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Bench and Pilot-Scale Investigation of Boron Removal for Seawater Membrane Desalination

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Presentation Outline

- Long Beach Overview
- Long Beach's Approach
- Water Quality Concerns
- Conclusion

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- **Long Beach Overview**
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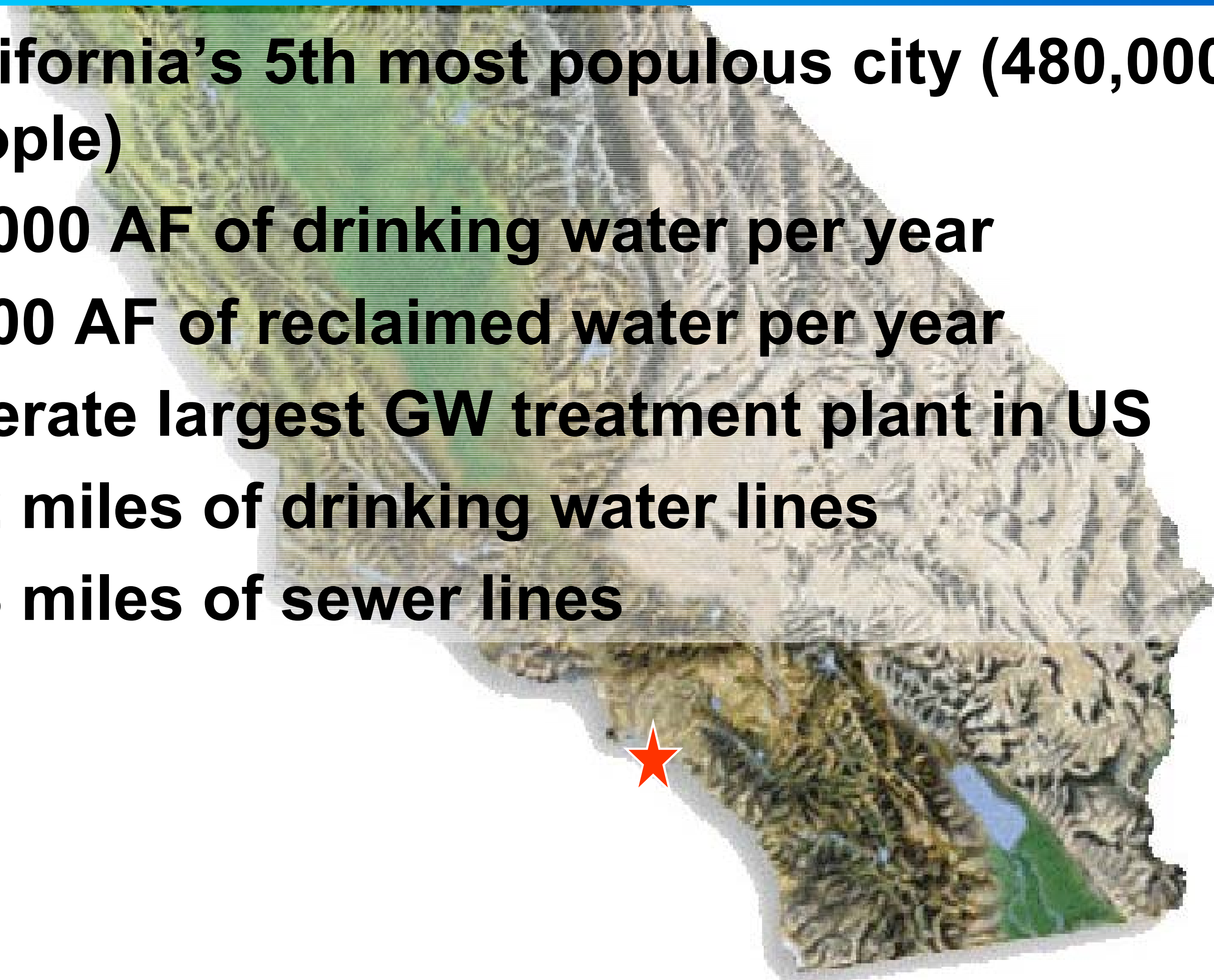
- **Conclusion**

Long Beach Water Department

- California's 5th most populous city (480,000 people)
- 70,000 AF of drinking water per year
- 5,500 AF of reclaimed water per year
- Operate largest GW treatment plant in US
- 912 miles of drinking water lines
- 763 miles of sewer lines



