SAND2010-1483P

High Efficiency Water Management Strategies for Power Plant Operation

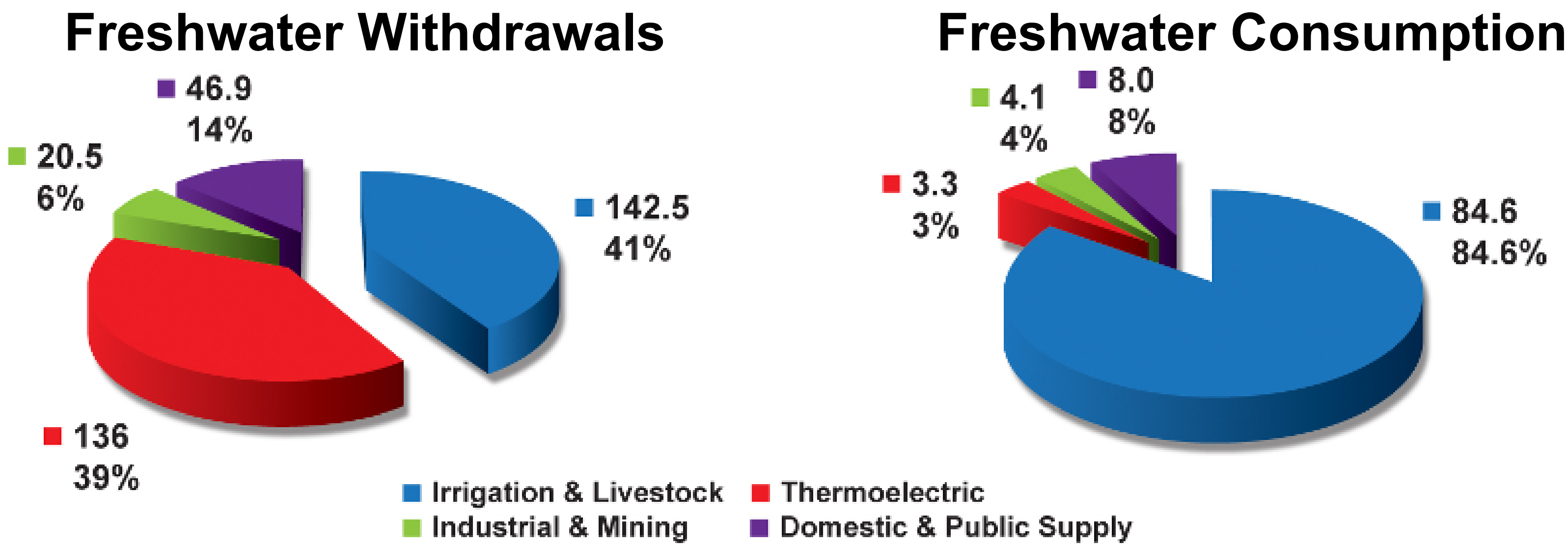
February 24, 2010

Susan J. Altman, Ph. D.
Principal Member of Technical Staff

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Goal is to Create "New Water" for Thermoelectric Power Plants

Thermoelectric Plants Account for 39 % of Freshwater Withdrawals and 3 % of Freshwater Consumption



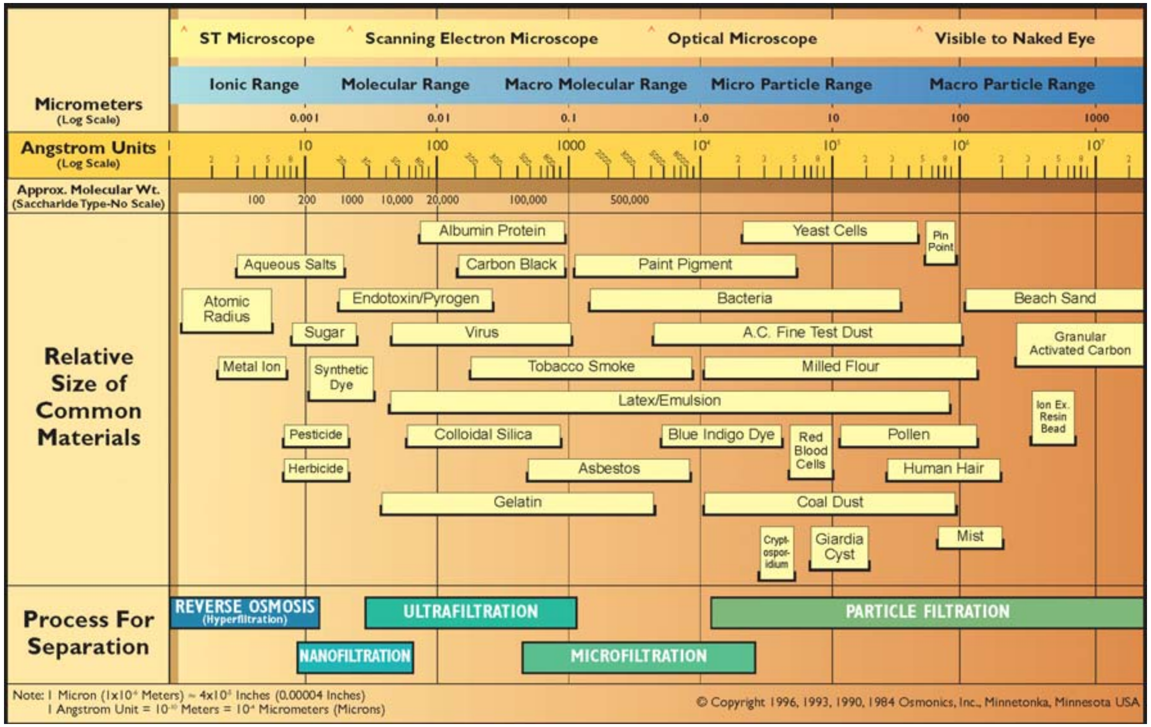
Values in billion gallons per day

Modified from Hutson et al., 2004 and Solley et al., 1998 for "Energy-Water Challenges and Research and Development Issues" in review.

Sandia National Laboratories

Phase I
Nanofiltration Treatment Options for Thermoelectric Power Plant Water Treatment Demands

Pilot operations to evaluate use of NANOFILTRATION FOR REUSE



Cooling Water Tower

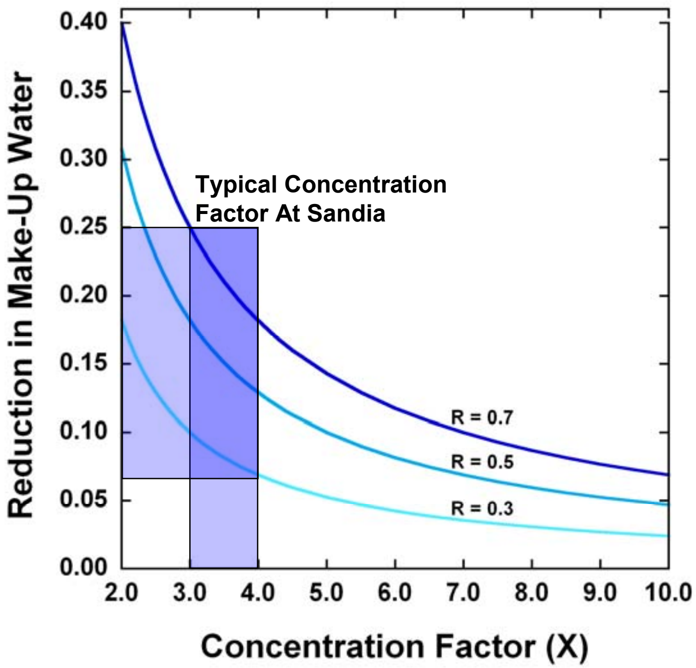
CBNG Produced Water Site

- Capable of decreasing total dissolve solids significantly
- High rejection rate for divalent ions
- Generally less prone to fouling than reverse osmosis membranes
- Operate at lower applied pressures and thus save energy and cost than reverse osmosis membranes

