Evaluation of Alternatives to Domestic Ion Exchange Water Softeners

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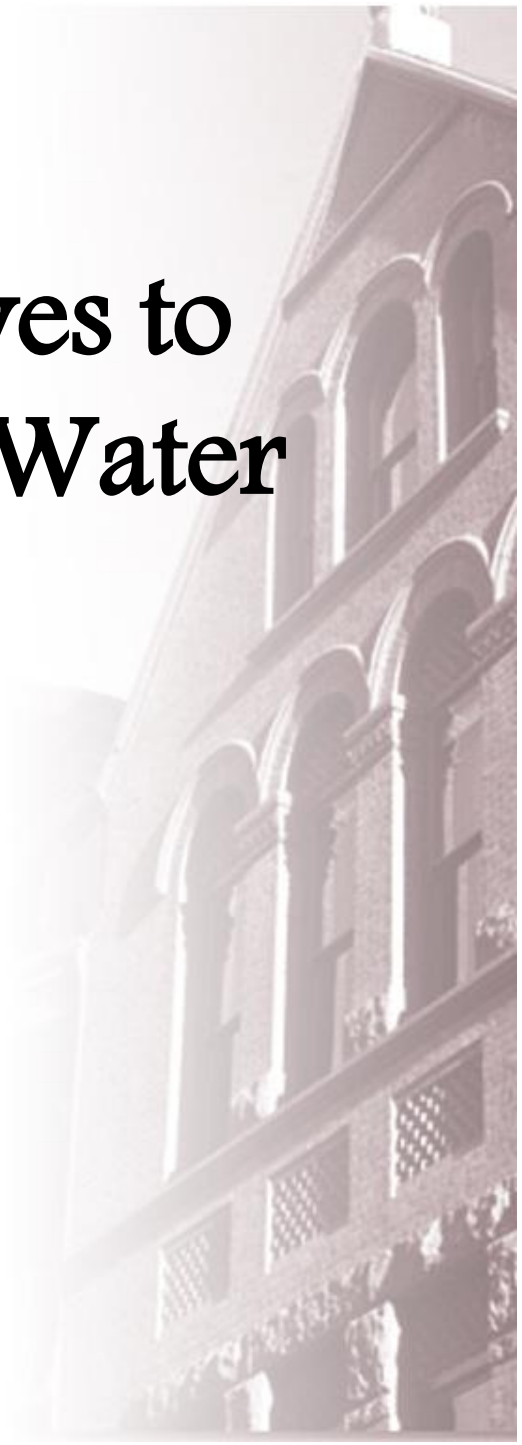

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April 26, 2011

OUTLINE

- **Water Quality and reuse in the Southwest US**
- Ion exchange water softening system process and effects on remediated water quality
- No-salt alternatives to ion exchange and the mechanisms by which they reduce scale formation
- Experimental procedure
- Results
- Future Work

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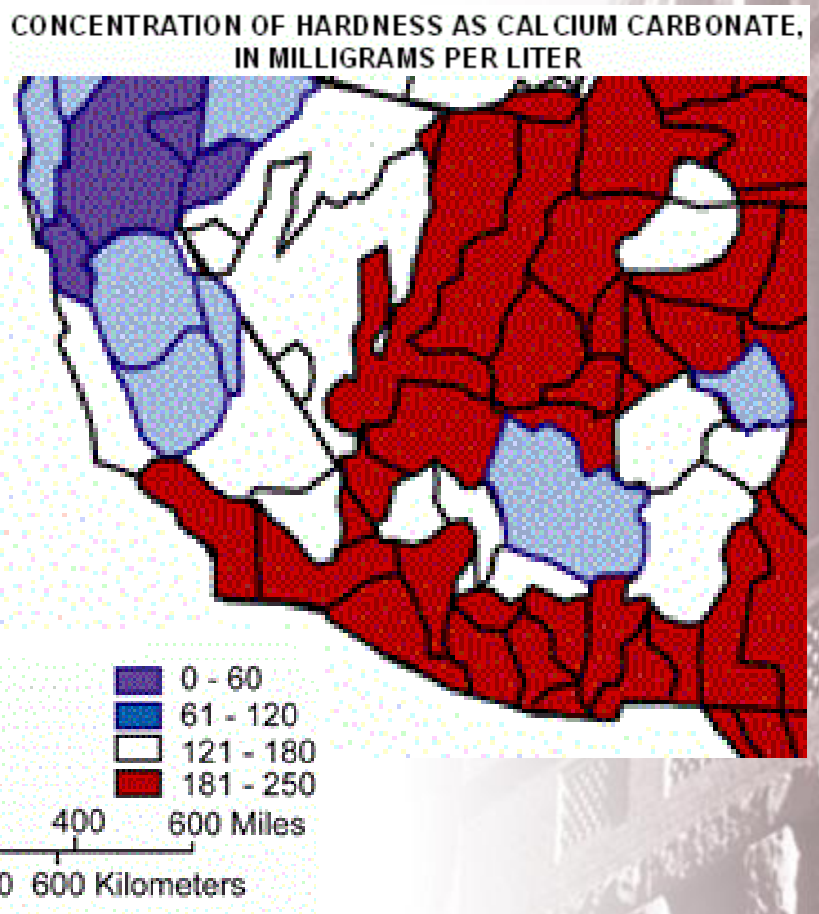
Water Quality and Reuse in the Southwest US

- Freshwater sources in the Southwest US are considered very hard ranging from 80 to 280 mg/L.

http://static.howstuffworks.com/gif/maps/pdf/NAM_US_THEM_Watersheds.pdf



http://water.usgs.gov/owq/hardness-alkalinity.html

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Water Quality and Reuse in the Southwest US

Hard Water Effects in the Home

- Spotted dishes from the dishwasher
- An inability for soap to lather and soap scum deposits
- Scale formation on faucets and showerheads
- Scale accumulation in pipes
- Scale fouling in water heaters increasing energy usage by up to 24%
- Scale formation on appliances

Calcium carbonate becomes less soluble at higher temperatures.

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Water Quality and Reuse in the Southwest US

- Consumers try to mitigate the effects of hard water by using water softening devices in their homes.
- The most common domestic water softening device uses ion exchange technology which releases additional salts to the waste stream.
- Consumers are reducing hardness in their homes but increasing TDS levels in reclaimed wastewater! (Not a sustainable practice)

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Water Quality and Reuse in the Southwest US

- TDS (salinity) is a measurement of total dissolved solids in water including inorganic (hardness, salts) and organic substances (pesticides, herbicides, etc.).

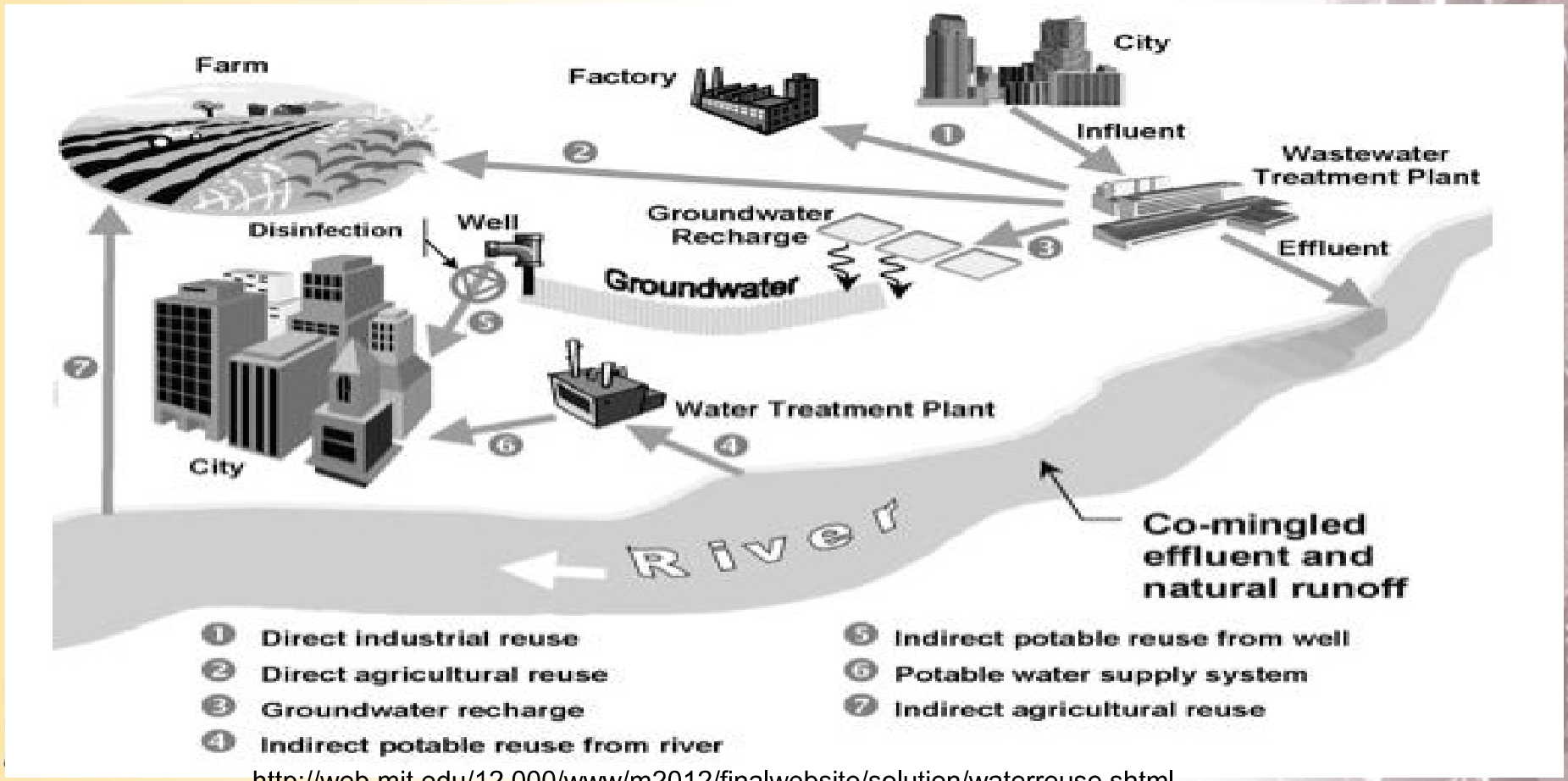
Sources of Salinity
• Natural minerals in rocks found in lakes, rivers, streams and aquifers
• Water from natural salt springs that enters into rivers, lakes and streams
• Agricultural fertilizers that drain from fields into rivers, lakes, streams and aquifers
• Water treatment chemicals such as chlorine that make water safe for human consumption
• **Home water treatment systems, like water softeners, that treat water for hardness**
• Cleaning chemicals
• Foods

