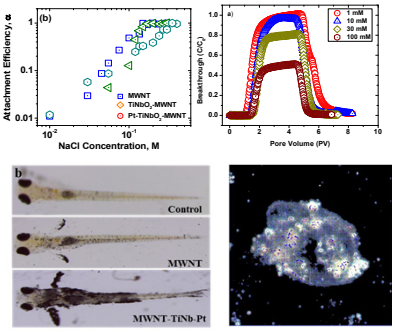


Figure 6. Breakthrough of AgNPs with and without NOM in column filtration experiments.

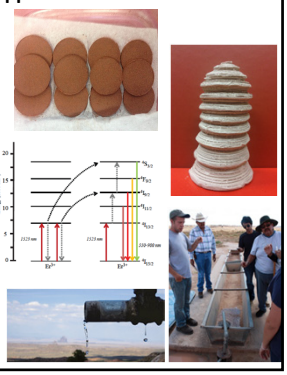
Material Synthesis/ Characterization



Safety assessment and Redesign

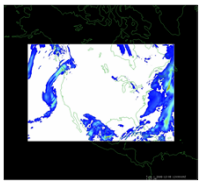


Applications in Water Treatment

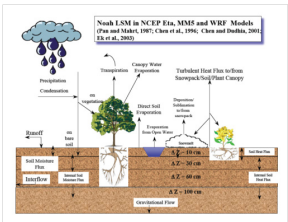


Flooding and Drought

Weather model and forecasts



Weather → Precipitation

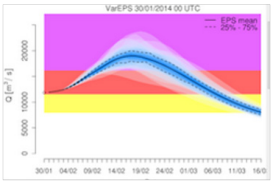


Land-Atmosphere Model

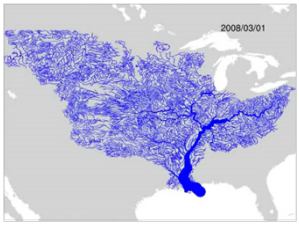
Catchment-level forecasts

Runoff →

Probabilistic flood forecasts



← Streamflow



Channel flow routing (for continental US)

Texas Soil Observation Network (TxSON)

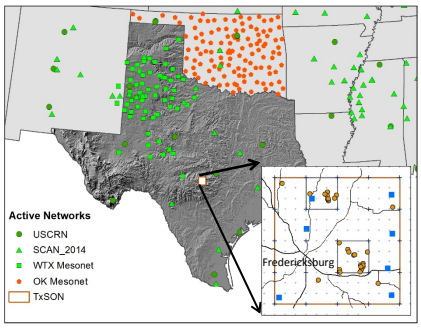
TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Bureau of Economic Geology

How can we utilize large-scale Soil Moisture?

NASA SMAP Core Cal/Val Site:

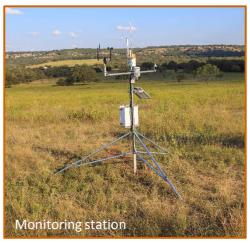
- Nested design: 41 total stations
- Covering 500 square miles, eastern Gillespie County
- Soil moisture at 5, 10, 20 and 50 cm
- Real-time data collection
- Ground validation for SMAP/NLDAS