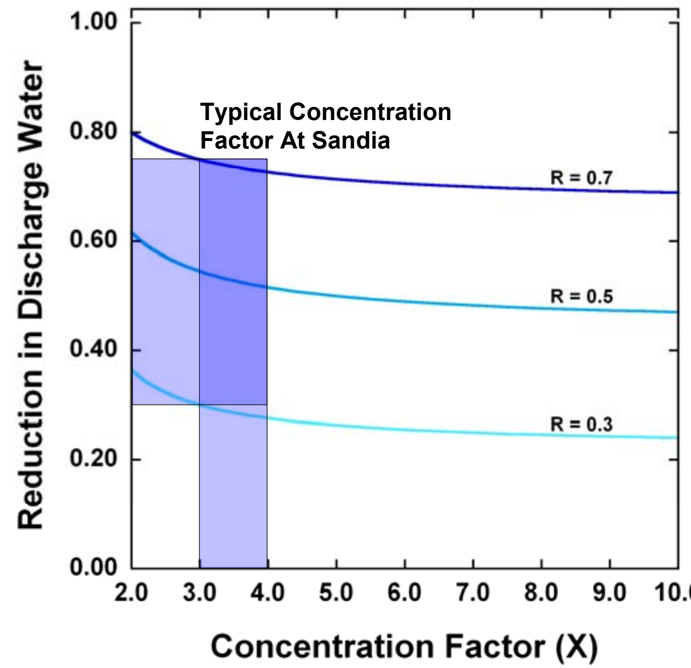
Sandia National Laboratories

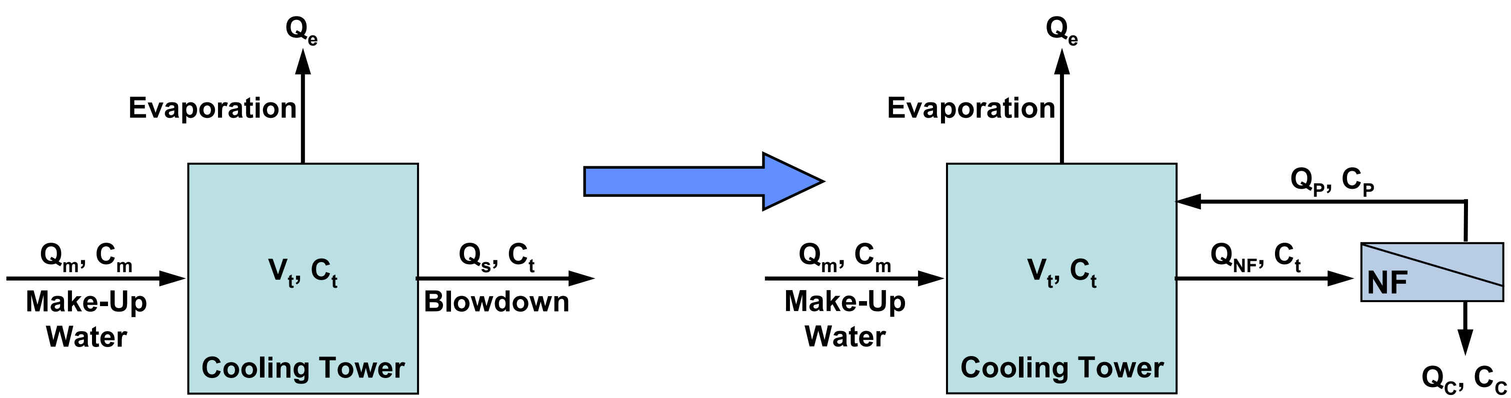
Adding Nanofiltration to System Configuration Leads to Make-up and Discharge Water Savings

Make-Up Water Reduction by ~ 7% - 25%



Discharge Water Reduced by ~ 28% - 75%





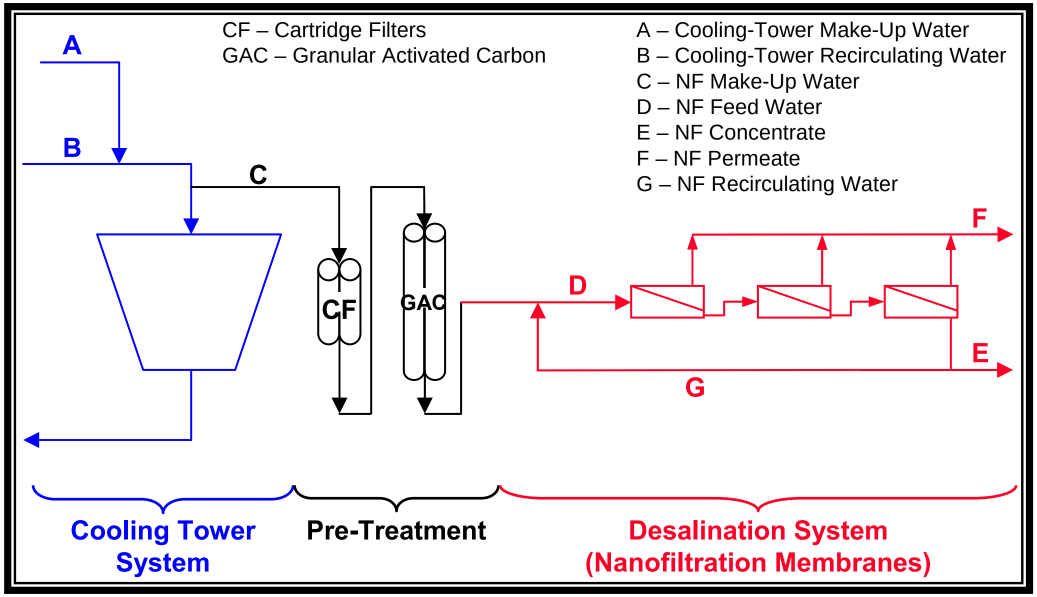
Sandia National Laboratories

Accomplishments of Phase I Work

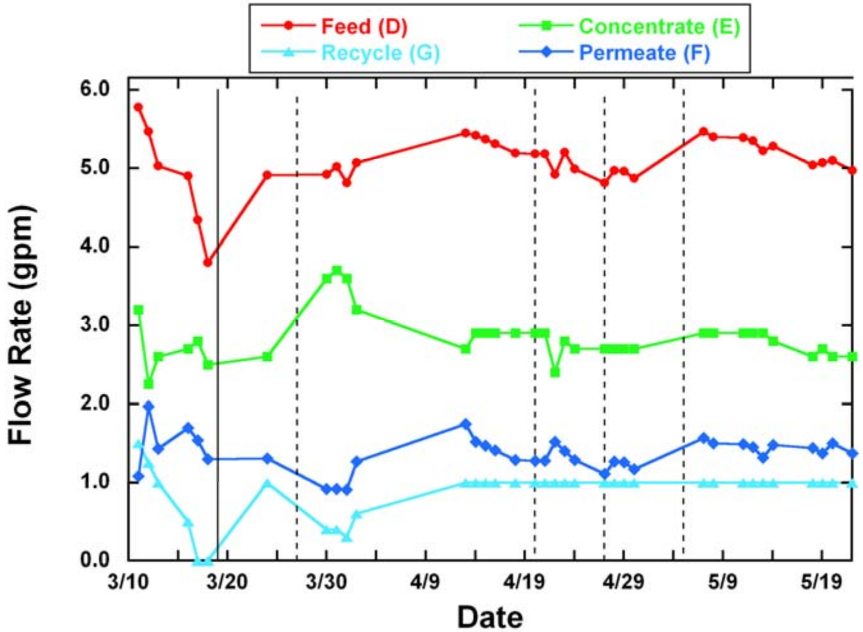
- Demonstrated nanofiltration can successfully treat both cooling tower and produced water
  - > 99% removal of divalent ions in cooling tower water
  - 78% - 96% removal of monovalen ions in cooling water
  - Almost 90% removal of silica in cooling tower water
  - > 95% removal of almost all constituents in produced water
- Theoretically demonstrated that nanofiltration can reduce both make-up water use and discharge water volumes
- Estimated operational costs for nanofiltration systems to be $0.50 - $0.90 per 1,000 gallons
- Estimated that a nanofiltration system would use 35% to 47% less energy than an RO system