Water Source	TDS in milligrams per liter
Salt River	580 mg/L
Verde river	270 mg/L
Central Arizona Project (CAP)	650 mg/L
Groundwater	200 - 5,000 mg/L
Reclaimed Water	Typically 300 - 500 mg/L higher than source water

Water Quality and Reuse in the Southwest US

Water Reuse

- A water conservation practice in which reclaimed water is used for a direct beneficial purpose.

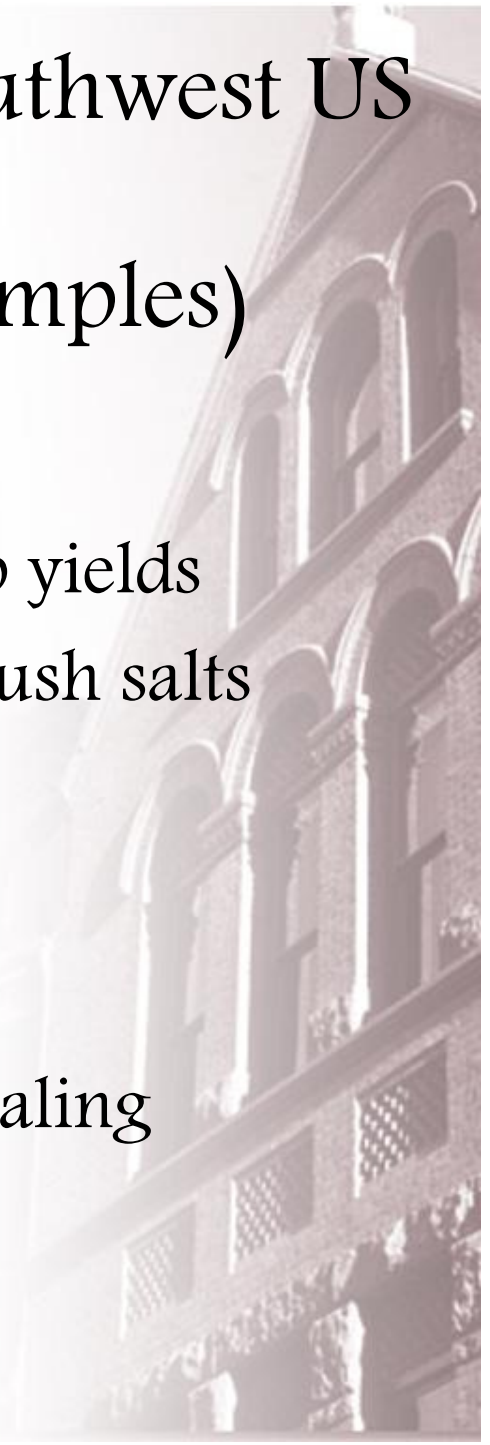


http://web.mit.edu/12.000/www/m2012/finalwebsite/solution/waterreuse.shtml

Water Quality and Reuse in the Southwest US

TDS effects on water reuse (examples)

- Agriculture
  - Crop salt tolerance, reduction of crop yields
  - Additional water may be needed to flush salts from root zone
- Cooling Tower
  - Increased water usage
  - Possible equipment damage due to scaling



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Study Objective

Provide technical data to identify credible **alternatives** to ion exchange water softeners that would provide consumers with the ability to reduce the impacts of hard water without creating the negative salinity impacts.

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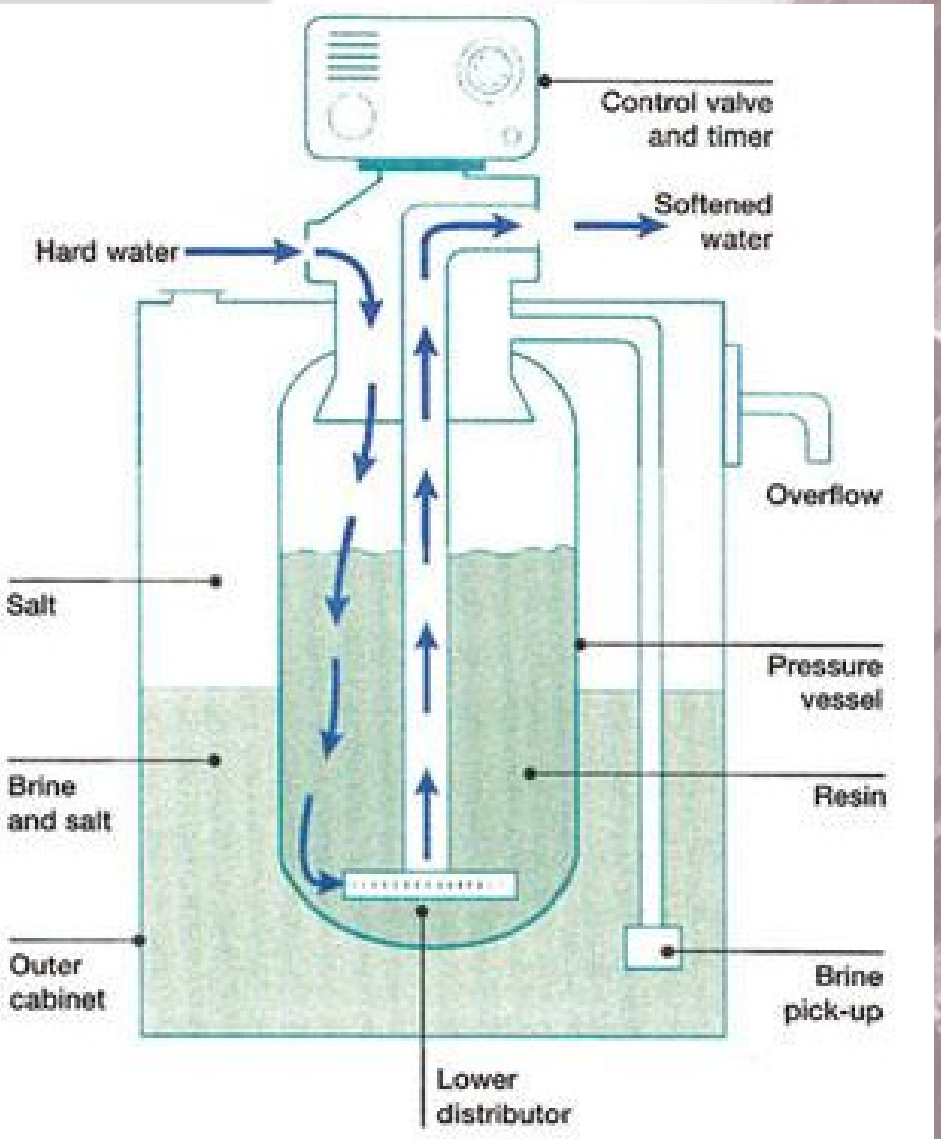
Ion Exchange Water Softening System

- The ion exchange unit removes hardness by exchanging sodium ions for the calcium and magnesium ions present in the water.
- It does this using resin beads that periodically need to be regenerated with a highly concentrated salt solution.
- There are two basic types of self-regenerating water softeners (SRWS): Timer Based and Demand Based.