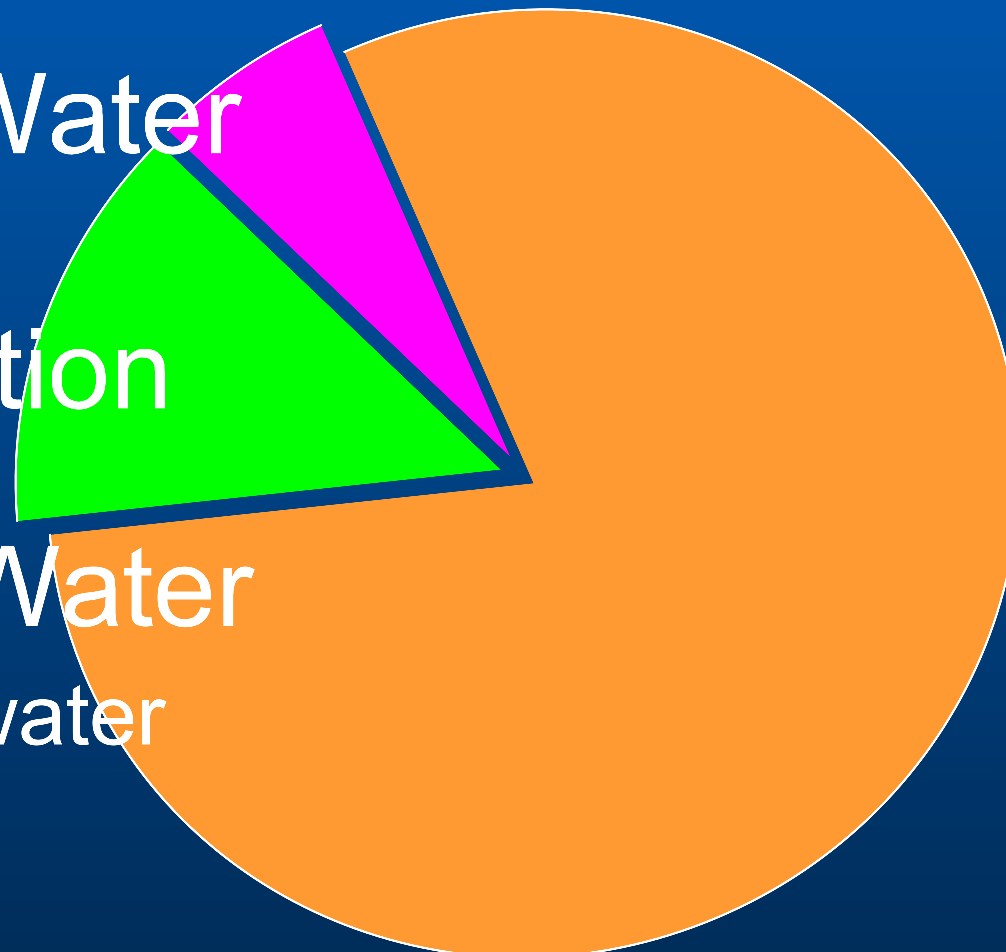
Long Beach Water Department

6%: Recycled Water

14%: Conservation

80%: Drinking Water

- -46% LB Groundwater
- -54% Imported



Imported Water Supply

...communities must produce more water locally to manage new limits on imports and growth in southern California's population and economy.

Future Reliability

- Very little population growth
- Expansion of recycled water and water conservation
- Seawater desalination necessary ==> supplement City's imported drinking water supply

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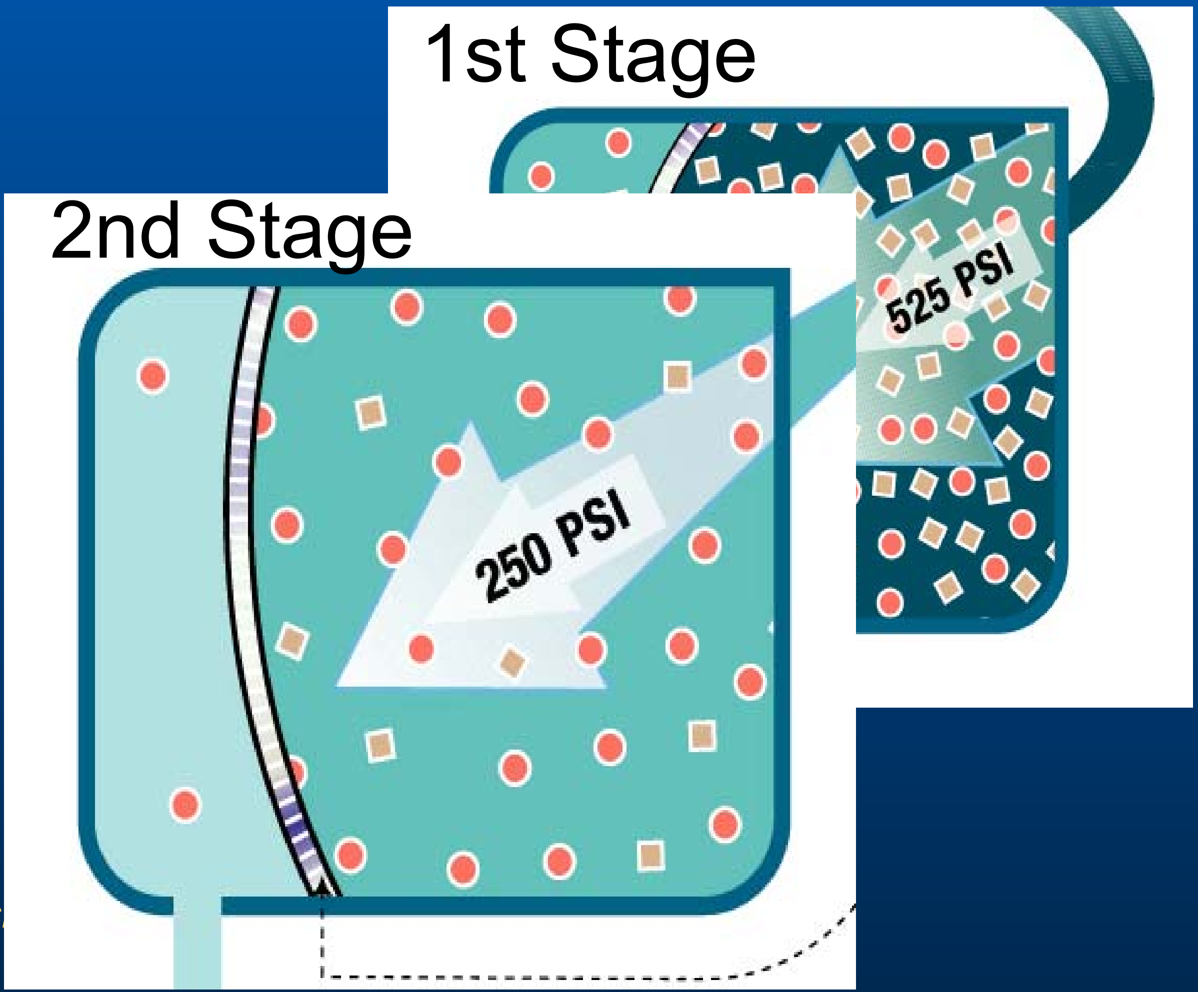
“Traditional” RO Process