Sandia National Laboratories

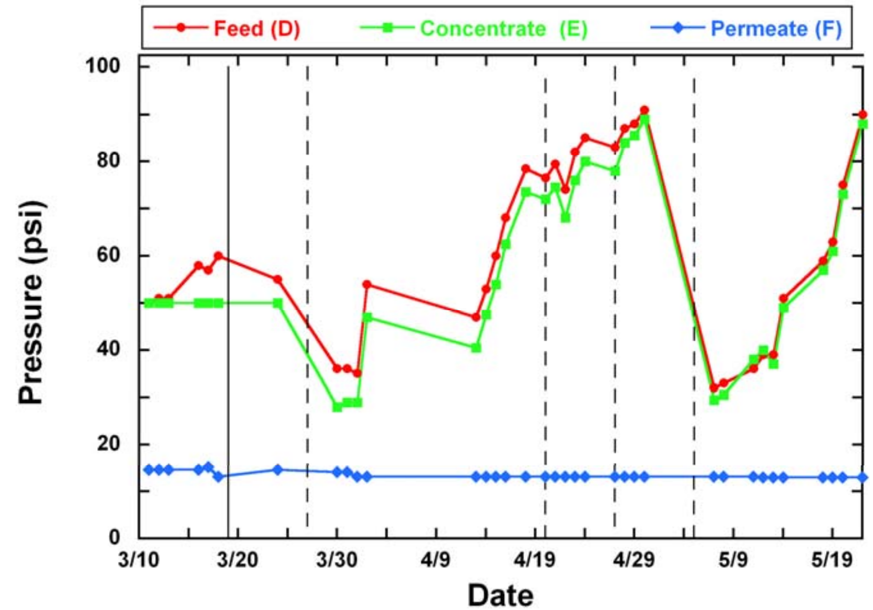
Cooling Water Pilot System



Operational Data



- Flow rates remained relatively constant
- Flow rates were close to that recommended by design calculations

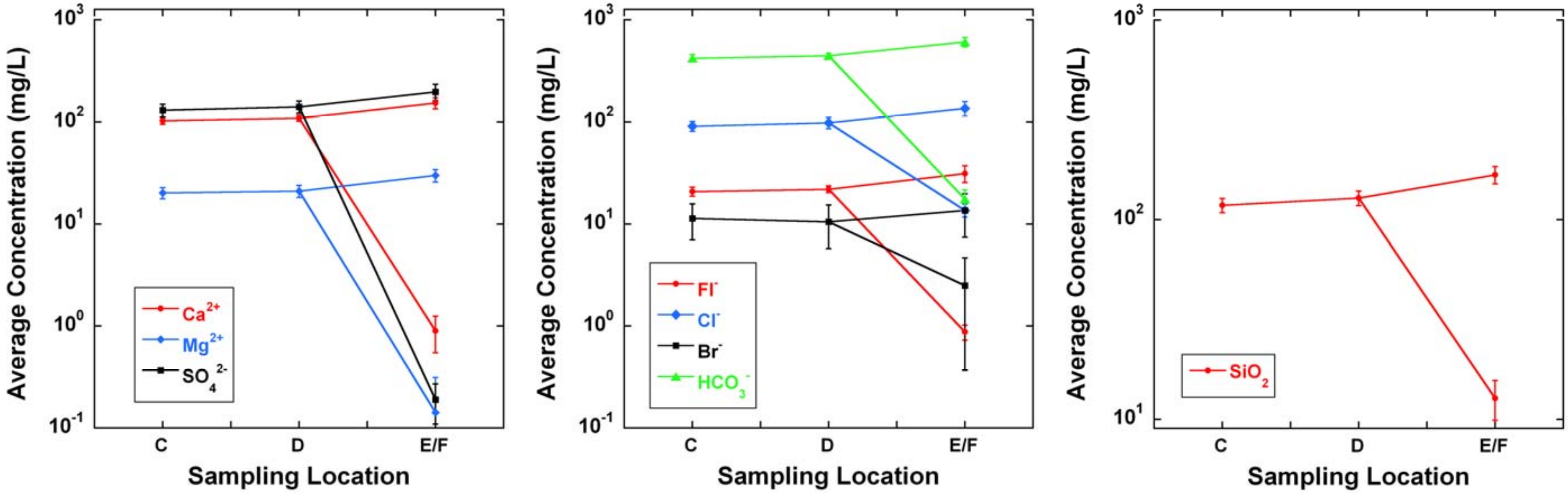


- Pressure increases observed after approximately 10 days of operation
- Pressure recovered after a high pH soaking followed by a low pH soaking

Note analysis of scale showed that it was primarily composed of calcium carbonate and some silica in the amorphous (not crystalline) form.

Sandia National Laboratories

Chemical Data

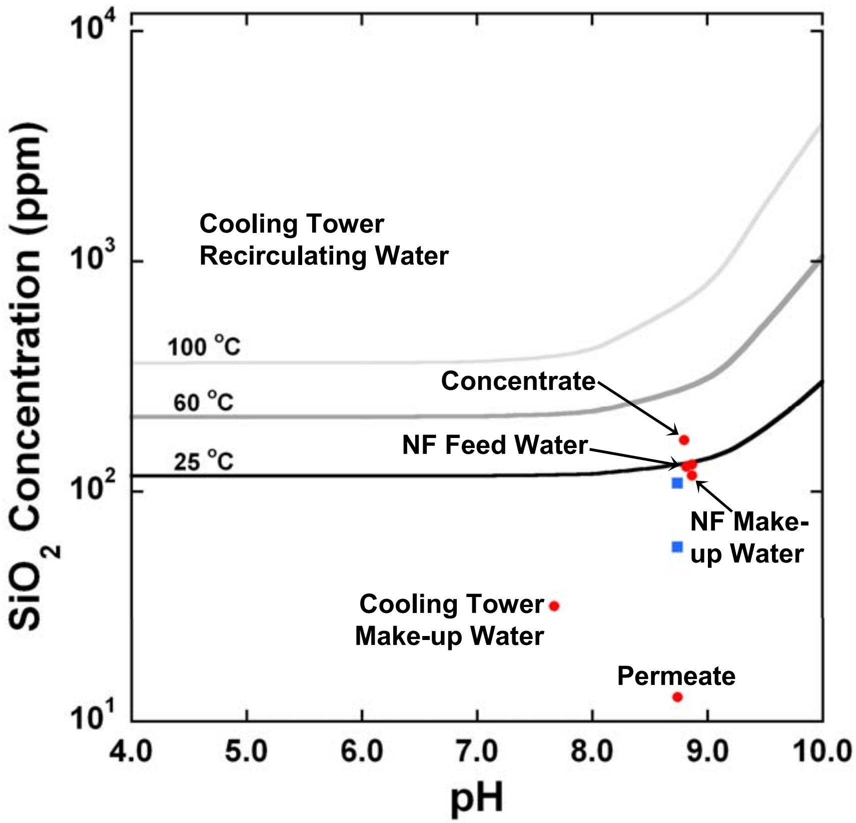


- **Divalent Ions**
  - **Over 2 order of magnitude decrease in concentration**
  - **> 99% removal**
- **Monovalent Ions**
  - **Over 1 order of magnitude decrease in concentration**
  - **78% - 96% removal**
- **Silica**
  - **One order of magnitude decrease in concentration**
  - **Almost 90% removal**