http://www.sterlingsofteners.co.uk/index.asp?mid=49

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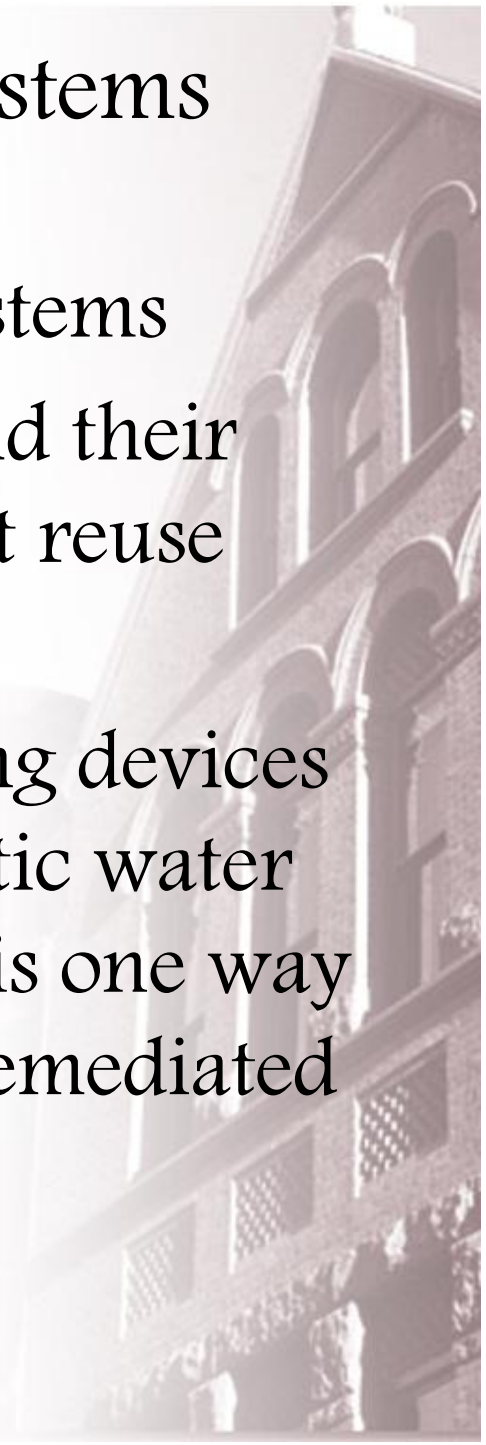
Ion Exchange Water Softener Systems

- Discharge brine into wastewater systems
- These unnatural quantity of salts find their way into the environment and affect reuse applications.
- The use of no-salt water conditioning devices to reduce scale formation on domestic water heaters and other home appliances is one way society can improve the quality of remediated water.



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No-Salt Alternatives to Ion Exchange

- Capacitive Deionization
- Electrically Induced Precipitation
- Template Assisted Crystallization
- Electromagnetic Water Treatment

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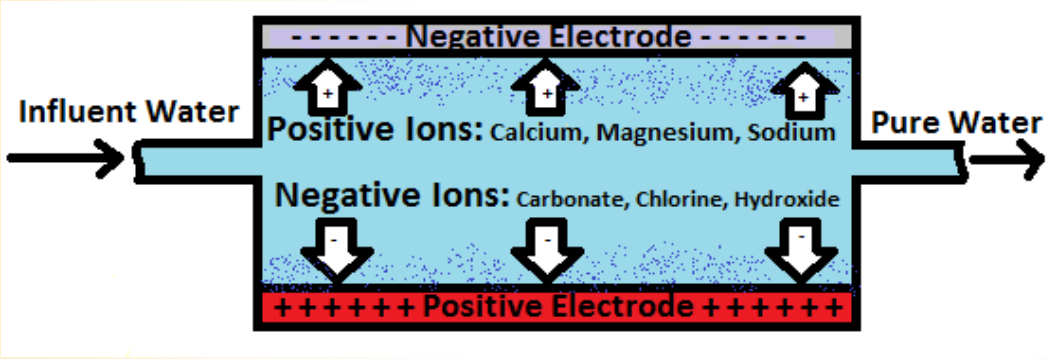
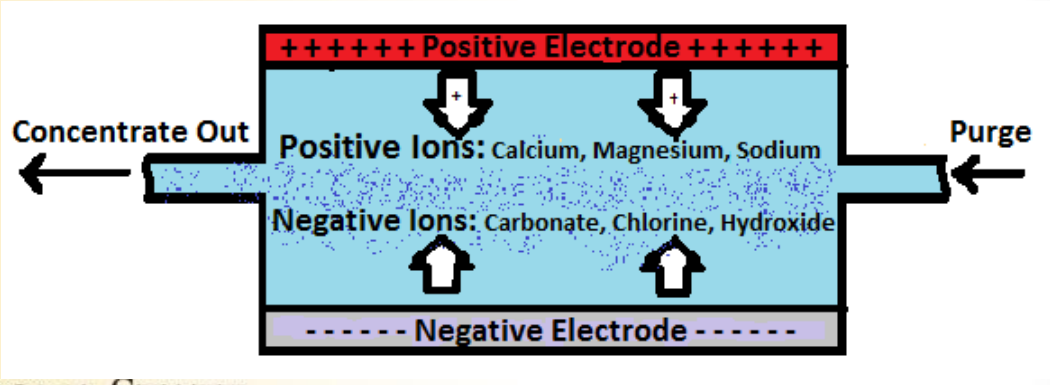
No-Salt Alternatives to Ion Exchange

Capacitive Deionization

Regeneration: Voltage potential turned on



Backwash: Voltage potential turned off or reversed



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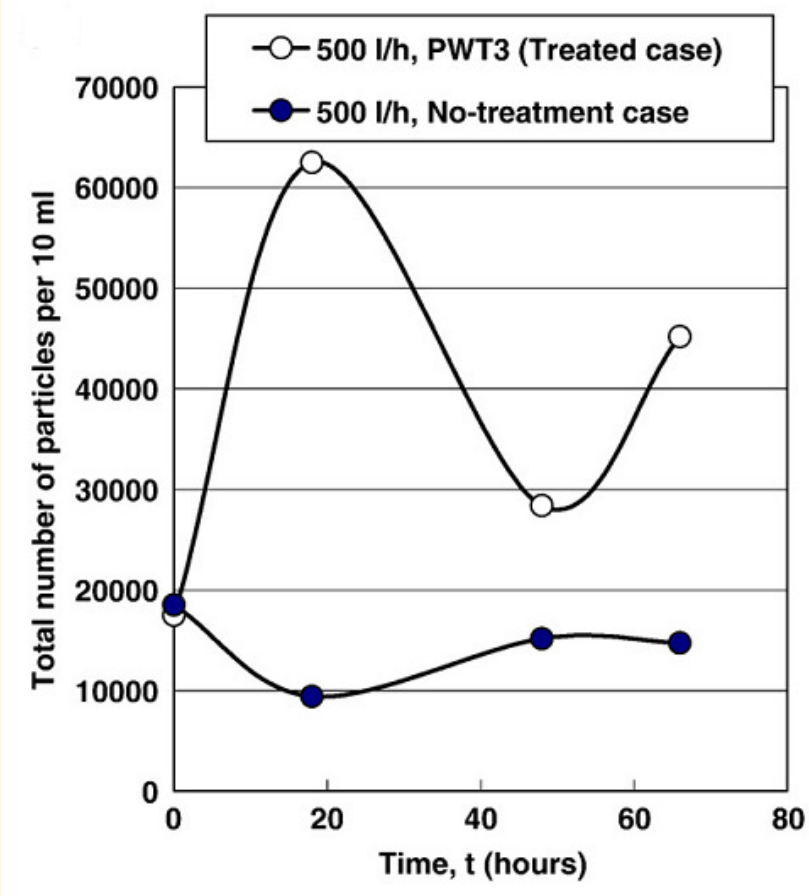
Electro-chemical Treatment