- Uses pressures in excess of 800 psi
- Energy intensive
- High-pressure materials required ⇒ high capital costs
- “Traditional” seawater desalination method cost prohibitive

Process Development

- Patent pending 2-pass Nanofiltration (NF^2) process



- Evaluating Energy Consumption
- Evaluating Quality protection

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Typical NF^2 Water Quality

- Water quality

	Unit	Raw Seawater	Stage 1 Permeate	Stage 2 Permeate	LBWD Tap
Mg^{2+}	mg/L	1532	28	0.2	13
Ca^{2+}	mg/L	546	10.1	0.1	39
SO_4^{2-}	mg/L	2888	33	0.2	100
Na^+	mg/L	11912	1280	92	75
Cl^-	mg/L	19737	1806	117	59
TDS	mg/L	37480	3247	218	390
Hardness (as $CaCO_3$)	mg/L	7755	140	1.26	151
pH	---	8.01	7.84	7.37	8.16
LSI	---	1.12	-1.93	-4.56	0.34

Water Quality Concerns

- Standard operating conditions:

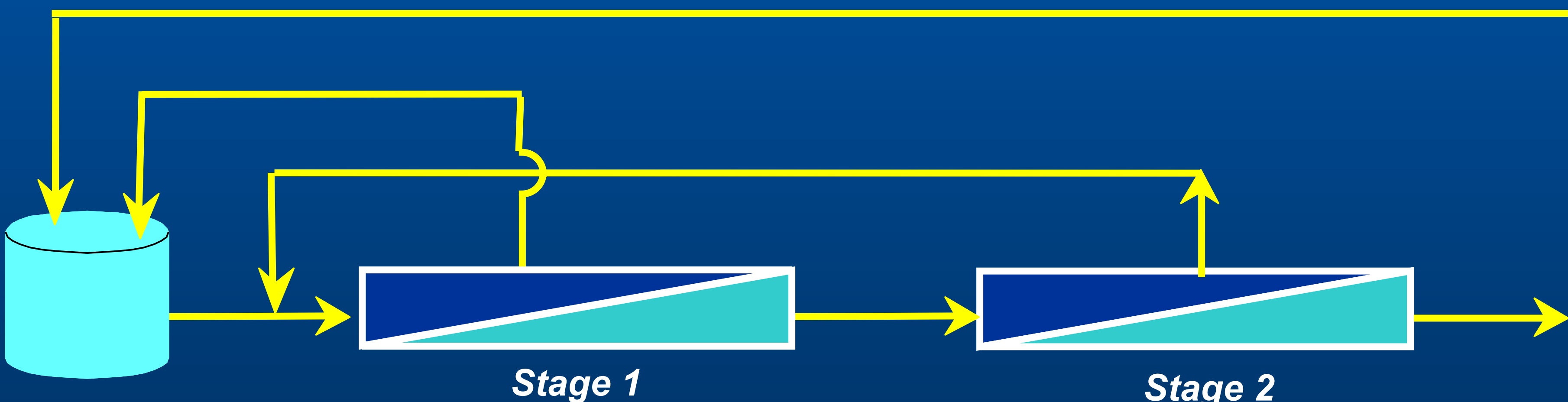
	Raw Seawater	NF^2 Permeate
TDS	~ 34,500 mg/L	< 300 mg/L
Bromide	~ 62 mg/L	0.4 - 0.6 mg/L
Boron	~ 4.5 mg/L	?