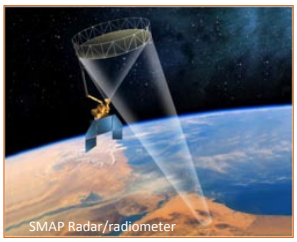
http://www.beg.utexas.edu/txson/

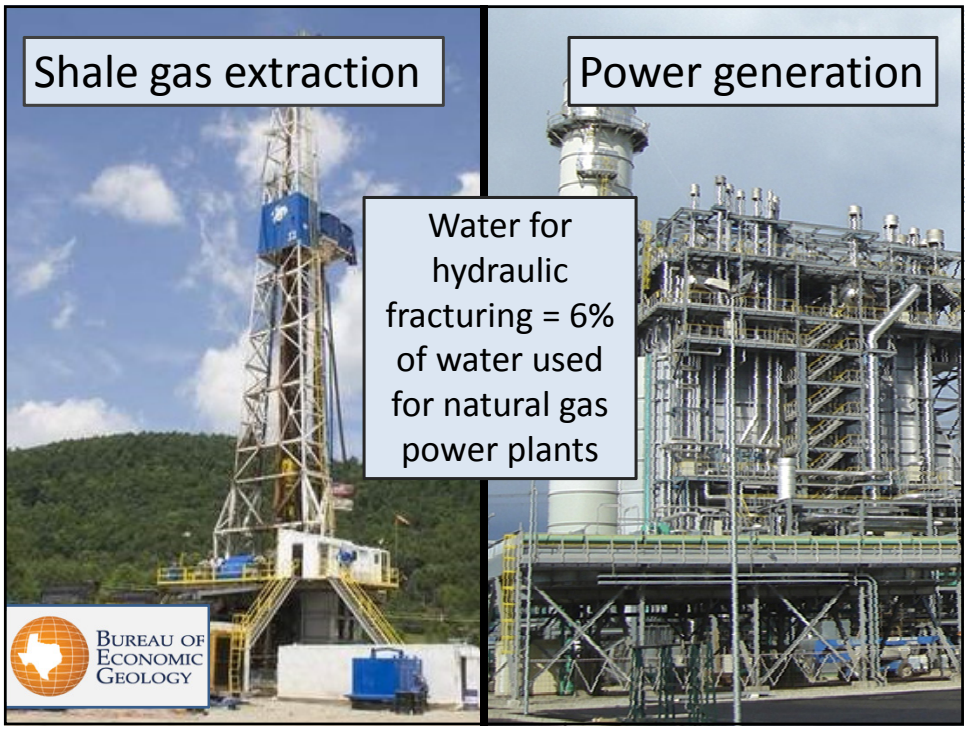


NASA Soil Moisture Active/Passive (SMAP)

- Launched January 31, 2015
- Global soil moisture at 9km
- ~every 50 hours

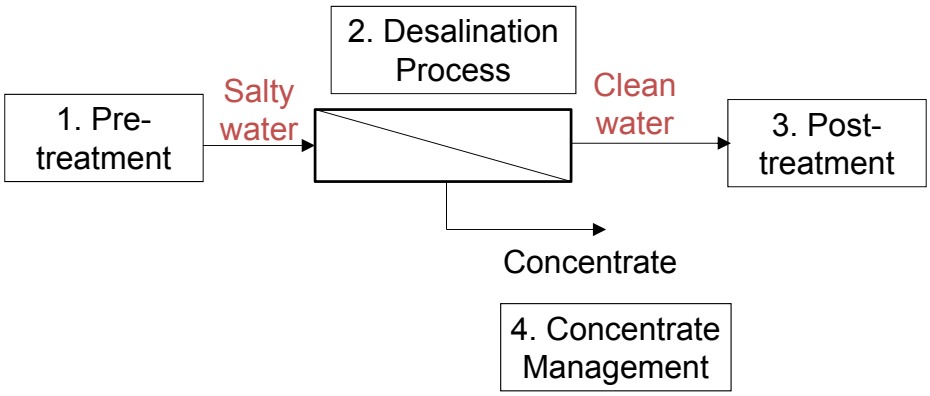

Monitoring station


SMAP Radar/radiometer



Research Focused on Desalination

Four key areas



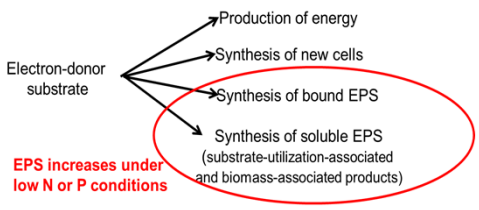
1. Pretreatment requirements, challenges, and opportunities