No-Salt Alternatives to Ion Exchange

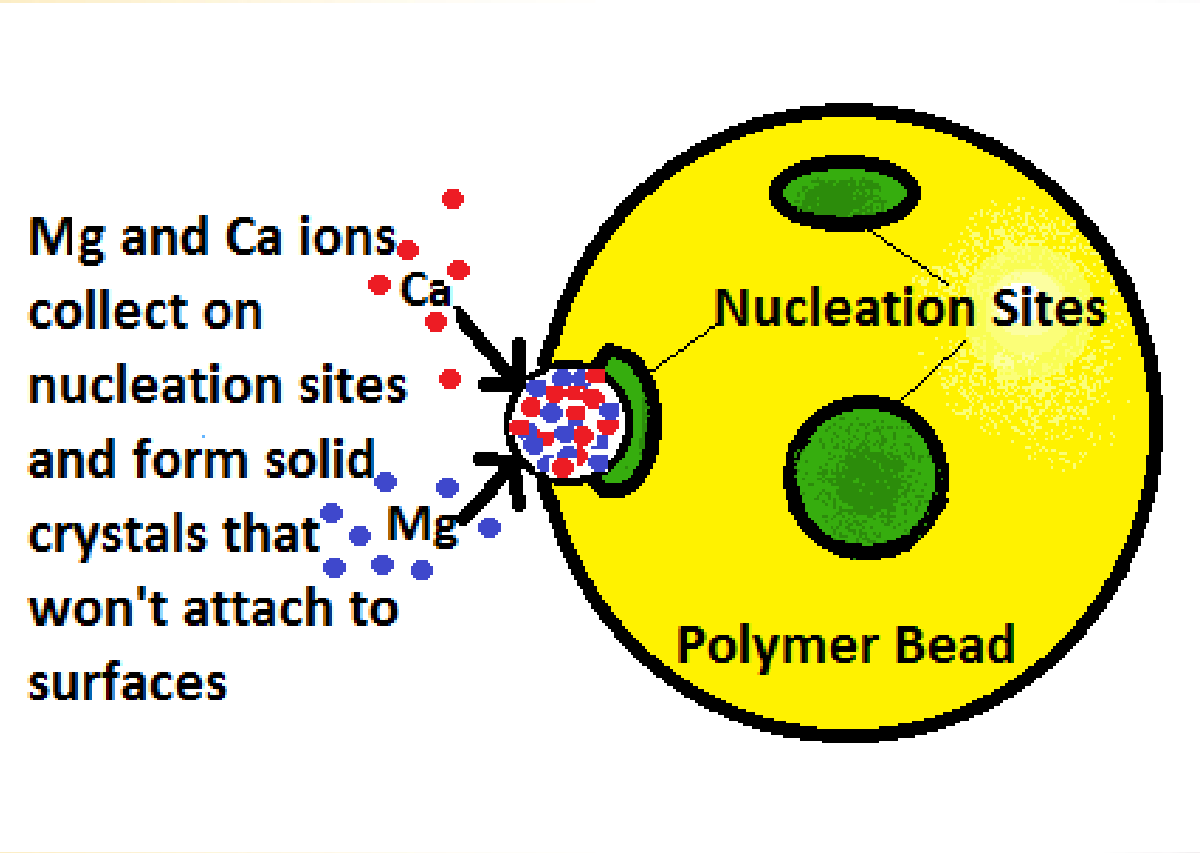
Electronically Induced Precipitation



Tijing et al, 2007

No-Salt Alternatives to Ion Exchange

Template Assisted Crystallization



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No-Salt Alternatives to Ion Exchange

Electromagnetic Water Treatment

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Physical Water Treatment

No-Salt Alternatives to Ion Exchange

Other possible mechanisms for magnetic treatment

- Reduction of the effect of the double layer
  - When the electrical double layer is reduced, more suspended coagulation can occur resulting in a light sludge that is easily wiped off of the surface.
  - This can be tested by measuring the zeta potential of a particle before and after treatment.

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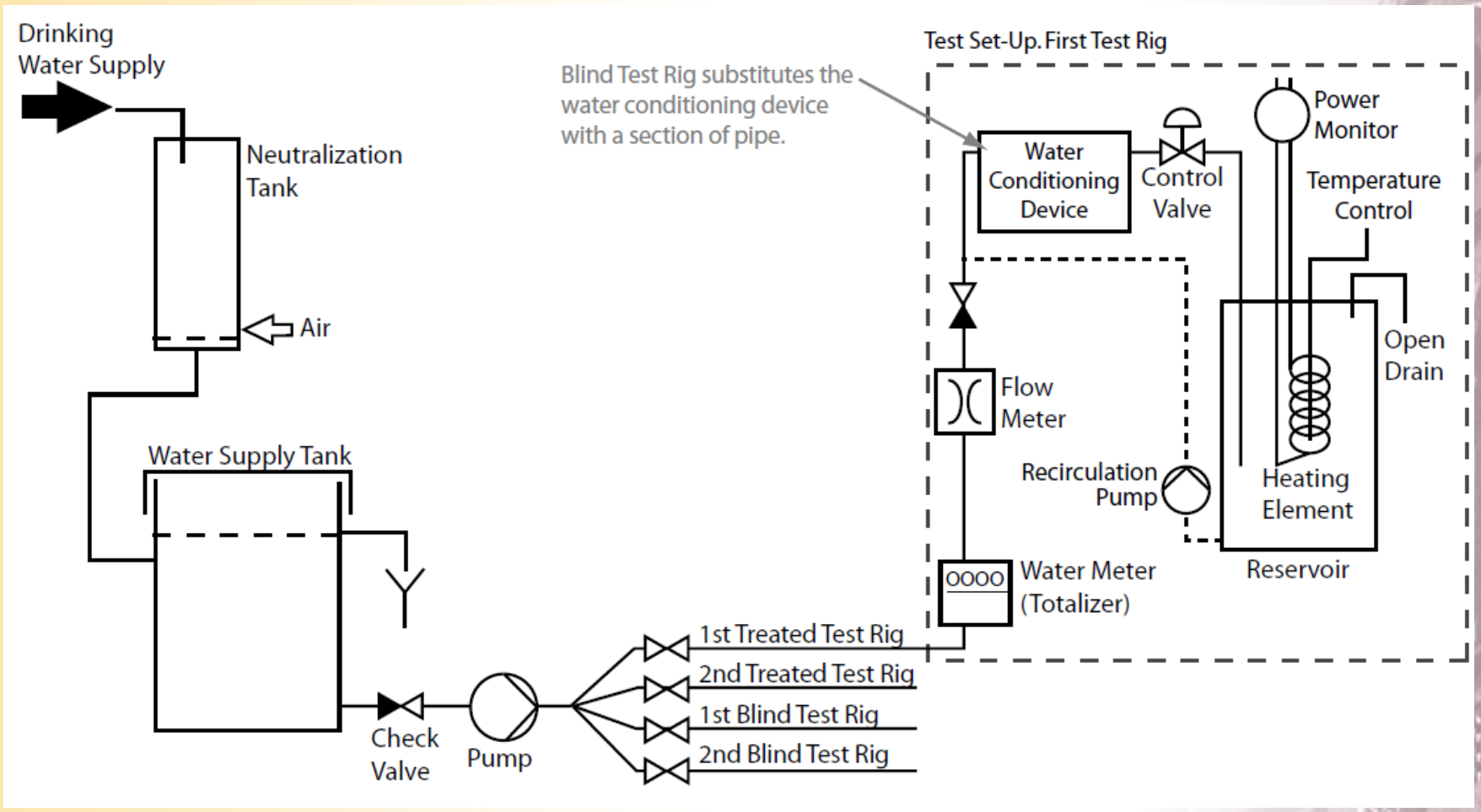
Experimental Procedure



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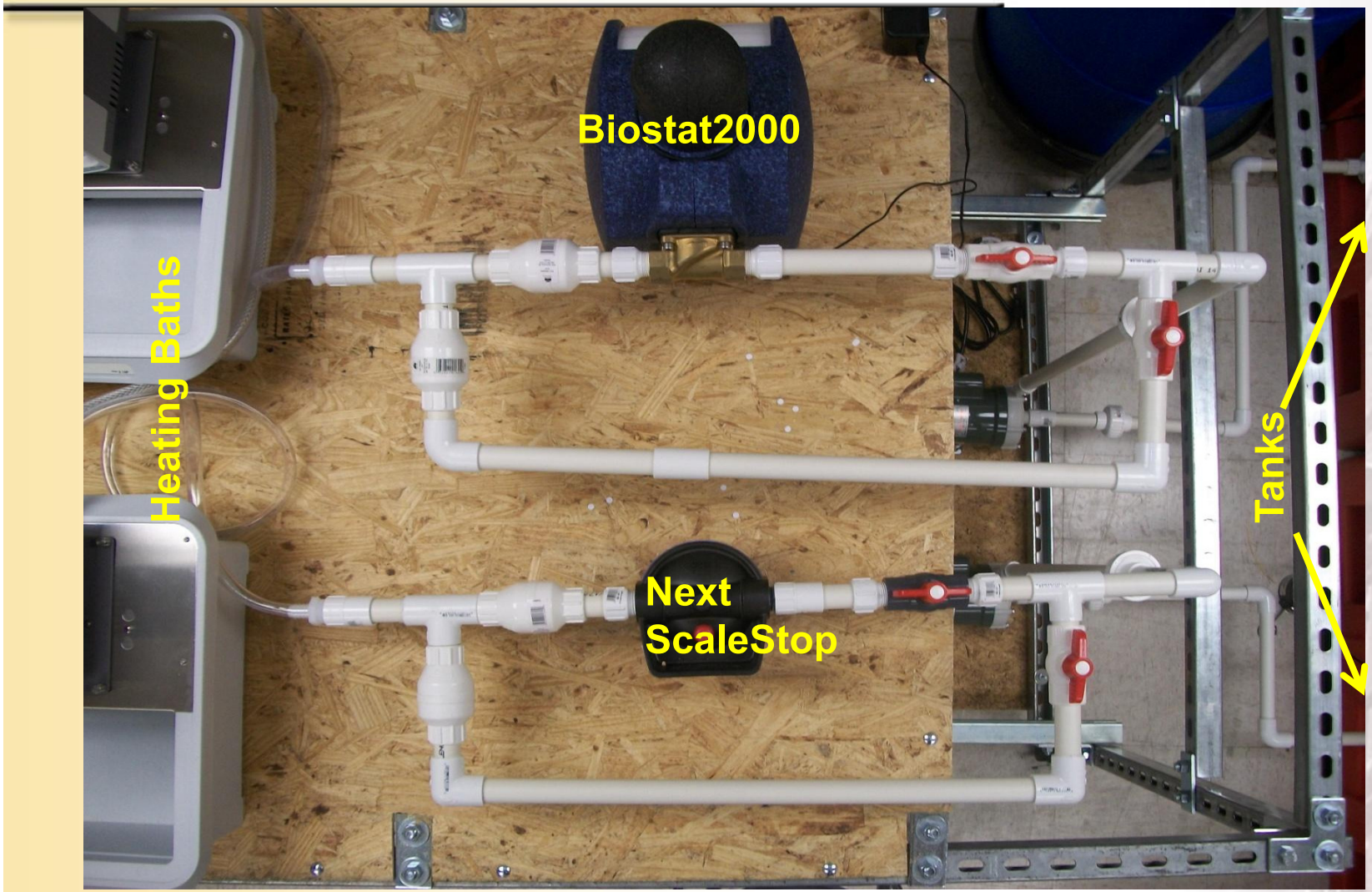
DVGW-W512 Protocol