Boron: Background

- Typically < 1 mg/L in surface waters
- Naturally occurring in seawater (~4.5 mg/L)
- Toxic to some common trees (0.3 - 1.0 mg/L)
- Show reproductive health effect in animals
- CDHS established Action Level at 1 mg/L
- No USEPA "MCL" but is on EPA CCL
- WHO guideline at 0.3 mg/L (original)
- WHO revised guideline to 0.5 mg/L (treatment limitation)
- Analytical interferences

Boron Removal

- Traditional single-pass SWRO achieves 43% - 78% rejection
- LBWD's NF² Process



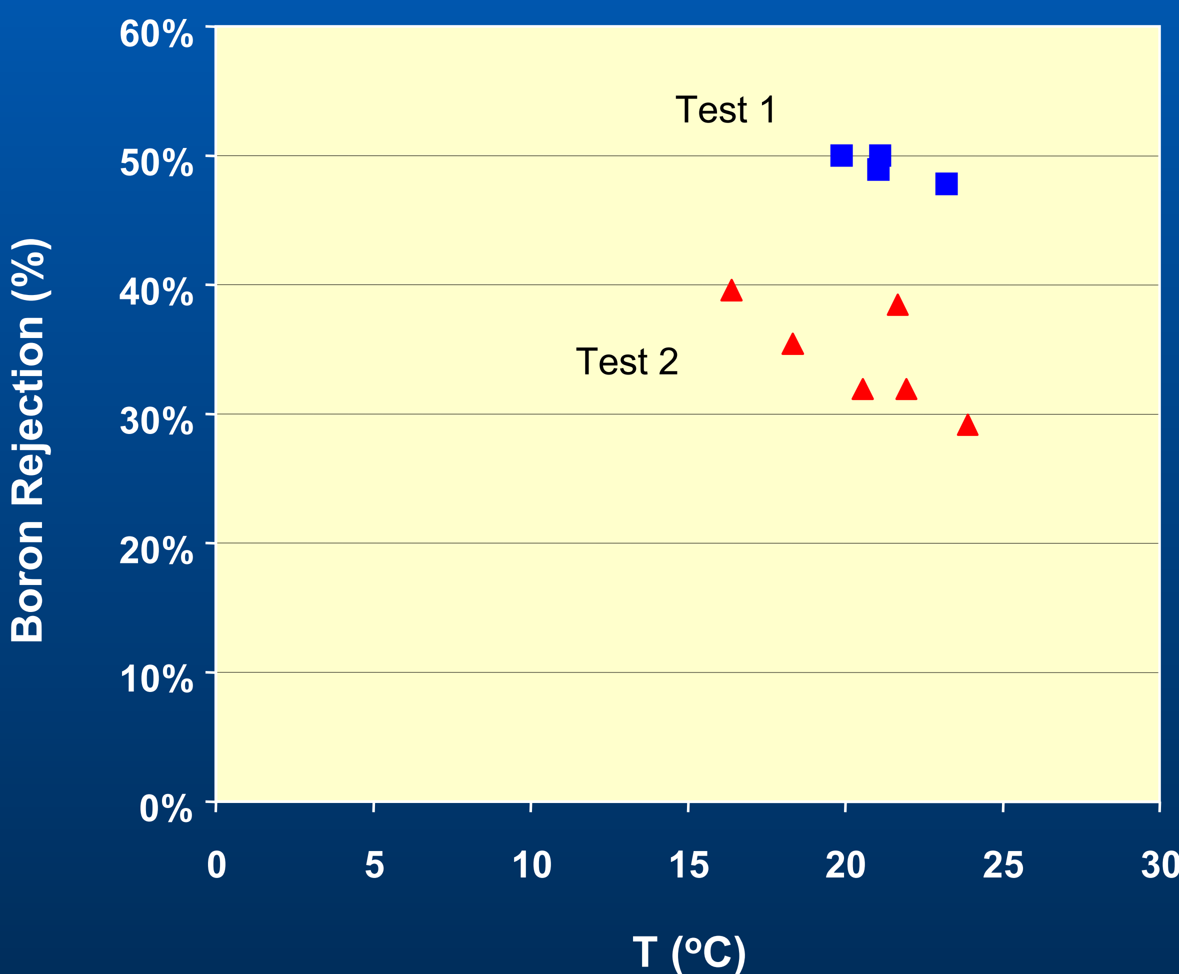
B = 4.6 mg/L *B = 3.7 mg/L* *B = 2.4 mg/L*

Stage 1 Rejection ~ 20% *Stage 2 Rejection ~ 35.1%*

Overall Rejection ~ 48%

Temperature Effects on Rejection

- Boron rejection substantially deteriorates with warm water temperatures
- Some membranes are less affected by temperature, but selection may be few, limiting market competition
- Successful boron control solution must be independent of temperature