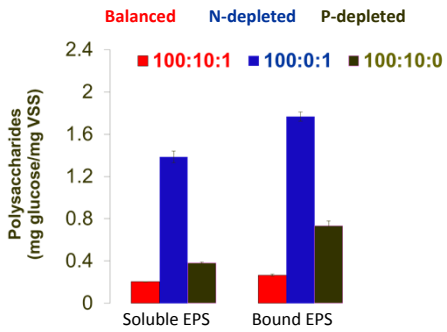
- Bio-fouling control (disinfection) often uses:
  - Chlorine—dechlorination or chlorine resistant membranes would be required
  - Ozone—formation of bromate in bromide-containing waters
  - UV
- Particle removal
  - Conventional treatment: coagulation & filtration
  - Membrane treatment: ultrafiltration
- Scaling control
  - Acid addition—prevents oxide, hydroxide, and carbonate solids from being formed, but adds to TDS
  - Organic anti-scalants
  - Silica control—precipitation prior to first stage or interstage treatment

1. Pre-Treatment Example: Reduction of biofouling

Lead Investigator: M. Kirisits

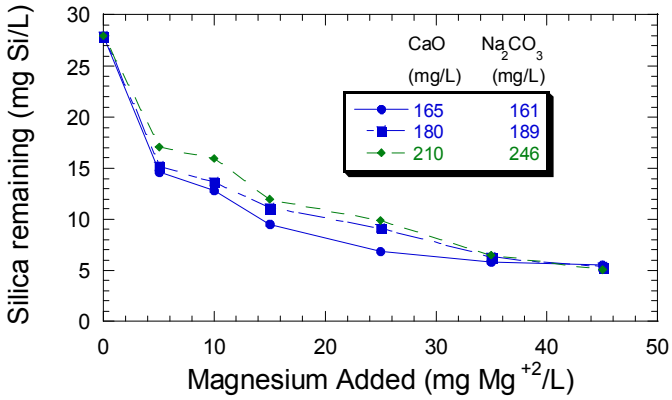
- Production of extracellular polymeric substances (EPS) can lead to biofouling of granular media and membrane filters.
- What operating conditions minimize EPS production?





1. Pretreatment Example: Precipitation can be used to reduce silica, calcium, barium

- Addition of magnesium increased silica removal via precipitation



Initial Amounts Added:

Ca^{+2} 50 mg/L

Mg^{+2} 20 mg/L

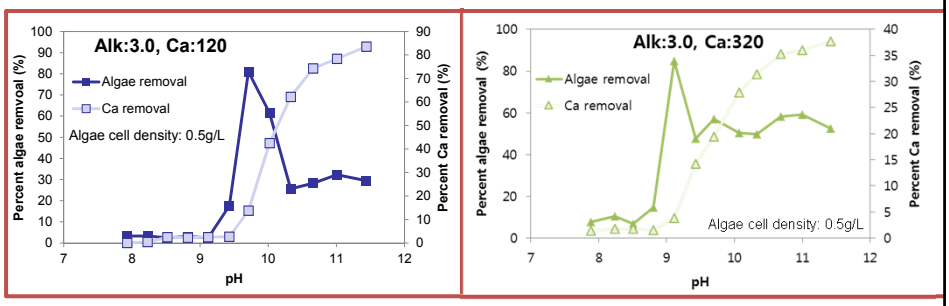
Si 28 mg/L

Lead Investigators: D. Lawler

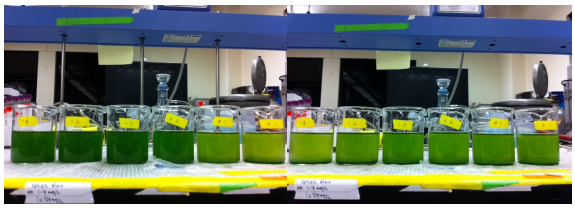
1. Pretreatment Example : Removal of algae and Ca via coagulation/flocculation

Lead Investigators: L. Katz and K. Kinney

- Maximum removal of algae coincides with the onset of Ca precipitation.