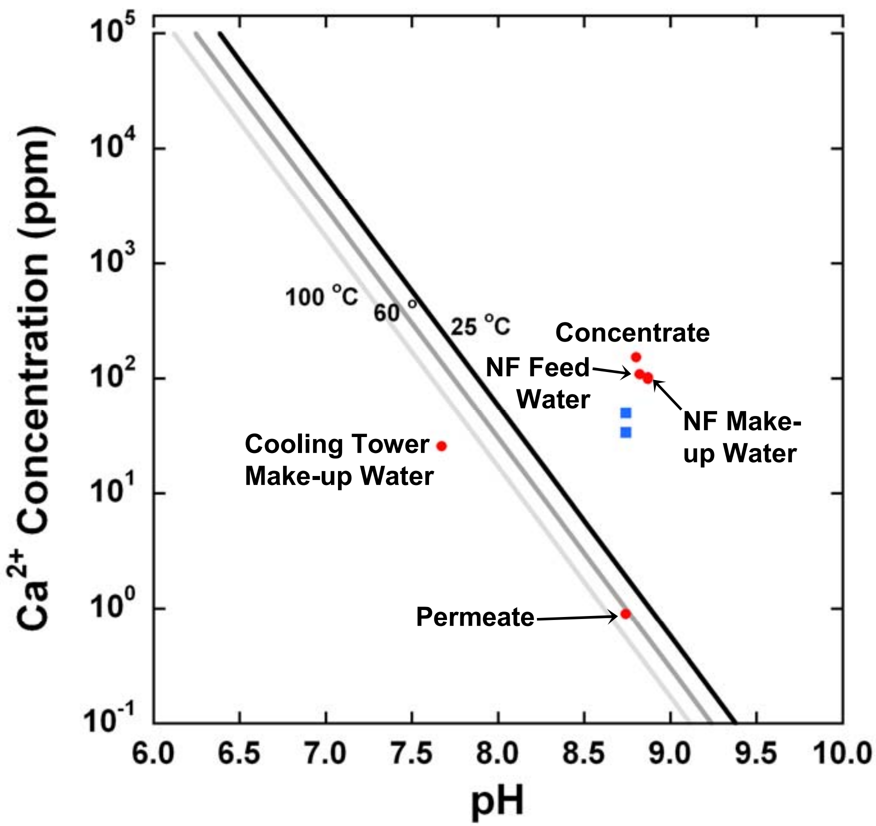
Sandia National Laboratories

$CaCO_3$ and Silica Solubility

NF Feed Water is at close to the solubility limit with respect to SiO_2



NF Feed water is supersaturated with respect to Ca^{2+}



Sandia National Laboratories

Carbonate and Potentially Silica Scaling of the NF System Needs to Be Resolved

The Scaling in the Cooling Tower System Will be Addressed by

- Designing a pre-treatment system specifically for the nanofiltration system
- Chose membrane elements with a lower solute rejection

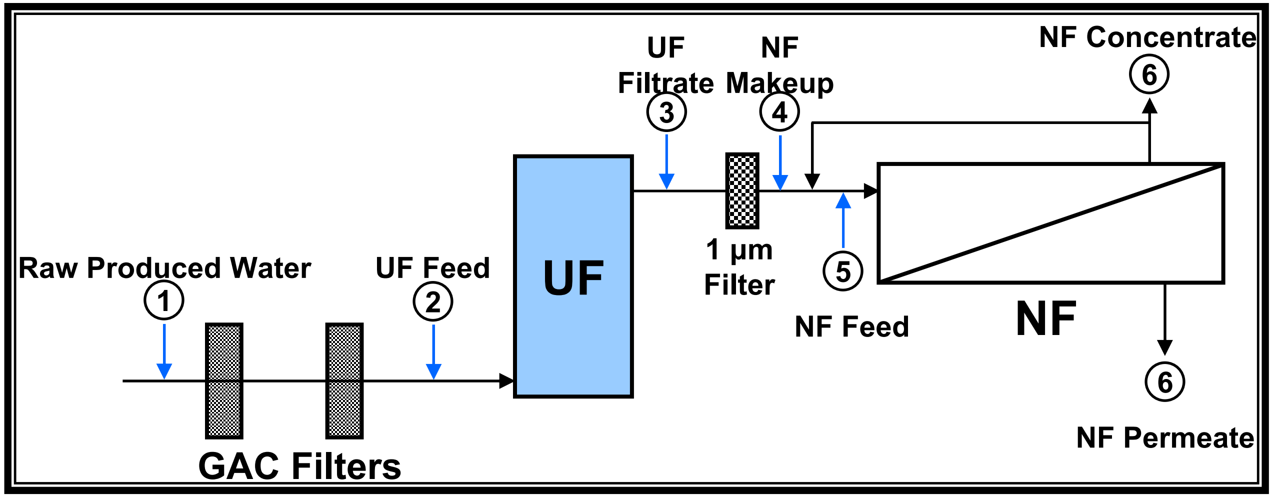
Nanofitration Treatment of Produced Water

Coalbed Methane Production Site in Northwest NM

Photograph of transportainer used for pilot study looking to the northwest.

Sandia National Laboratories

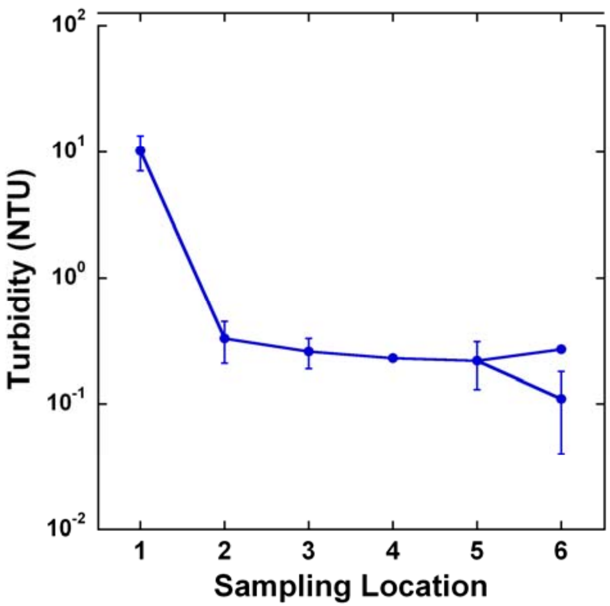
CBM Nanofiltration System Configuration

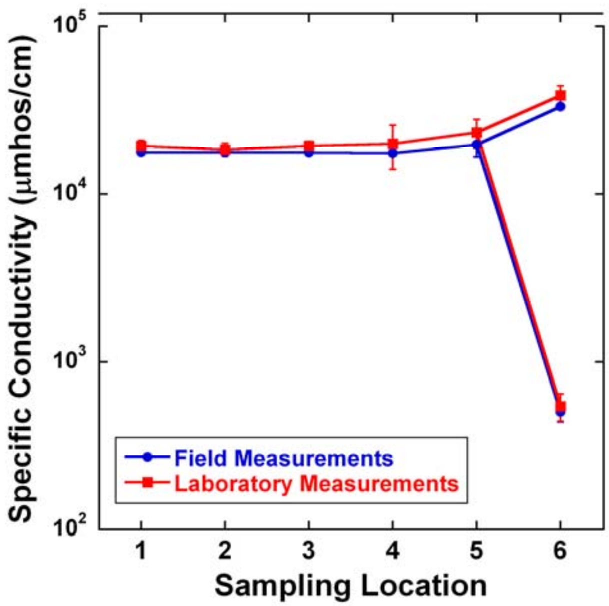


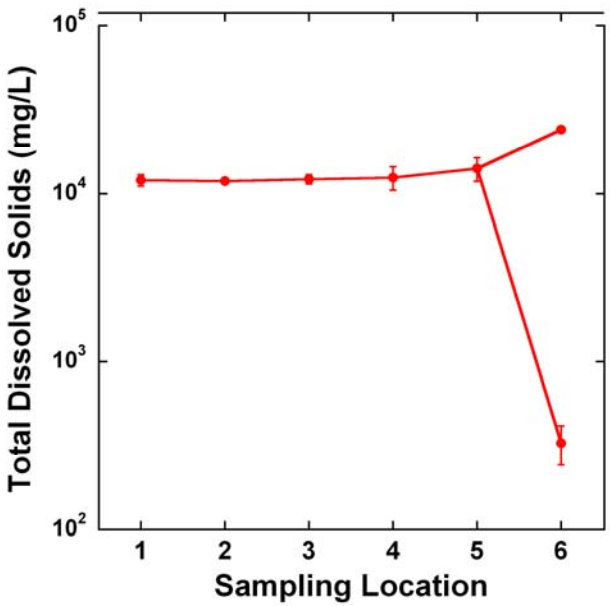
Sandia National Laboratories

Field Data

- Greatest turbidity decrease from GAC filters
- NF also decreased turbidity
- Almost 2 order of magnitude decrease in specific conductivity and total dissolved solids