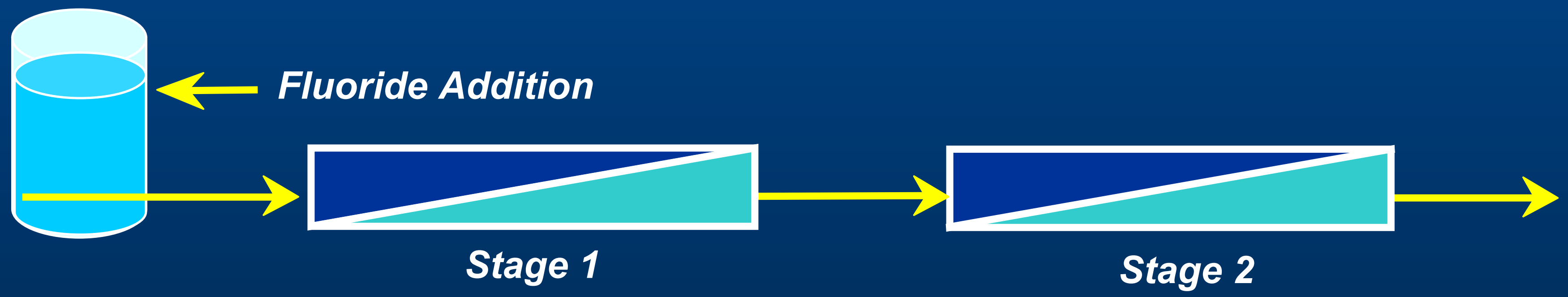
Literature Review

Technology	Water Tested	% Removal	Comments	Reference
Softening	Seawater	Insignificant	Batch tests of calcite precipitation	Kitano et al., (1978)
Coagulation	Drinking Water	<28%	Typical removal < 10%	Borax (1996)
Activated Carbon	Synthetic Water	Up to 90%	High carbon doses needed	Choi et al, (1979)
Reverse Osmosis	Seawater	43 - 78%	Survey of 8 operating RO Plants	Magara (1996)
Ion Specific Resin	RO Permeate	>99%	pH of produced waters <4.5 for 600 bed volumes	Nadav (1999)
2-pass RO with pH adjustment	RO Permeate	40 - 100%	Best removal at pH 10.5	Prats et al (2000)
Boron Chelation	Synthetic Water	>80%	N-methyl-D-glucamine	Smith et al, (1995)
	RO Permeate	>98%	Fluoride	Derwent (1997-1999)

*Edwards, M (2000)

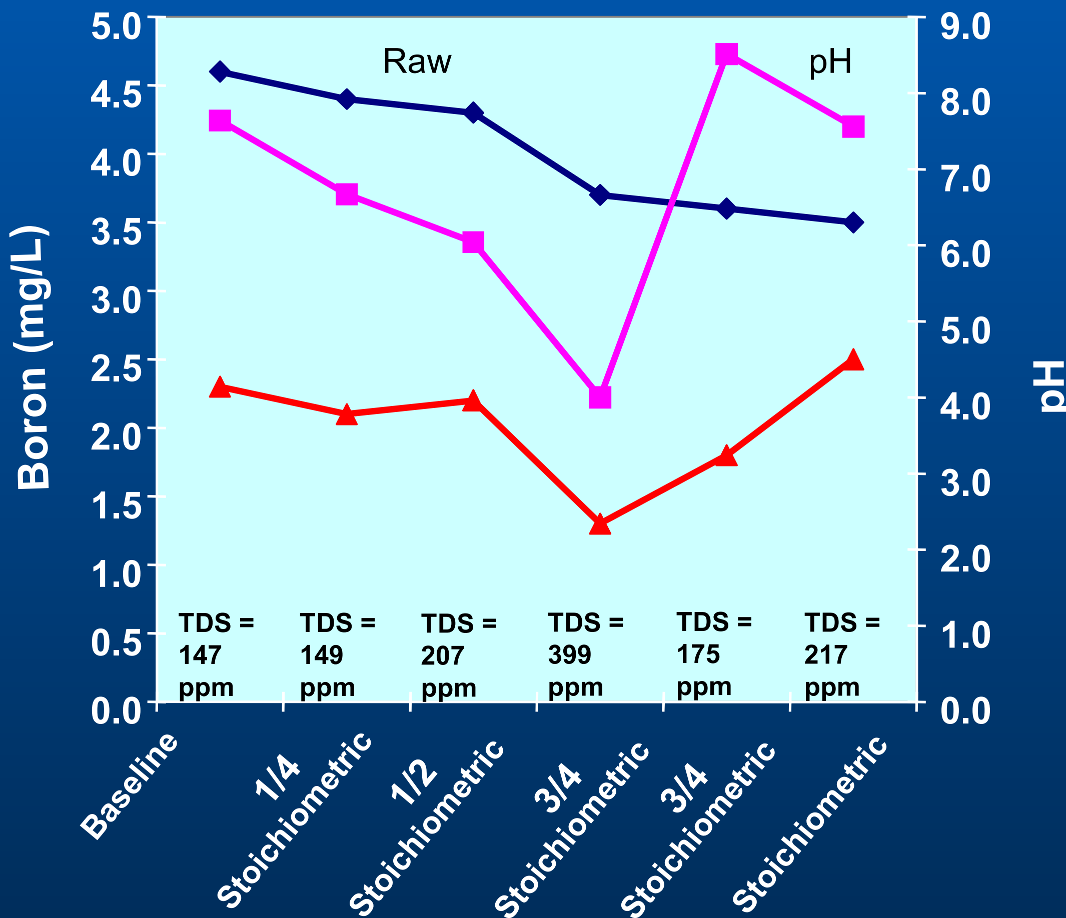
Fluoride Addition

- Two fluoride sources added
  - H_2SiF_6
    - Adjust pH
  - KF
- Fluoride added in stoichiometric ratio increments (¼, ½, ¾, 1)