Algae cell density: 0.5g/L,
Alk: 1.0meq/L, Ca: 120mg/L



2. Desalination Membrane Processes

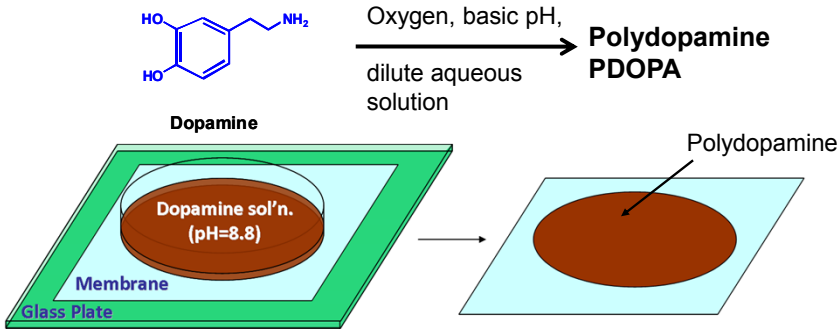
- Chlorine-tolerant desalination membranes based on sulfonated polymers.
- Fouling resistant ultrafiltration and microfiltration membranes.
- Desalination membranes by melt processing.

- Fundamentals of fouling of porous membranes.
- Fundamentals of water and ion transport in polymers.
- Influence of multiphase block copolymer morphology on water and ion transport.

2. Membrane Development: Fouling resistant membrane coatings

Lead Investigator: B. Freeman

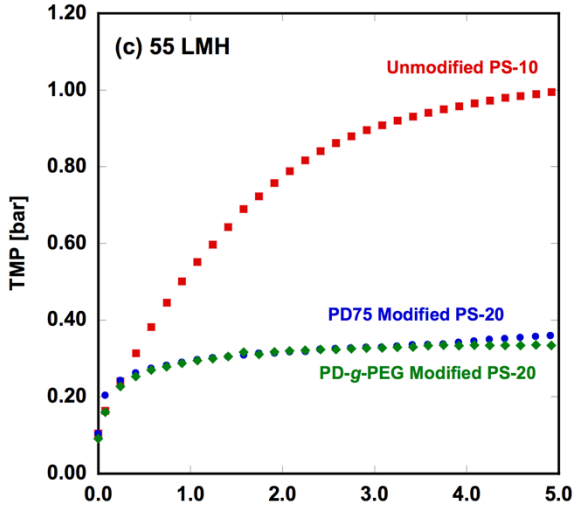
- Polydopamine deposits onto and adheres to virtually any membrane surface and renders that surface hydrophilic.



B.D. McCloskey, H.B. Park, H. Ju, B.W. Rowe, D.J. Miller, B.J. Chun, K. Kin, B.D. Freeman, *Polymer* 51, 2010, 3472-3485; D.R. Dreyer, D.J. Miller, B.D. Freeman, D.R. Paul, C.W. Bielawski, *Langmuir* 28, 2012, 6428-6435.

57

2. Surface Modified Membranes Outperform Unmodified Membranes



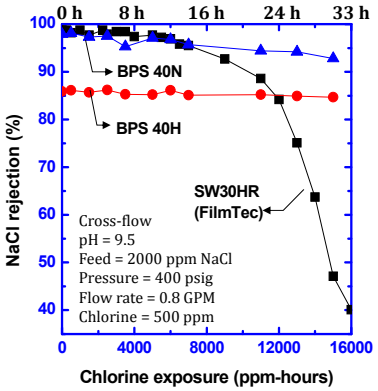
Lead Investigator: B. Freeman

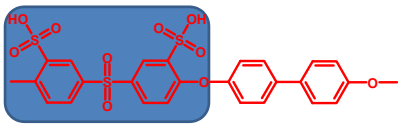
58

2. Membrane Development: Chlorine Tolerant Membranes

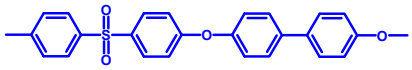
Lead Investigator: B. Freeman

- **Sulfonated polysulfone membranes exhibit high chlorine tolerance**





Hydrophilic segment



Hydrophobic segment

- **High water permeability**
- **High chlorine tolerance**
- **Excellent fouling-resistance**
- **Good reproducibility**