Experimental Procedure



Plan View

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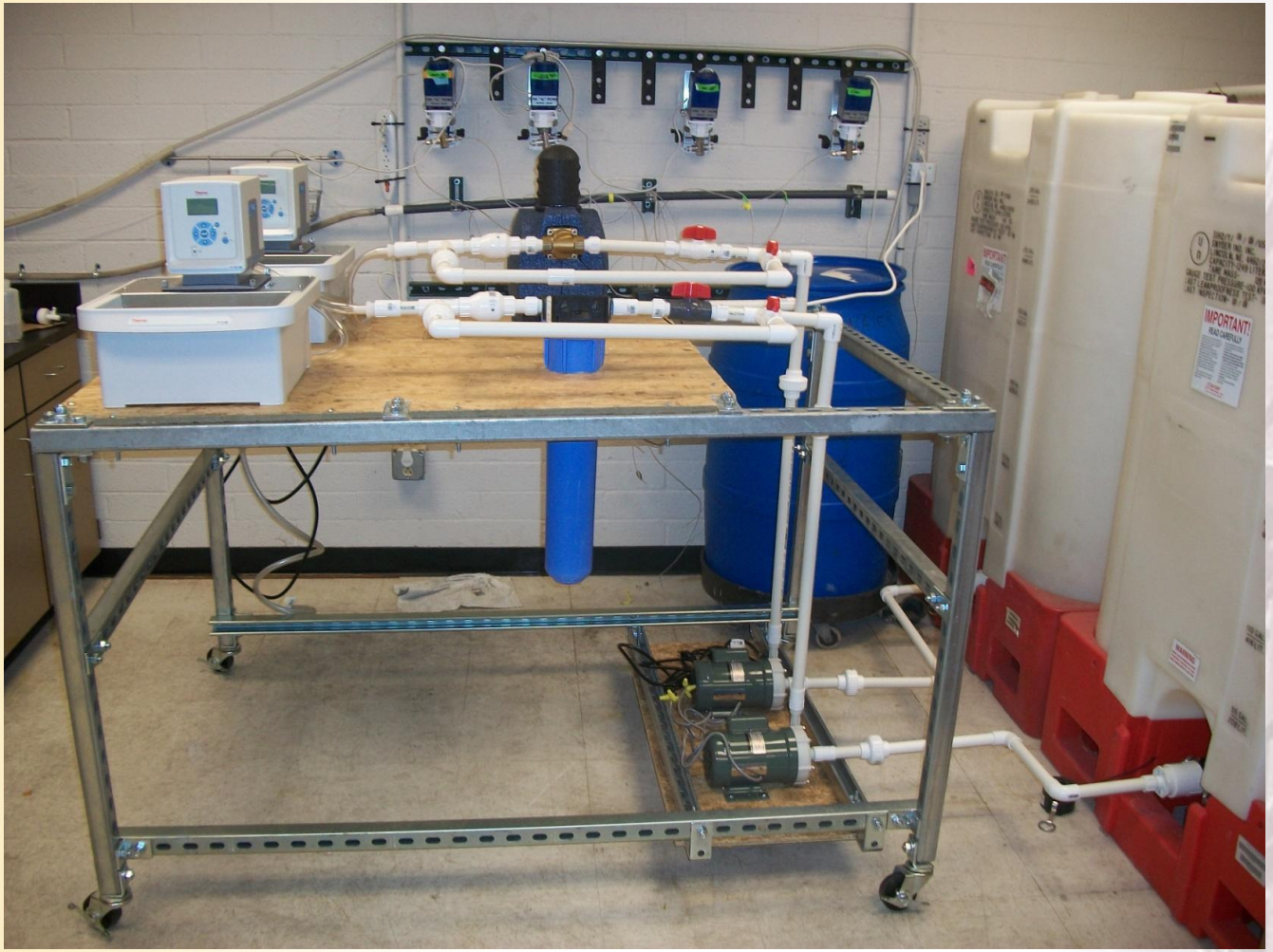
Experimental Procedure



Side View

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Experimental Procedure

- Once the 21 days of testing is over, the bath and heating element are cleaned using a 1N HCl solution.
- The solid scale is weighed and the scale dissolved by the HCl solution is measured using a Hach kit which utilizes the EDTA complexing method.
- This procedure will be repeated for all alternative devices using 3 different water qualities.

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Experimental Procedure

Water Qualities Included

- Salt River water (Tempe tap water)
- Central Arizona Project (CAP) canal water
- Scottsdale groundwater

	TDS (mg/L)	Hardness (mg/L as $CaCO_3$)
Salt River water (Tempe tap water)	479	180
Central Arizona Project (CAP) canal water	666	150 - 220
Scottsdale groundwater	465	200 - 250

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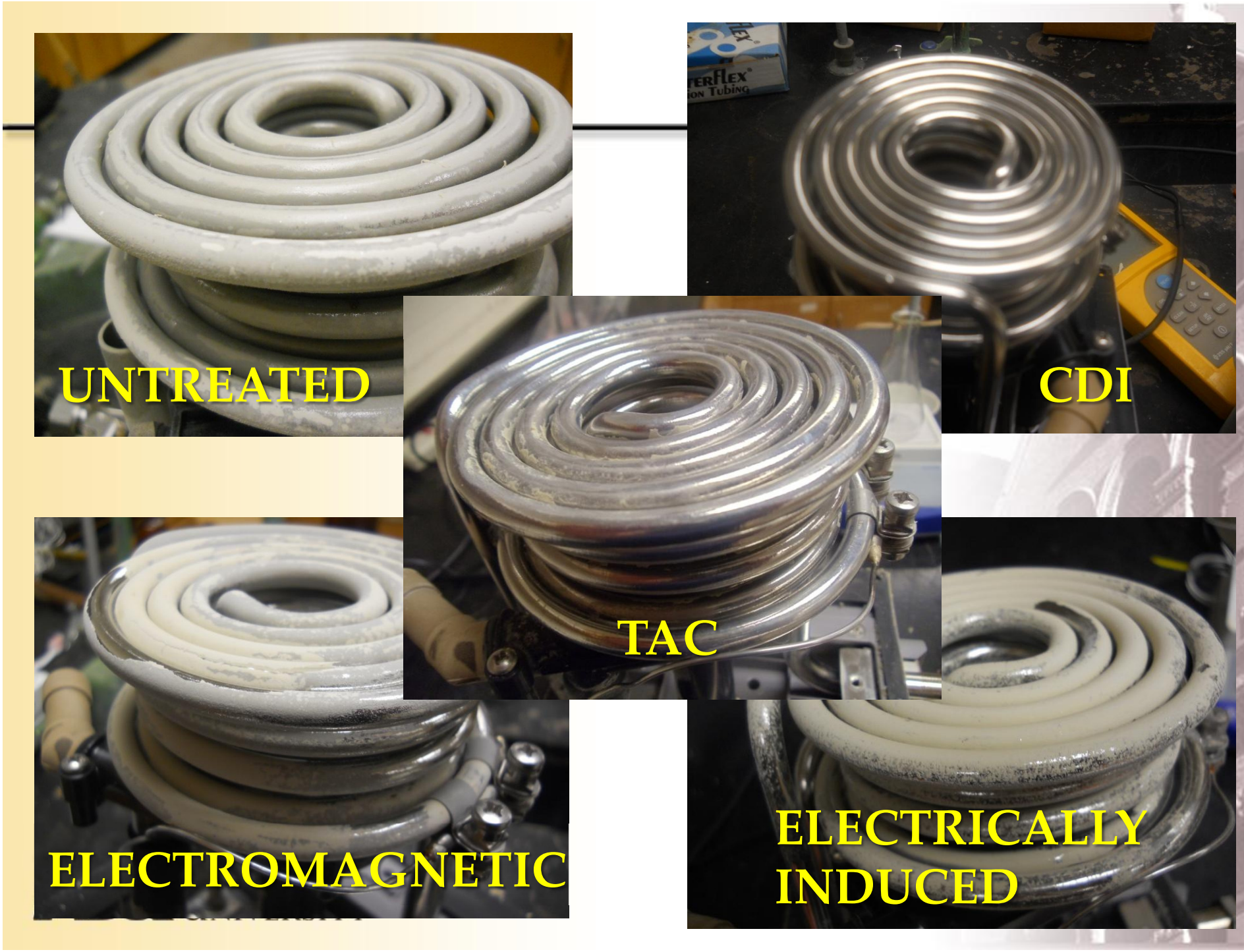
Results