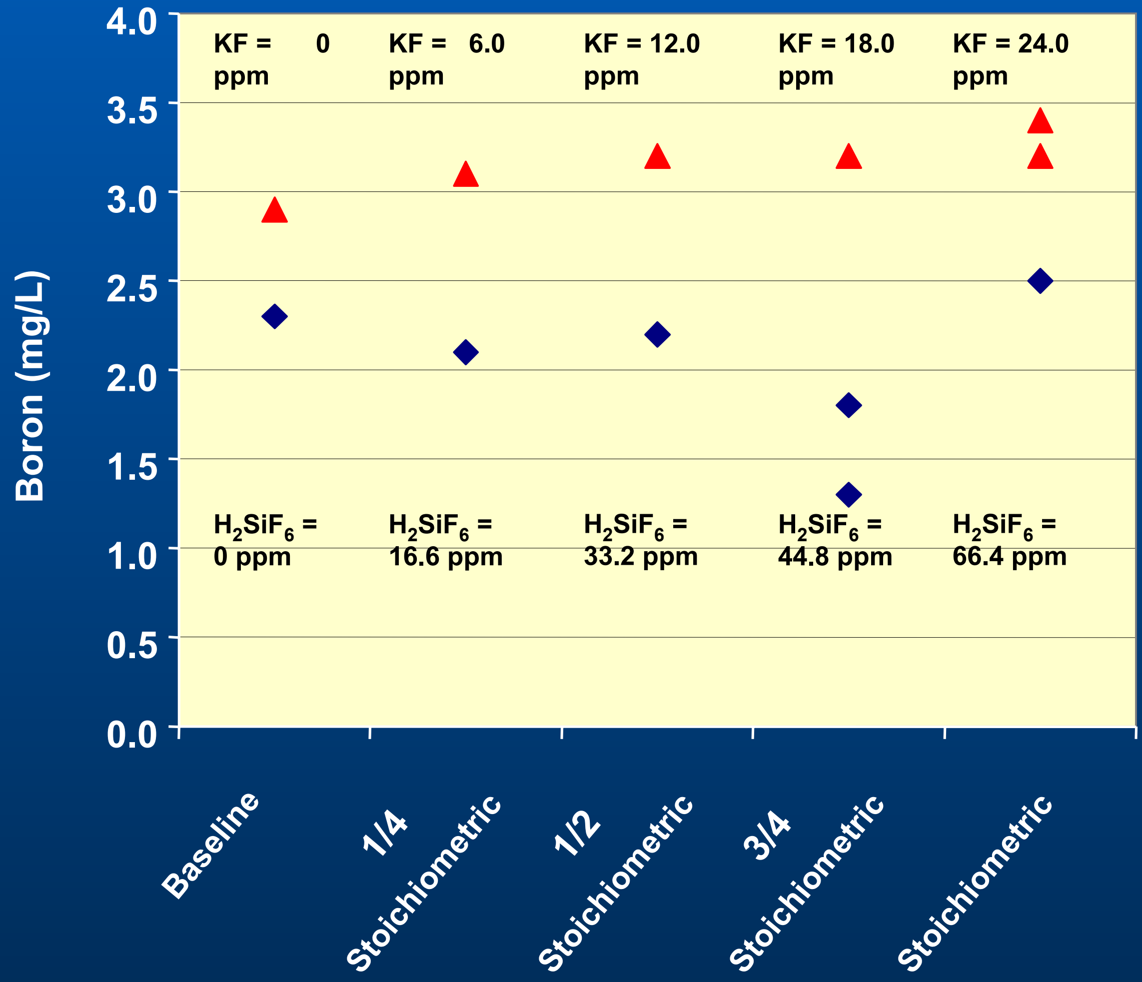
Fluoride Addition

- Initially, H_2SiF_6 addition appear to improve boron rejection.
- Improvement appears to be correlated to pH, not fluoride.
- Although lower pH improved boron rejection, lower pH deteriorated TDS quality.
- H_2SiF_6 addition appeared to reduce raw water boron levels.
- Increase in boron rejection may be associated with co-precipitation of boron.



Fluoride Addition

- Isolating pH effect by adding KF, fluoride did not appear to improve boron rejection compared to H_2SiF_6.
- Fluoride dose required to reach stoichiometric ratio with raw water boron was an order magnitude greater than typical water treatment doses.