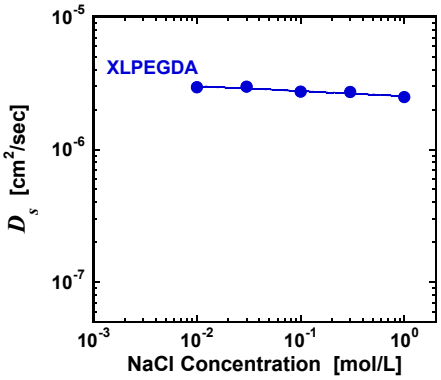
H.B. Park, B.D. Freeman, Z.B. Zhang, M. Sankir, and J.E. McGrath, Highly Chlorine-Tolerant Polymers for Desalination, *Angew. Chem.-Int. Edit.* 47 6019-6024 (2008).

2. Membrane Treatment: Understanding Mechanisms

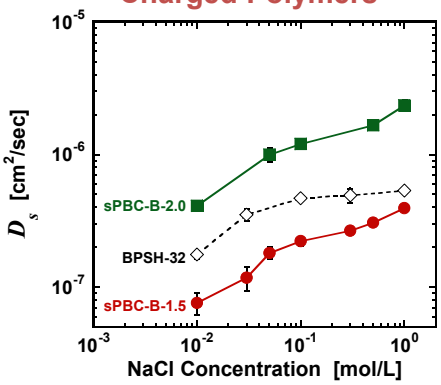
Lead Investigator: B. Freeman

- Influence of Salt Concentration on Salt Diffusion Coefficient Depends on Polymer Charge

Uncharged Polymer



Charged Polymers



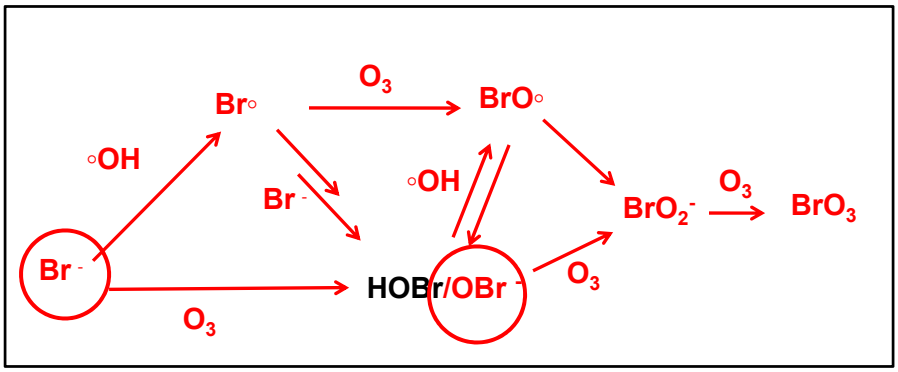
Geise, G.M., B.D. Freeman, and D.R. Paul, "Sodium Chloride Diffusion in Sulfonated Polymers for Membrane Applications," *J. Membrane Sci.*, 427, 186-196 (2013).

60

3. Post-desalination water treatment: challenges and opportunities

- Water may be too clean to use or too corrosive to pipe
  - Adding minerals for taste (Ca, Mg)
  - Adding carbonate to adjust alkalinity
  - Possible to blend with small volume of concentrate, but water quality essential
  - Possible stripping of H_2S
  - Adding polyphosphates for corrosion control
- Disinfection; Treatment of disinfectant residuals

Disinfection By-Products: Bromate formation



Pinkernell and von Gunten, (2001)

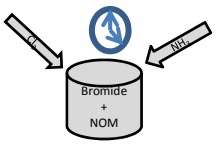
- Desalinated seawater can contain elevated bromide.
  - 650 µg/L (Magara et al., 1996; Obolensky and Singer, 2005)
- Bromate (BrO_3^-) is formed from bromide (Br^-) during ozonation.