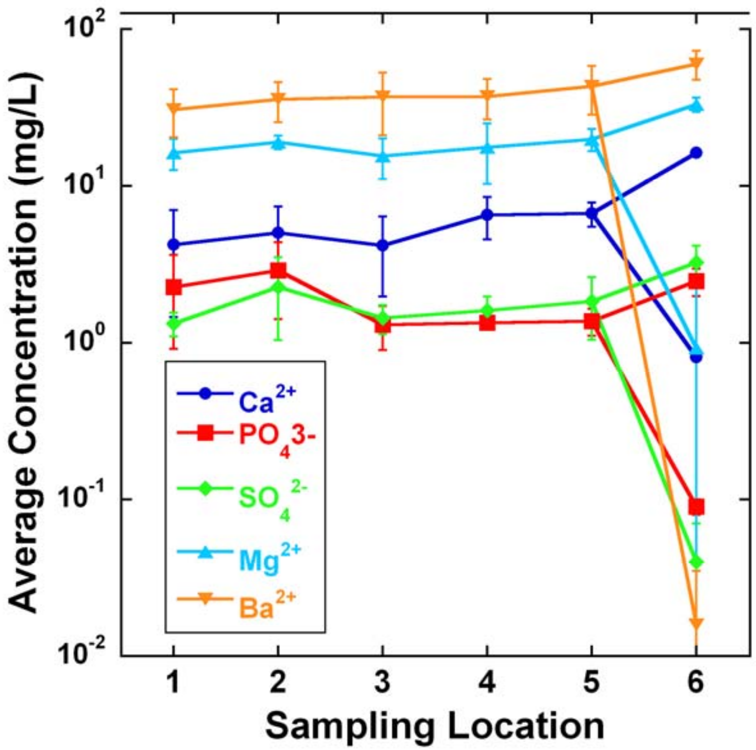


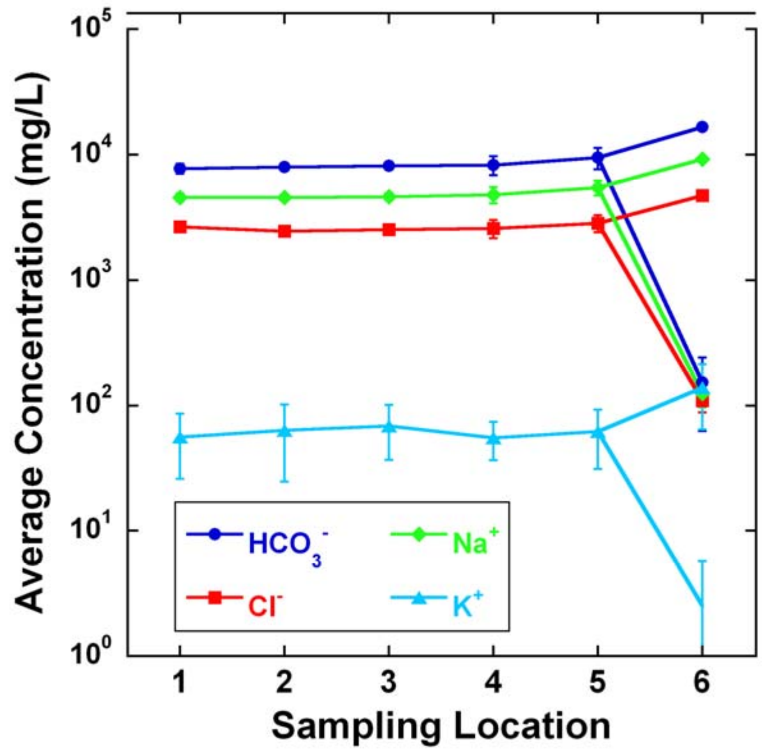


Sandia National Laboratories

CBM Chemical Data

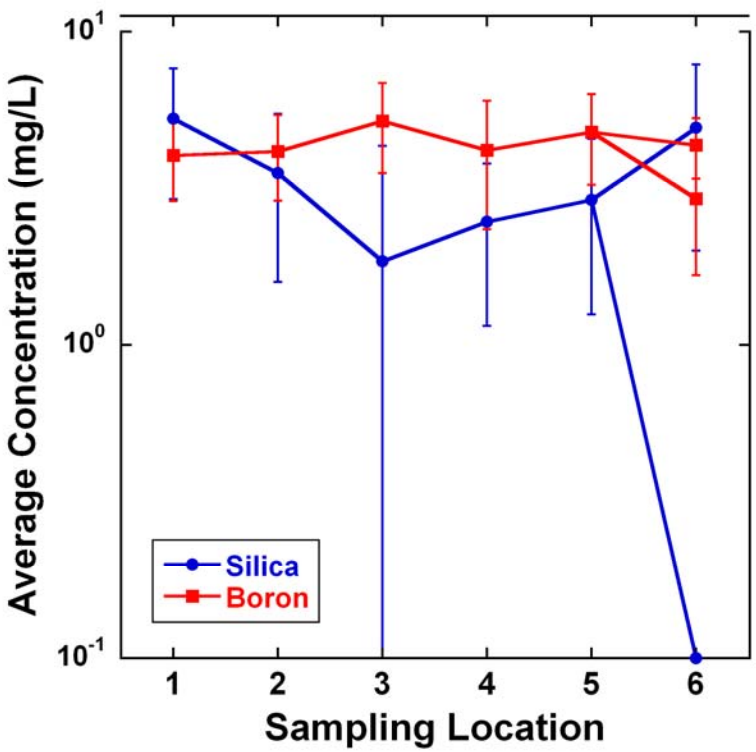
- 94% decrease in phosphate
- 88% - almost 100% removal of divalent ions
- 96% - 98% removal of monovalent ions

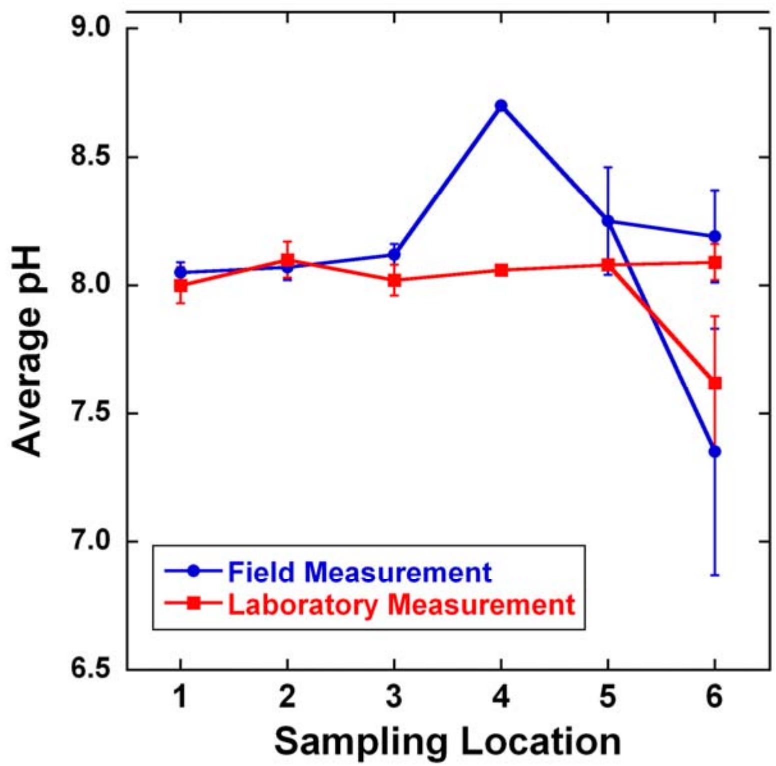




Chemical Data (continued)

- Silica removed to below detection limit
- 30% to 56% removal of boron
- 96% - 98% removal of monovalent ions
- Removal of bicarbonate leads to a decrease in pH