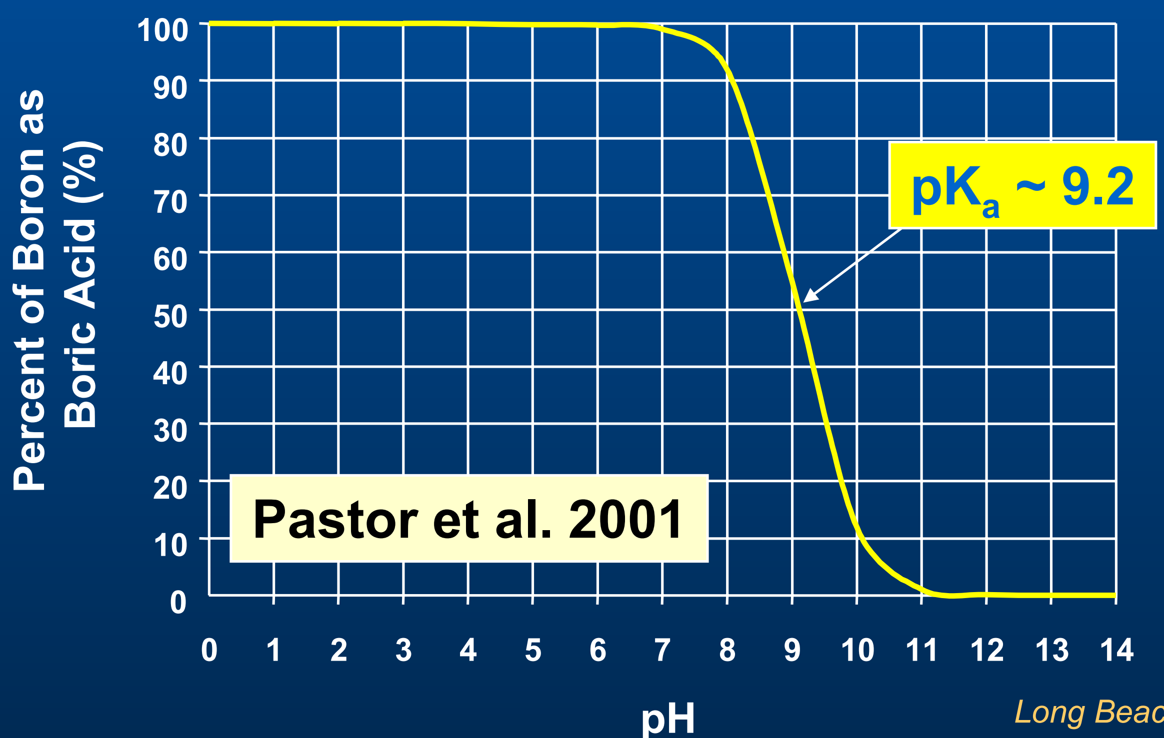


Fluoride Evaluation Summary

- Reduction in pH appears to improve boron rejection, while inversely affecting TDS.
- H_2SiF_6 addition appears to improve boron rejection, but benefits appear to be associated with boron reduction in raw water, possibly due to co-precipitation.
- H_2SiF_6 doses necessary to achieve potential boron regulatory targets may be impractical.
- Fluoride alone does not appear to improve boron rejection, as illustrated by KF addition.

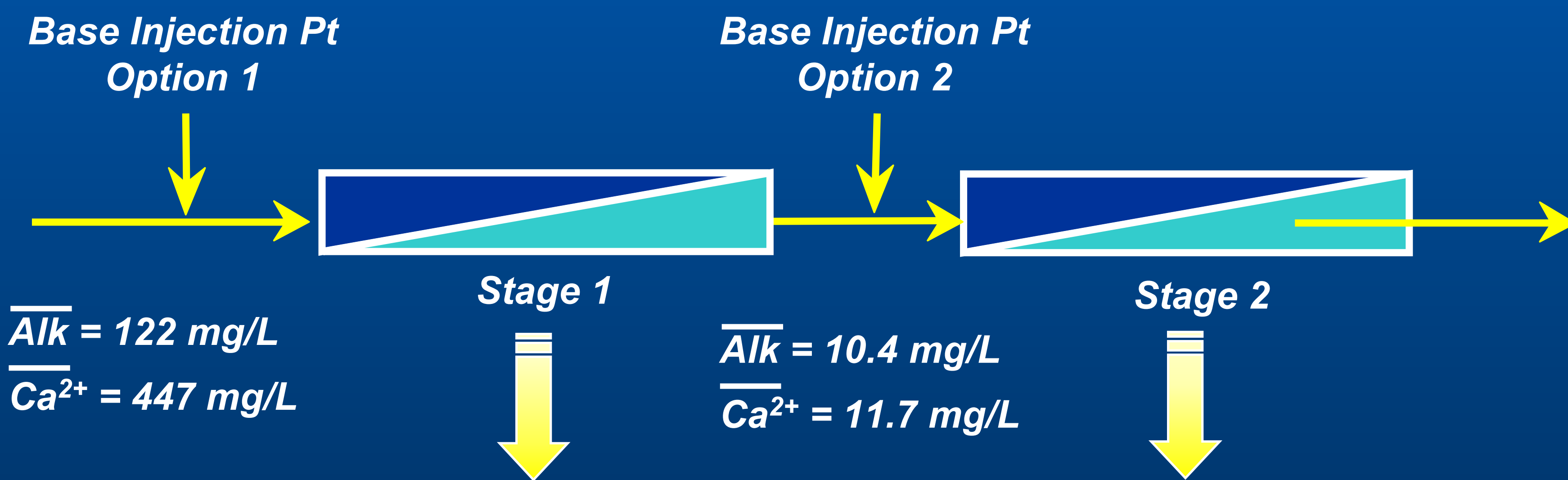
Base Addition

- $B(OH)_3 + OH^- \rightarrow B(OH)_4^-$
- Boron rejection can be improved by increasing pH