62

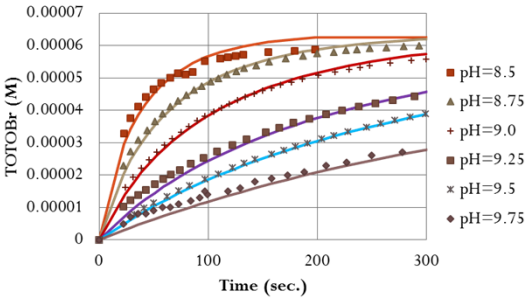
Manipulating operating conditions in pre-chloramination to decrease free bromide

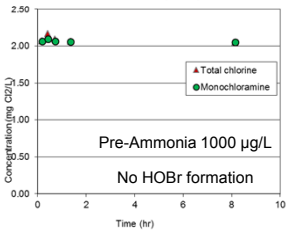
Lead Investigators: G. Speitel and L. Katz

Unified Haloamine Model can guide operating strategies that tie up bromide in other non-reactive species



1) $HOCl + NH_3 \rightarrow NH_2Cl + H_2O$
2) $NH_2Cl + H_2O \rightarrow NH_3 + HOCl$
3) $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$
4) $NHCl_2 + H_2O \rightarrow NH_2Cl + HOCl$
5) $NH_2Cl + NH_2Cl \rightarrow NHCl_2 + NH_3$
6) $NHCl_2 + NH_3 \rightarrow NH_2Cl + NH_2Cl$
7) $NH_2Cl + NHCl_2 \rightarrow N_2 + 3H + 3Cl$
8) $NHCl_2 + H_2O \rightarrow NOHl + 2HCl$
9) $NOH + NHCl_2 \rightarrow N_2 + HOCl + HCl$
10) $NOH + NH_2Cl \rightarrow N_2 + H_2O + HCl$
11) $HOCl + Br^- \rightarrow HOBr + Cl^-$
12) $HOBr + NH_3 \rightarrow NH_2Br + H_2O$
13) $HOBr + NH_2Cl \rightarrow NHClBr + H_2O$
14) $NH_2Cl + NH_2Cl + Br^- \rightarrow NHClBr + Cl^- + NH_3$
15) $NHClBr + NHClBr + H_2O \rightarrow N_2 + HOBr + HBr + 2HCl$
16) $NH_2Br + NH_2Br \rightarrow NHBr_2 + NH_3$
17) $NHBr_2 + NH_3 \rightarrow NH_2Br + NH_2Br^-$
18) $NHBr_2^- + NHBr_2 \rightarrow N_2 + 3H^+ + 3Br^-$
19) $NH_2Br + NHBr_2^- + H_2O \rightarrow N_2 + HOBr + 3H^+ + 3Br^-$
20) $NH_2Cl + NHClBr^- \rightarrow N_2 + 3H + 2Cl + Br^-$
21) $OBr + NH_3 \rightarrow NH2Br + H_2O$
22) $OBr + NH_2Cl \rightarrow NHClBr + H_2O$

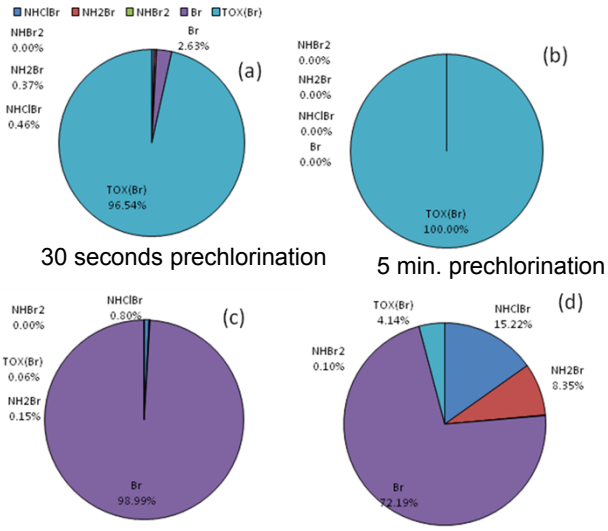




63

Engineering significance of pre-chloramination

- Sequestration of bromide is a key to controlling bromate formation.
- Less bromate will be formed with less free bromide ion available.