$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

Sandia National Laboratories

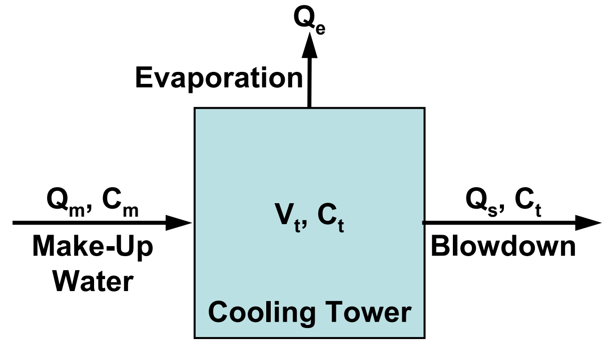
Pretreatment of Produced Water Needs to Be Resolved

What Will Be Different About Phase II Pilot

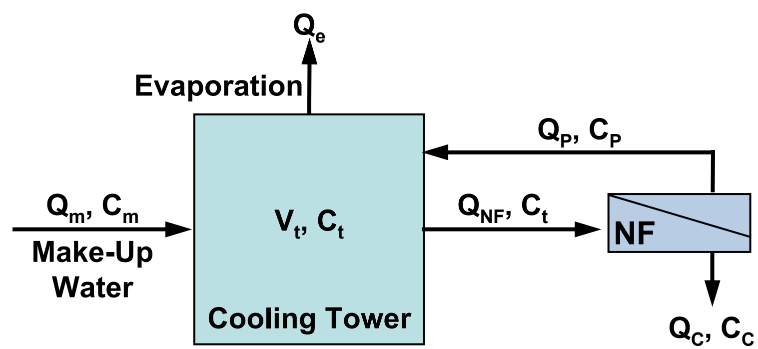
- Nanofiltration permeate will be returned to the cooling tower
- Nanofiltration concentrate will be discharged into the sewer system
- Energy usage will be monitored
- Flow rates have been carefully chosen to maximize water savings
- Will be able to compare water usage of cooling tower to that of past years

Three Conceptual Models Used for Theoretical Calculations

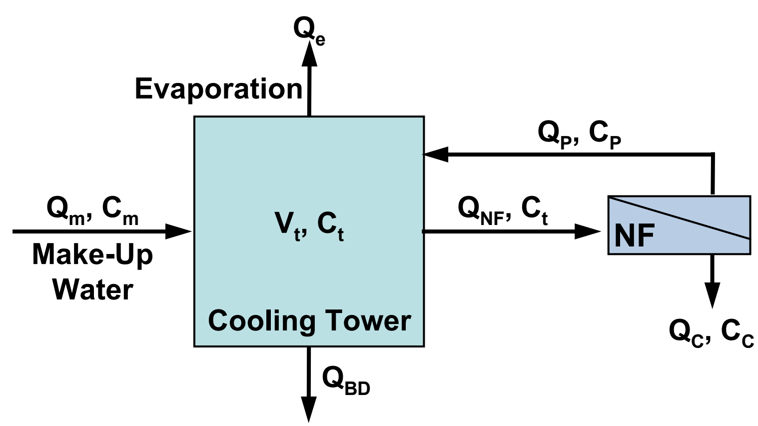
Conceptualization of Traditional Cooling Tower



Conceptualization of Cooling Tower with Water Treated by Nanofiltration (No Blowdown)

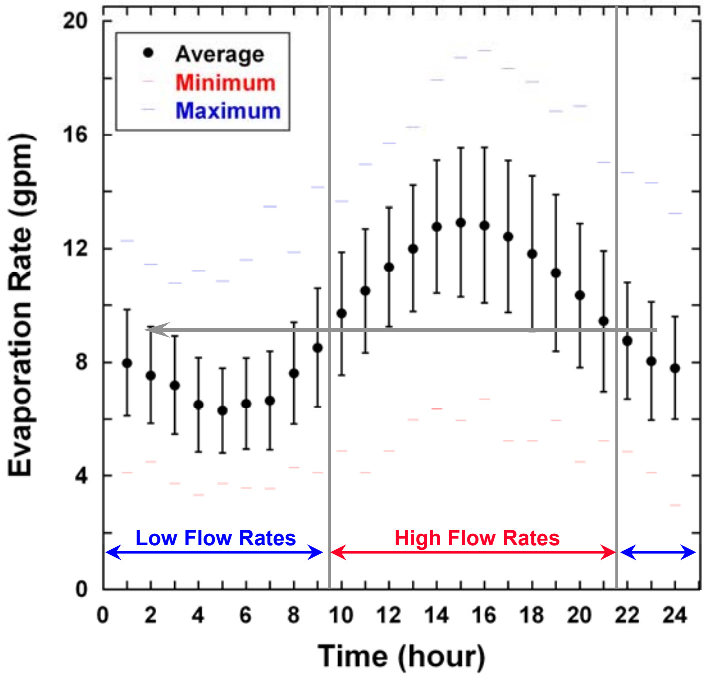


Conceptualization of Cooling Tower with Water Treated by Nanofiltration

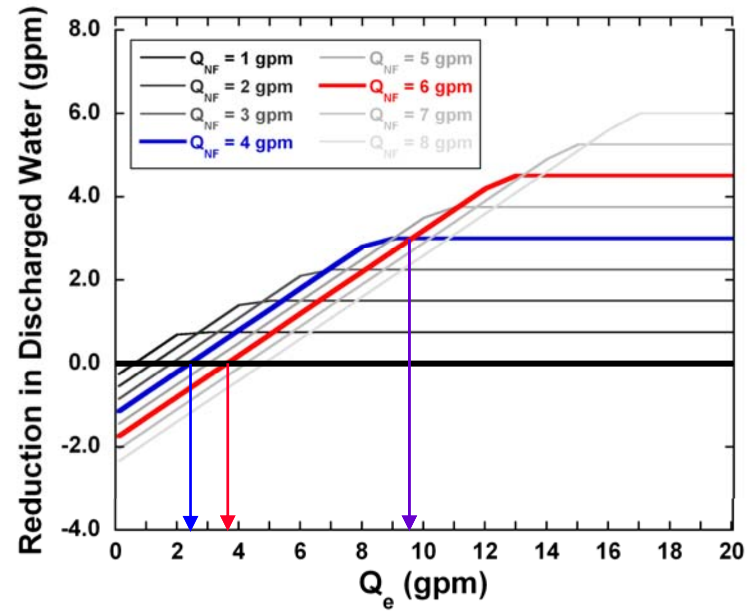


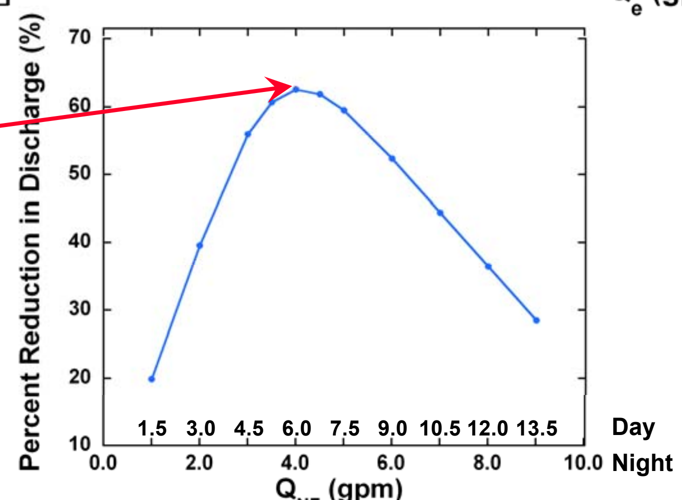
Maximum Water Savings at Flow Rates of 4 gpm at Night and 6 gpm During the Day

Average (± 1 Standard Deviation), Minimum and Maximum Evaporation Rates for July 2007, 2008, and 2009



Reduction in Discharge Water as a Function of Evaporation Rate and Pumping Rate to NF System