Water Type	Treatment device used	Scale scraped off of heating element (g)	% Ca in scale formed	Ca formed in solid scale precipitate (g Ca)	Scale from bath and heating element dissolved with HCl (g Ca as $CaCO_3$)	Total calcium formed during test (g Ca as $CaCO_3$)	Photo of heating element with scale
Tempe tap water	**No Treatment**	-	NA	0.00	8.36	8.36	
	TAC	0.00	NA	0.00	0.12	0.12	
	EIP	0.68	34.88	0.24	3.60	3.84	
	MAG	1.44	34.88	0.50	3.47	3.97	
	CDI	0.00	NA	0.00	1.41	1.41	


UNTREATED
CDI
TAC
ELECTROMAGNETIC
ELECTRICALLY
INDUCED

Results

Mass Balance

Treatment Device	Total Initial Ca as $CaCO_3$ (g) Before Treatment*	Ca as $CaCO_3$ Found on Heating Element and Bath (g)	Total effluent Ca as $CaCO_3$ exiting the system (g)	% Scale Formed on Heating Element and Bath
No Treatment	294	8.36	285.64	**2.84%**
TAC	294	0.31	293.69	**0.11%**
EIP	294	4.07	289.93	**1.38%**
MWT	294	4.86	289.14	**1.65%**
CDI	294	1.41	292.59	**0.48%**

*Initial Ca indicates the average calcium content in 700gal Tempe tap water

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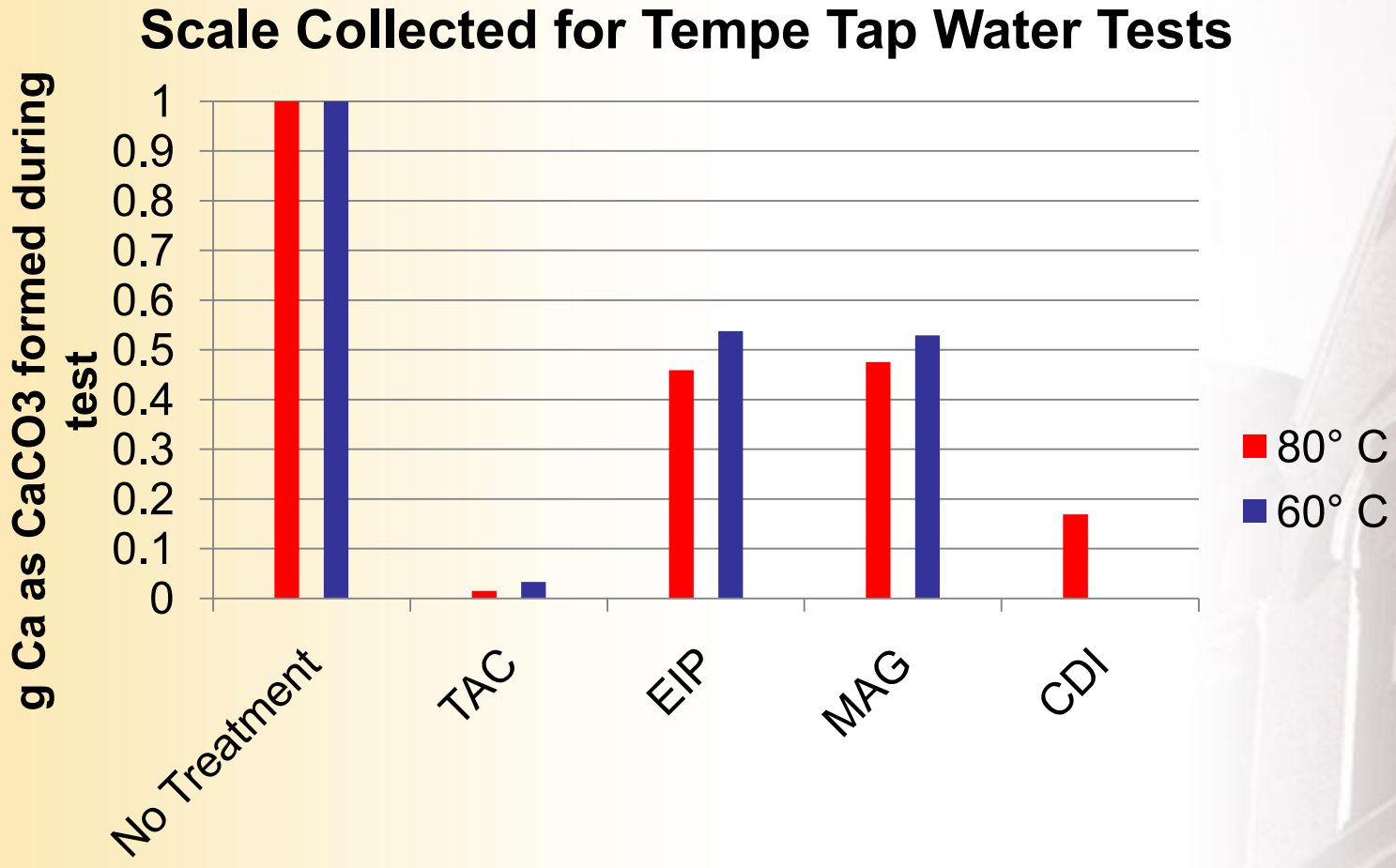
Results

Water Type	Treatment device used	Solid calcium collected from element (g Ca)	Scale from bath and heating element dissolved with 0.18N HCl (g Ca as $CaCO_3$)	Scale from bath dissolved with 1N HCl (g Ca as CaCO3)	Total calcium formed during test (g Ca as $CaCO_3$)	Photo of heating element after 21 days of testing
Tempe tap water 60°C	No Treatment		5.92	19.00	24.92	
	TAC		0.83		0.83	
	EIP	0.33	5.88	7.19	13.40	
	MAG		6.20	7.00	13.20	

Results



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Results

Percent Removal Compared to Untreated Case		
	Tempe Tap	
	80°C	60°C
No Treatment	0	0
TAC	99	97
EIP	54	46
MAG	53	47
CDI	83	

To "pass" the DVGW-W512 test, a percentage of 80 or higher is required.

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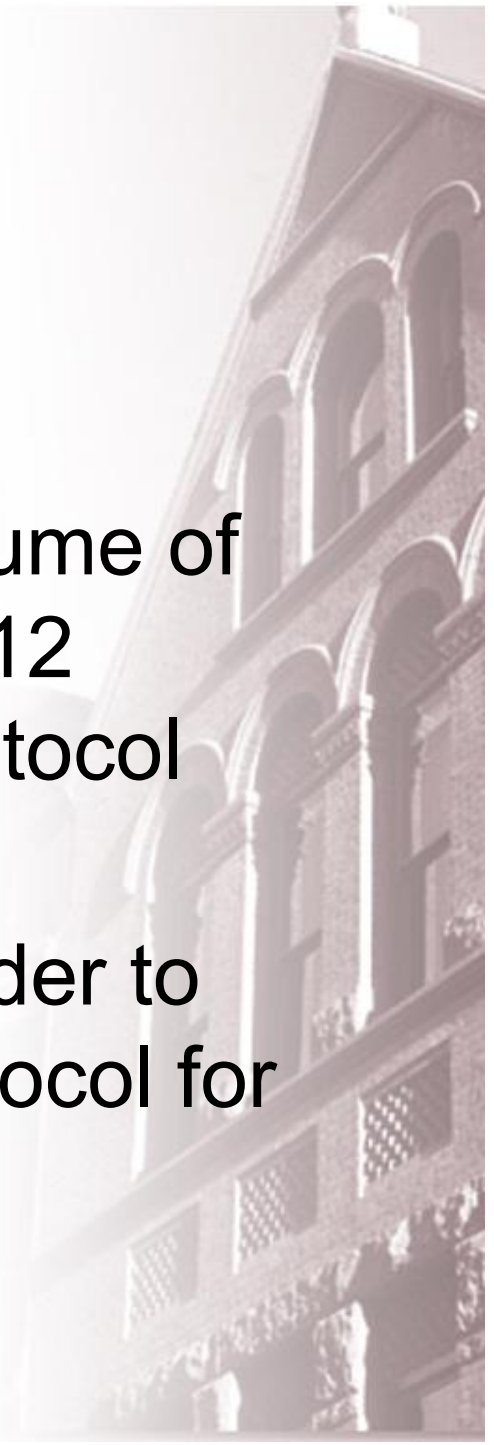
Results

Rapid Test

- Due to the length of time and volume of water needed for the DVGW-W512 protocol, a more rapid testing protocol would be highly desirable.
- Some routes were explored in order to develop a more rapid testing protocol for the scale inducing technologies.