30 seconds prechlorination

5 min. prechlorination

Preformed monochloramine

Simultaneous chlorine and ammonia addition

64

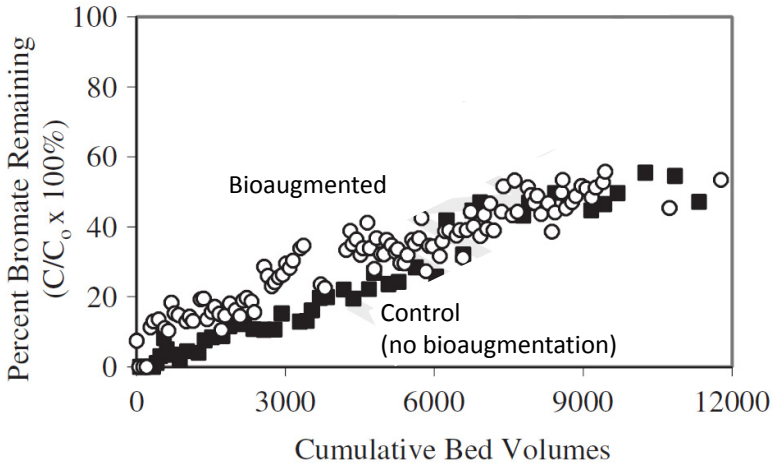
Lead Investigator: G. Speitel and L. Katz

Post-Treatment: Biological bromate reduction

Lead Investigator: M. Kirisits

- Microbial reduction of BrO_3^- to Br^-
  - Occurs under low dissolved oxygen conditions
- Bioaugmentation of isolated bromate-reducing bacteria to a granular activated carbon filter was studied.

Bioaugmentation appears unnecessary. Indigenous bacteria reduce bromate.



Lead Investigator: M. Kirisits

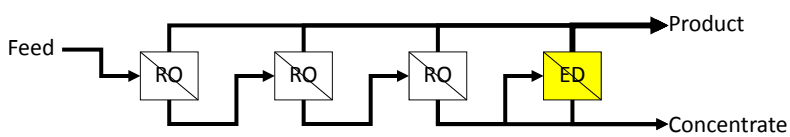
4. Concentrate Management

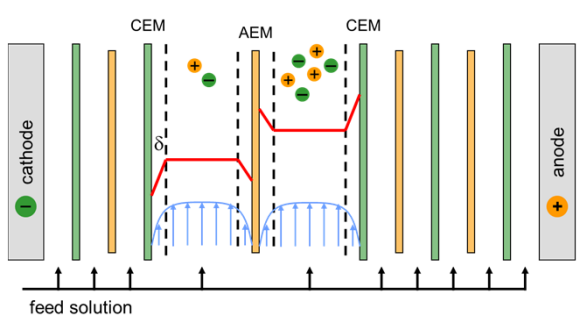
- For inland desalination, concentrate disposal is the predominant challenge
- Reverse osmosis (RO) recovery is limited
- Increasing recovery means decreasing concentrate volume
- Consider a treatment of concentrate to increase recovery