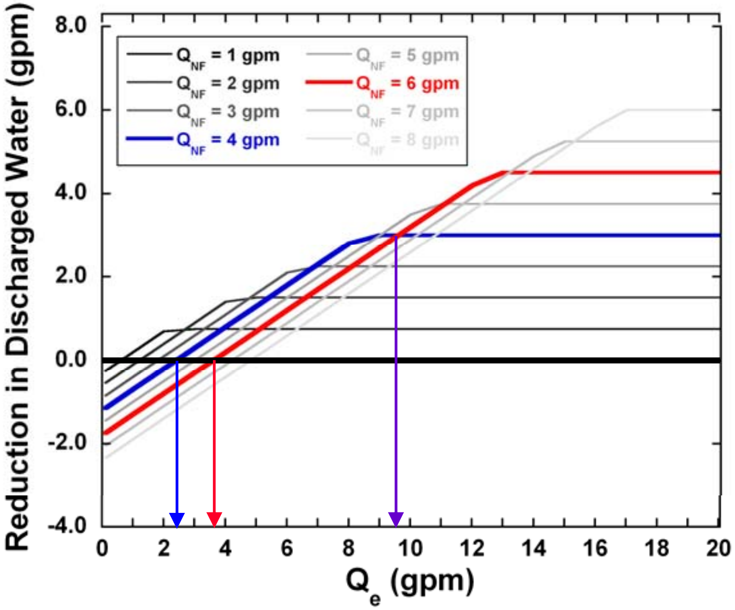
Maximum Water Savings

Assumption, R = 0.7 and w = 0.8

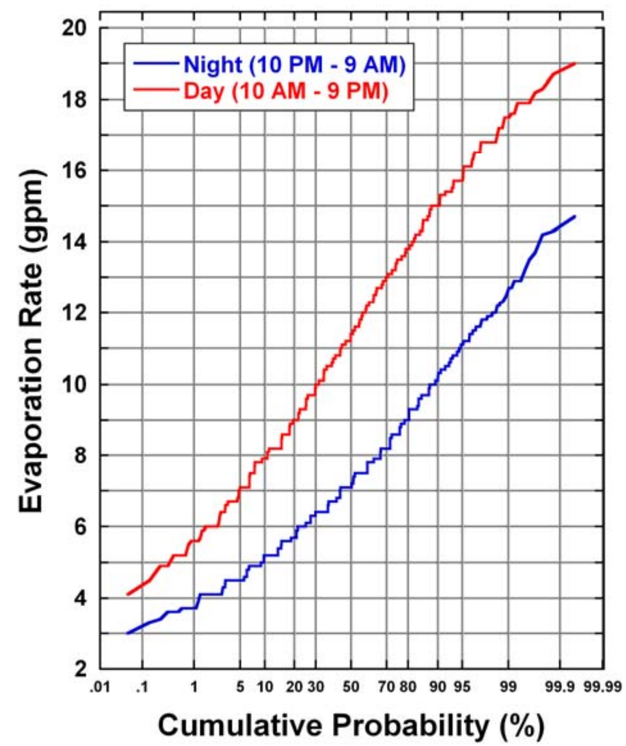
Sandia National Laboratories

Careful Design Important so that Water Usage in Not Increased

Reduction in Discharge Water as a Function of Evaporation Rate and Pumping Rate to NF System



Cumulative Probability for Evaporation Rates from July 2007, 2008, and 2009 Data

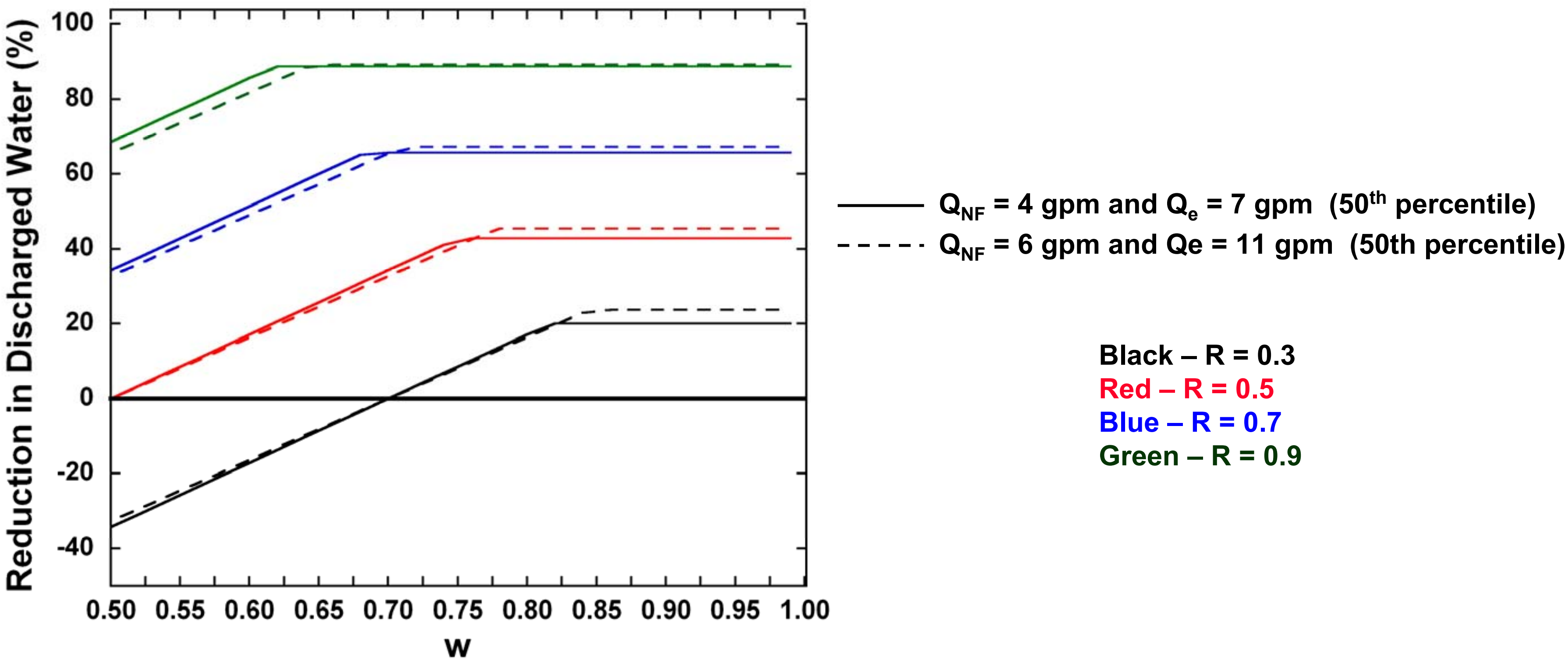


Assumption, R = 0.7 and w = 0.8

Sandia National Laboratories

R Most Sensitive Parameter for Water Savings

- R (fraction of water that passes through the membrane) has the largest impact on water savings
- It is possible to sacrifice permeate water quality and without impacting water savings



Our Goal is to Start the Pilot April 1, 2010

- We are currently
  - Working with contractor to build membrane system
  - Working with Sandia's Facilities Group to build electrical system
  - Collecting background water quality data for make-up water and cooling tower water
- Next steps include
  - Choosing membrane elements that will work best for our pilot system
  - Installing the pilot system
  - Starting the pilot (our goal is April 1, 2010)

Summary

What We Have Done

- Completed Phase I Cooling Tower Project
- Completed Phase I Produced Water Treatment Pilot
- Demonstrated efficacy of nanofiltration
- Theoretically demonstrated water savings from NF
- Estimated operational cost

What We Are Doing

- Preparing for Phase II cooling tower pilot
  - Will measure water usage
  - Will monitor energy usage
- Initiated programs to control SiO_2 scaling
- Evaluating availability of waste heat at power plants for use of membrane distillation

Where Are We Going

- Solve optimization problem to design NF system
- Evaluate water savings for a power plant
- More systematic and complete studies for SiO_2 scale control
- Add more detailed membrane distillation model
- Produced water treatment?