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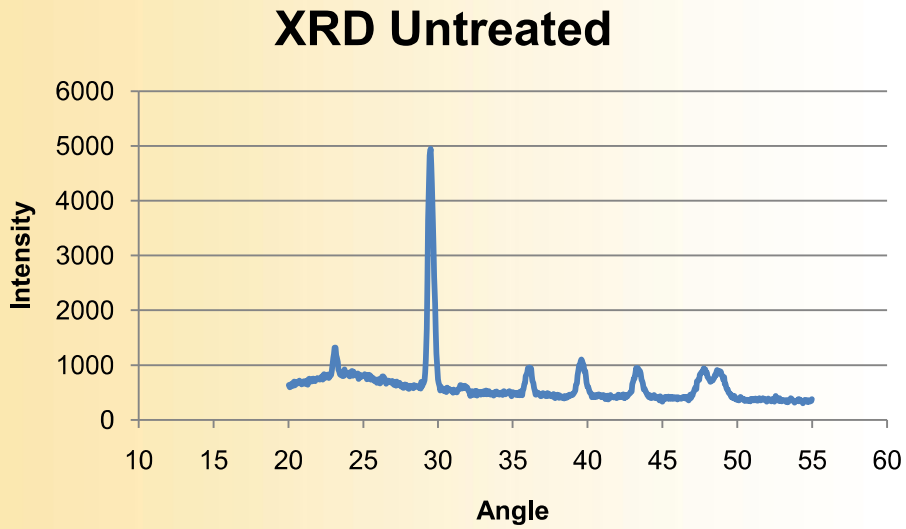
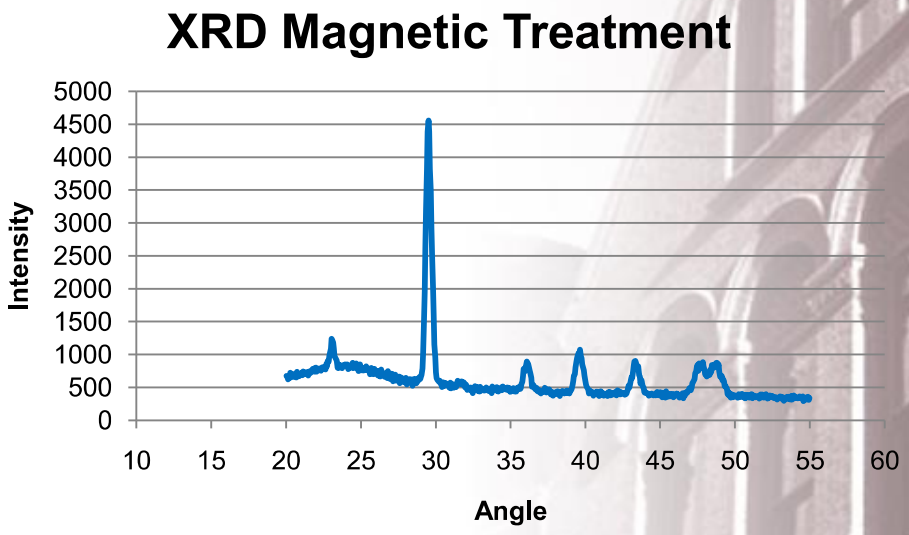
Results

X-Ray Diffraction





Both untreated and magnetically treated cases have calcite patterned peaks

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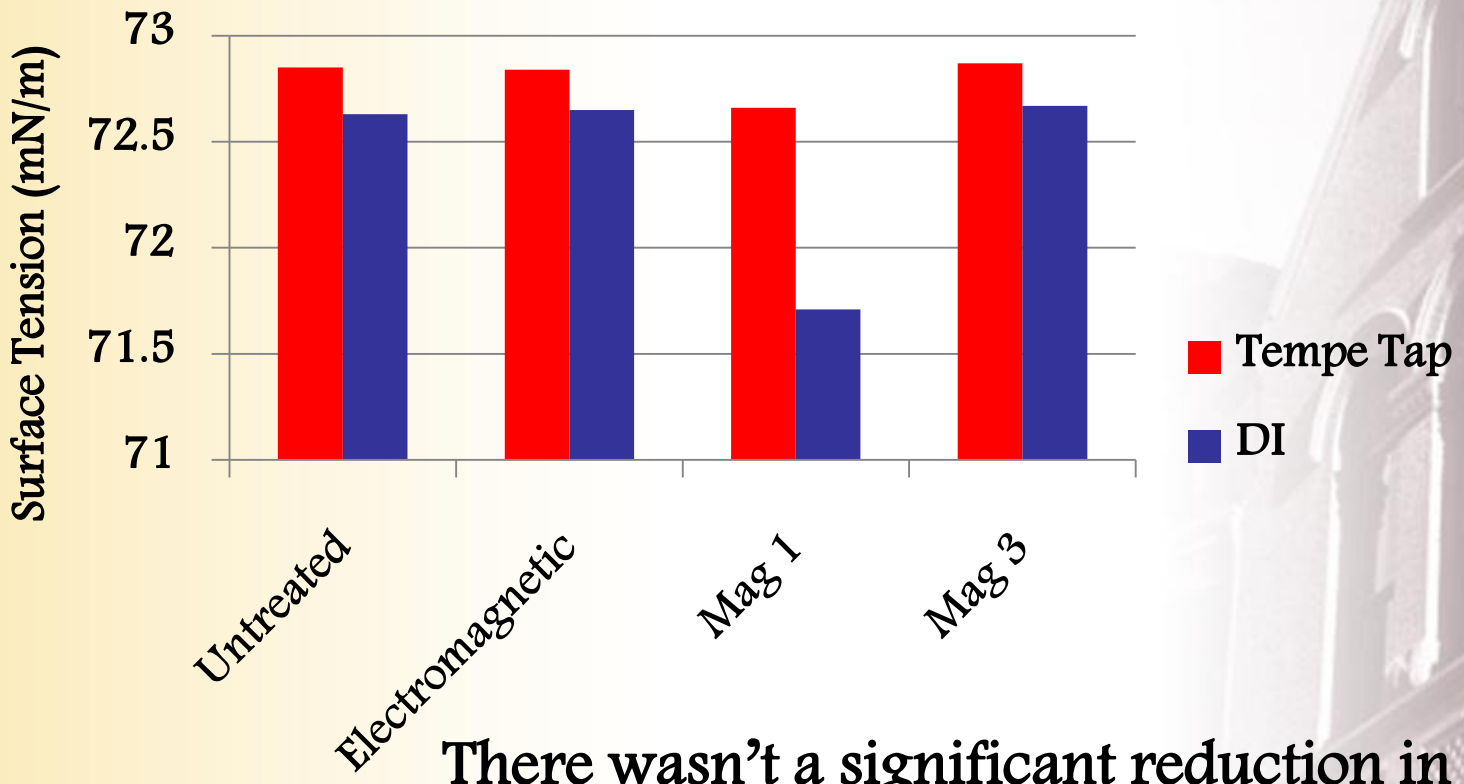
Results

Surface Tension



There wasn't a significant reduction in surface tension for any of the magnetic devices.

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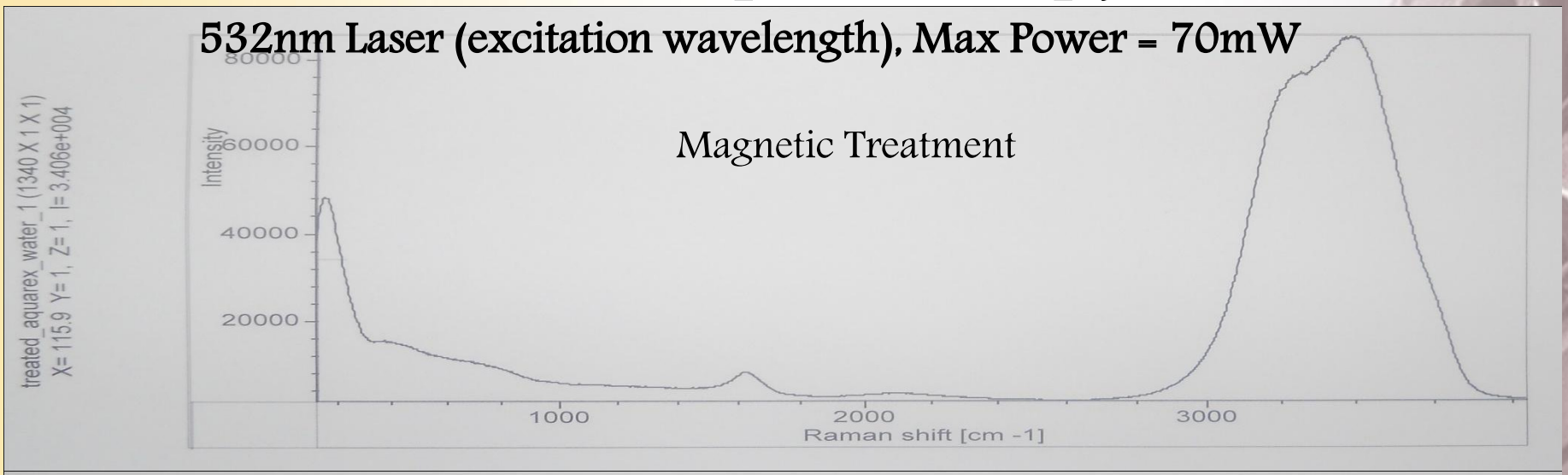
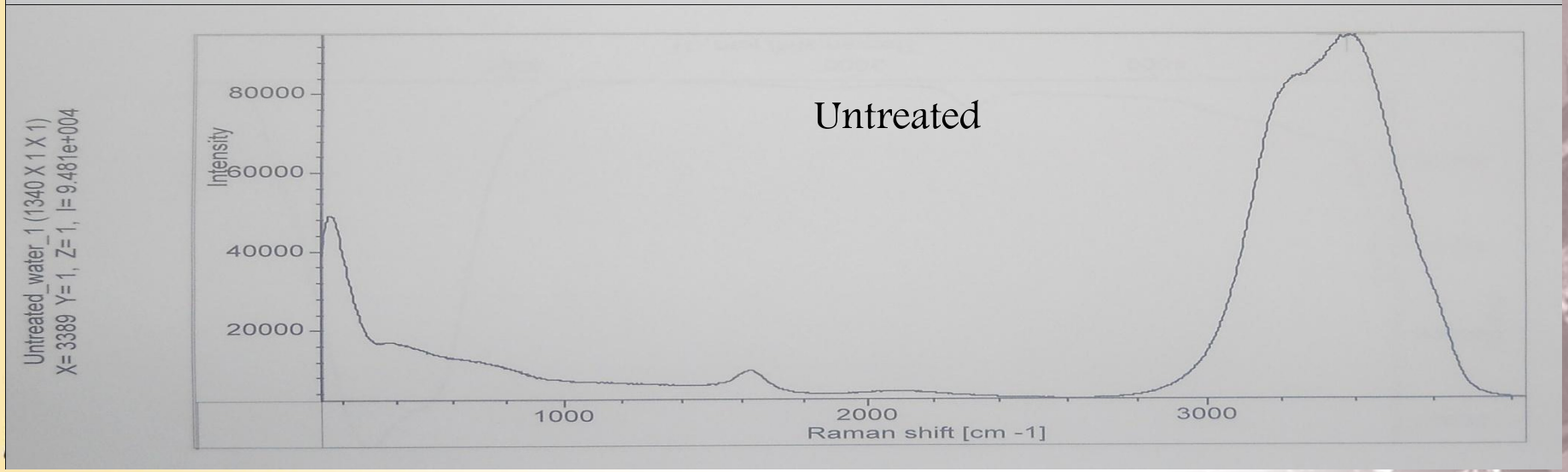
Results