Base Addition Strategy

- Selecting appropriate base addition location is critical

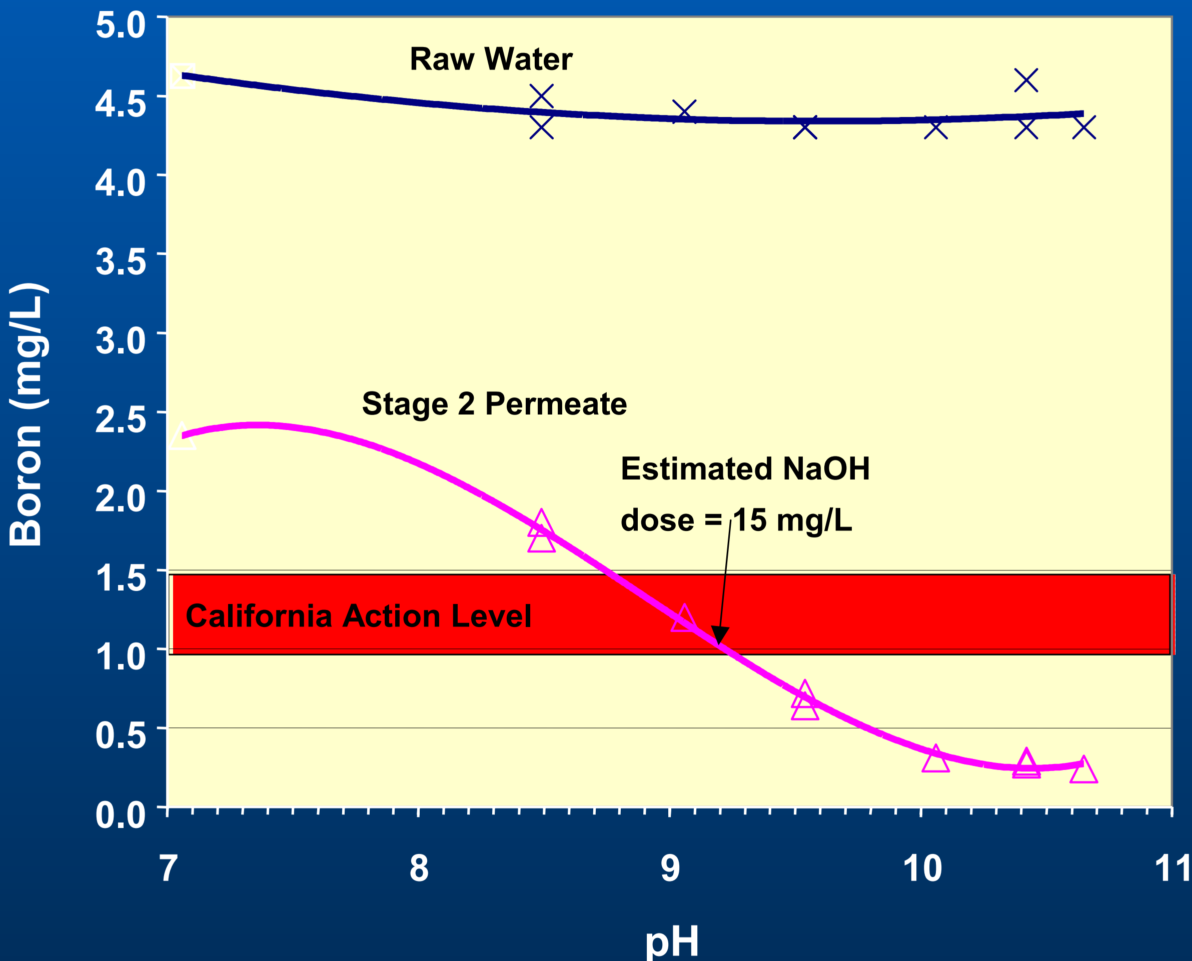


- *More base required to alter pH*
- *HIGH potential for fouling*

- *Less base required to alter pH*
- *97% rejection of Ca^{2+}. Decreased potential for fouling*

Boron Addition Results

- California Action Level for boron is 1 mg/L.
- 1.49 mg/L would comply with action level.
- LBWD's boron goal is < 1.0 mg/L to minimize "significant digit" confusion to customers.
- Results show 15 mg/L NaOH (estimated) required for permeate boron to be < 1.0 mg/L.



Base Evaluation Summary

- Base can be added at the pass 2 feed to prevent inorganic precipitation.
- For membranes and water tested, pH 9.2 improves boron in permeate to < 1.0 mg/L.
- Increasing pH to 9.8 would meet WHO limit of 0.5 mg/L.
- Estimated cost (caustic only):
  - < 1.0 mg/L boron = $0.02/1000 gallons
  - <0.5 mg/L boron = $0.04/1000 gallons

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Conclusions

- General WQ parameters consistent with single-pass SWRO.
- Preliminarily results suggest boron rejection with fluoride is not practical.
- Base addition can be used with NF^2 process for boron control, with minimal capital cost.
- Additional chemical cost (caustic soda only) for meeting regulatory guidelines is estimated at $0.02 to $0.04 per 1000 gallons.

References

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