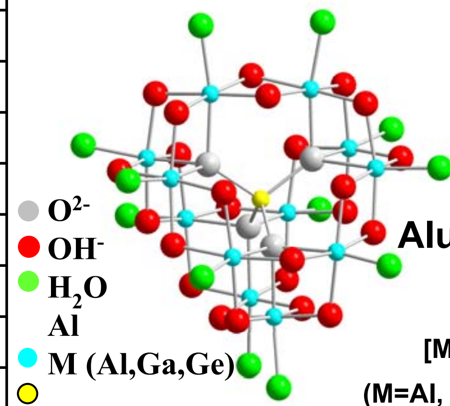
Sandia National Laboratories

Phase II:

Subtask 2.1: Sio_2 Control Through Enhancing Precipitation By Advanced Coagulation And Flocculation Processes

coagulant	PPM Metal of added coagulant	final pH after coagulant addition	Co-coagulant	% SiO_2 Removal
$GaAl_{12}$ -M	80	7.2	Bis-Tris buffer for pH	55%
$GaAl_{12}$ - M	80		Polyacrylamide	20%
PAX10	80	3.5	citric acid for pH	0
PAX10	80	8.7	Cetyl-TMACl 125 ppm	45%
PAX10	178	6.6	Cetyl-TMACl 63 ppm	40%
PAX10	178	6.6	SDS 100 ppm	45%
PAX10	178	6.6		42%
Na_2MoO_4	1280	3.25	Cetyl-TMACl 63 ppm	7%
PAX10	178	6.6	SDS 50 ppm	56%
PAX10	178	6.0	SDS 50 ppm	35%
PAX18	128	5.5	9 mM Mg, SDS 50 ppm	51%
PAX18	128	6.1	9 mM Mg, SDS 50 ppm	58%
PAX18	128	7.0	9 mM Mg, SDS 50 ppm	71%
PAX18	178	5.9	9 mM Mg	45%
PAX18	178	6.1	9 mM Mg	55%
PAX18	178	6.5	9 mM Mg	62%
$MgSO_4$	217	8.96	9 mM Mg	6%
PAX18	178	7.0	9 mM Mg	75%
PAX18	178	7.0	9 mM Mg, SDS 50 ppm	74%
PAX18	**178**	**7.0**		**81%**
PAX18	**178**	**7.0**	**Cetyl-TMACl 125 ppm**	**80%**
Na_2MoO_4	**3500**	**3.5**	**Cetyl-TMACl 90 ppm**	**95%**

- **$SiMo_{12}$ Keggin Ions Succeeded at Removing 95% of Silica**
- **Aluminum Coagulants Removed 40 – 81% of Silica**



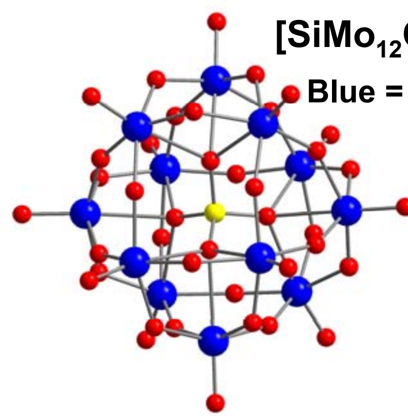
Aluminum polycation Keggin ion

$[MO_4Al_{12}(OH)_{24}(H2O)_{12}]^{7,8+}$

(M=Al, Ga, Ge): Al_{13}, $GaAl_{12}$, $GeAl_{12}$

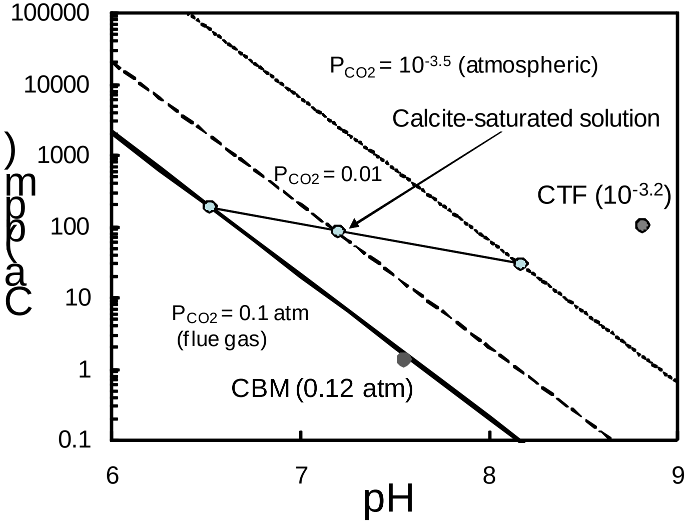
$[SiMo_{12}O_{40}]^{4-}$ Keggin ion, $SiMo_{12}$

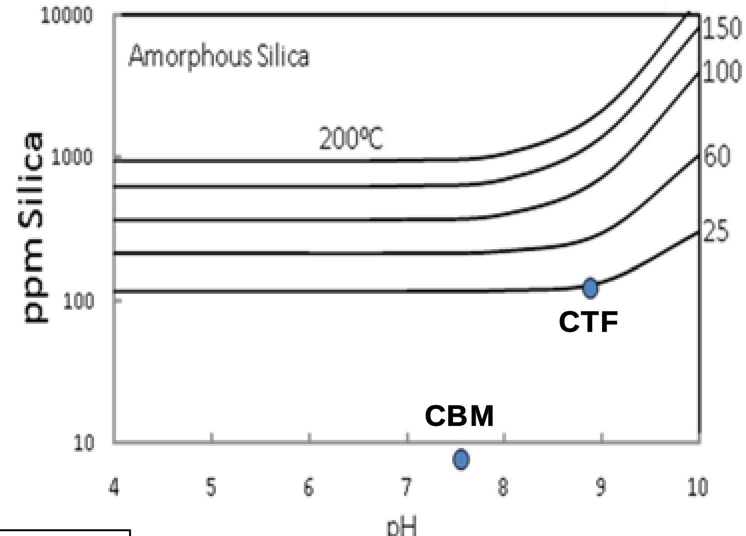
Blue = Mo; Yellow = Si; Red = O

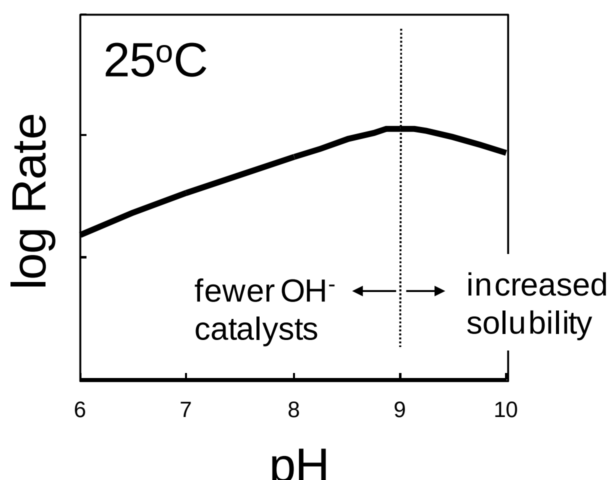


Phase II:
Subtask 2.2: Retardation of SiO_2 Precipitation by pH Control

4.5 (flue gas) ← **pH** → **11 (fly ash)**





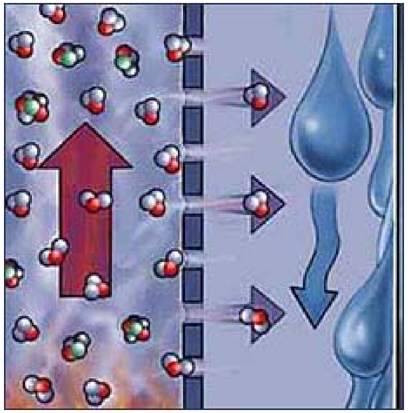


P.I. Pat Brady

Sandia National Laboratories

Phase II:
Task 3: Feasibility Of Using Waste Water And Heat To Produce Fresh Water Via Membrane Distillation

- Use waste heat source from power plants to treat non-traditional water sources
- Water evaporates across a porous, hydrophobic membrane
- Lower energy requirements than distillation



P.I. Brian Dwyer

Sandia National Laboratories