67

Concentrate Management: Electrodialysis treatment

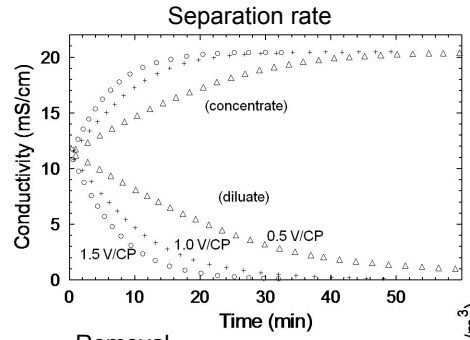
Lead Investigator: D. Lawler

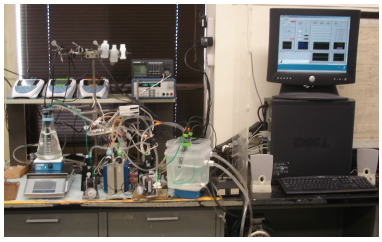


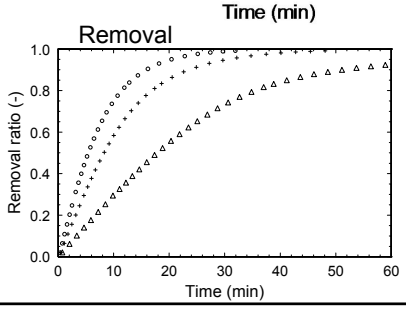


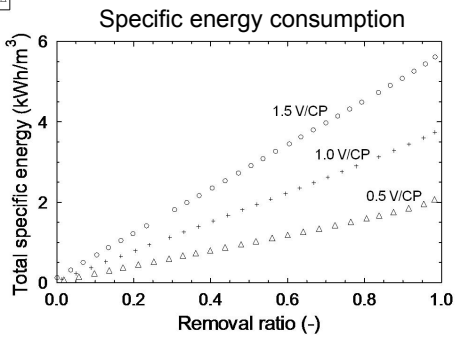
Strathmann, H. (2004). *Ion-exchange membrane separation processes*, Elsevier, Boston.
AWWA. (1995). "M38 - Electrodialysis and Electrodialysis Reversal." P. Murray, ed.

Electrodialysis: Performance and energy consumption



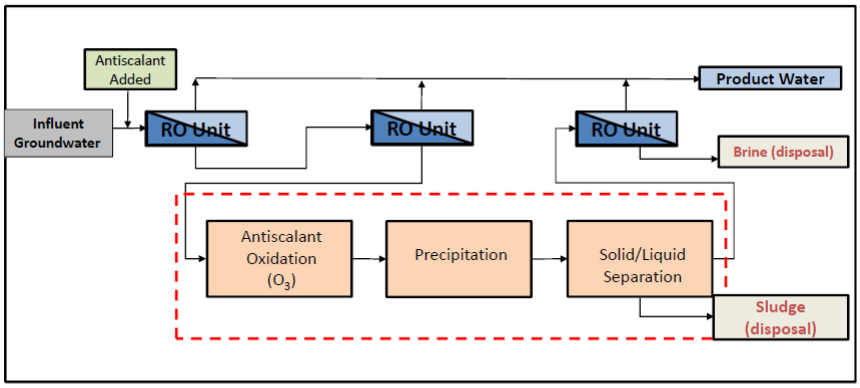






Concentrate Management:RO concentrate treatment

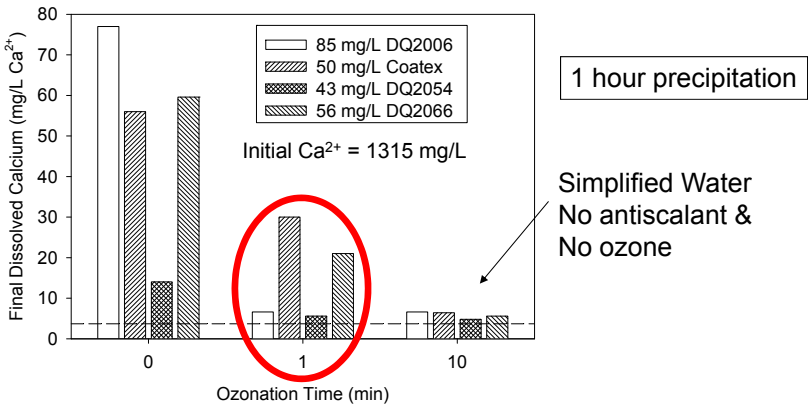
Lead Investigators: Des Lawler and Benny Freeman



Minimizing Concentrate through chemistry
Advanced Oxidation to remove antiscalant
Increase pH, add carbonate to precipitate calcium carbonate

Effects of antiscalant and antiscalant ozonation on calcium precipitation

- Ozonation of antiscalant can allow for enhanced precipitation of calcium during concentrate treatment.



Experimental conditions: Ozonation 3 mg/min O_3 at pH 6.0, H_2O_2/O_3 = 0.8, precipitation 1 hr at pH 10.5, $NaHCO_3$ and NaOH added for precipitation.

Lead Investigators: D. Lawler and Benny Freeman