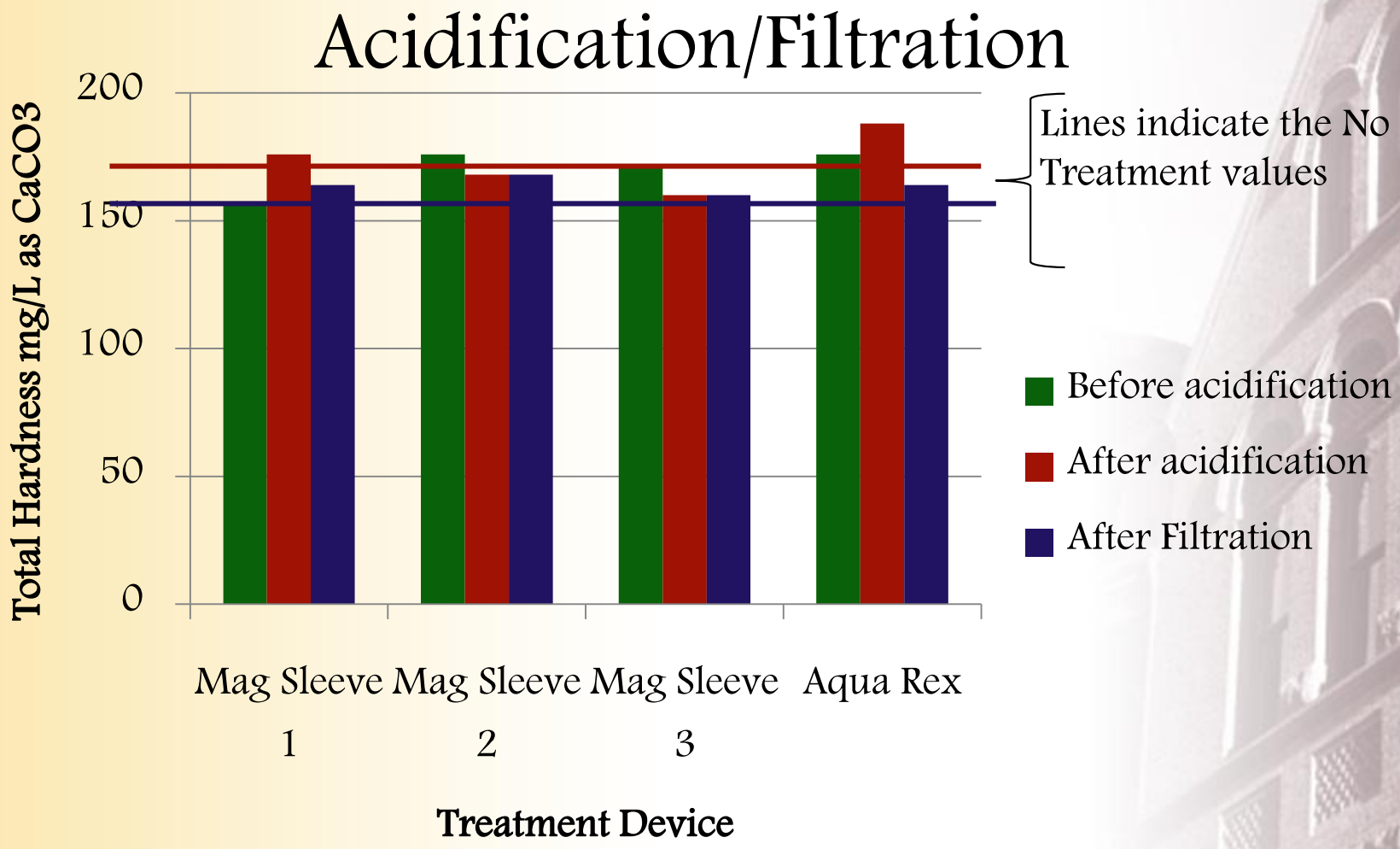
RAMAN Spectroscopy

532nm Laser (excitation wavelength), Max Power = 70mW





Results



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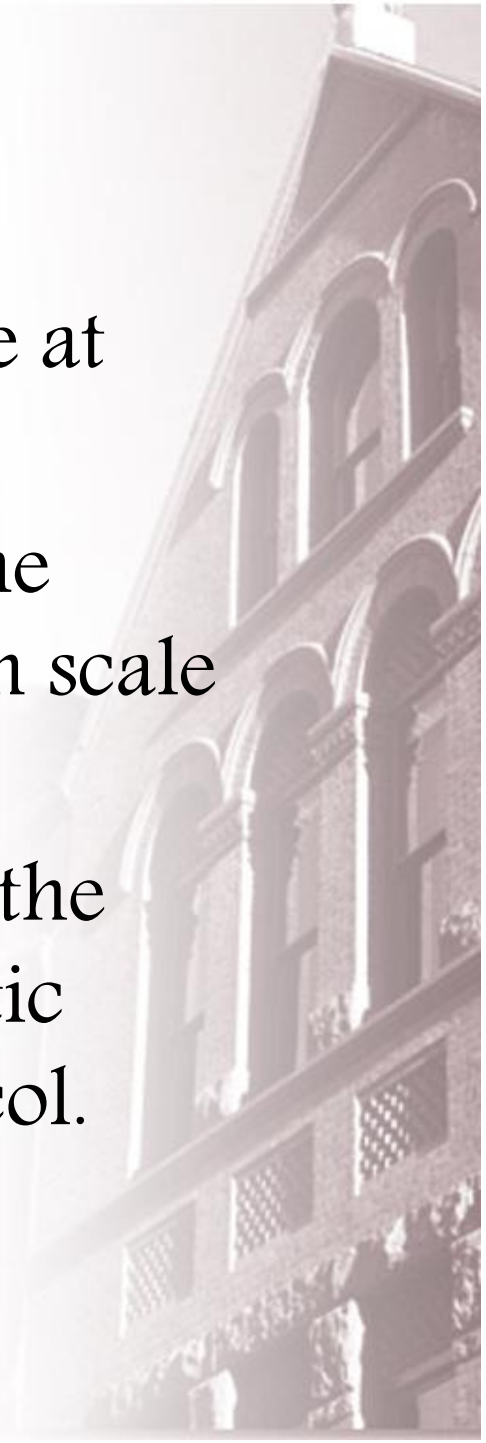
Conclusions

- All alternative devices were effective at reducing scale.
- The most promising technology is the template assisted crystallization with scale reductions of over 90%.
- Further study is needed to look into the mechanisms at work for the magnetic treatment and a rapid testing protocol.



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Future Work

- Complete testing of CAP canal and Scottsdale groundwater
- Continue exploring possibilities for a more rapid testing protocol
- Consider other no-salt water conditioning devices
- Develop guidelines for consumers such as a rating system to compare water conditioning devices

Aknowledgements

- WateReuse Foundation
- HDR, INC.
- Dr. Peter Fox
- Dr. Paul Westerhoff
- Emmanuel Soignard
- Cities of Phoenix, Scottsdale, and Tempe

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