



Removal of Strontium by Ion Exchange and Lime Softening

Darren Lytle, Hannah Chait, Dan Williams, , Maily Pham, Christy Muhlen

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Stable Strontium (Sr)

- **Elemental Properties**

- Naturally occurring alkaline earth metal
- Behaves very similar to calcium

- **Manufacturing Usage**

- Making of pyrotechnics, alloys, ceramics, and glass
- Block x-ray emissions from cathode-ray tubes

- **Locations Found**

- Widely distributed in the earth's crust and ocean
- Majority of strontium compounds dissolve in water

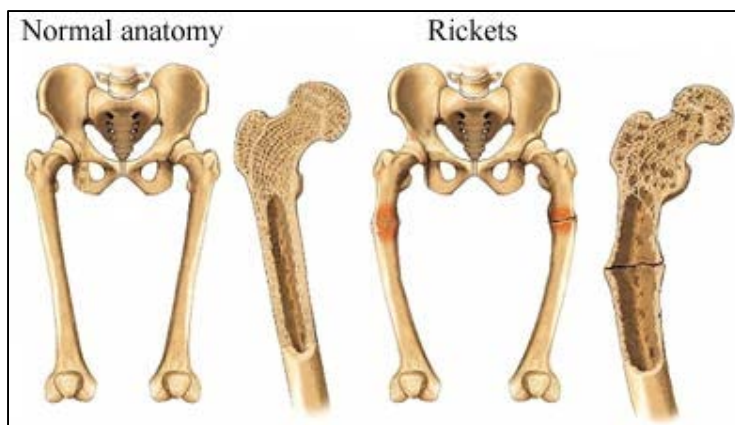
- **Exposure**

- Drinking water
- Food
 - Grains, leafy vegetables, dairy products are the largest contributor to dietary strontium.



Strontium Health Effects

(1992 IRIS Risk Assessment)



- Limited studies
- No indication of tumorigenic effects
- High levels effect infants, children, and adolescents
- Abnormal skeletal development (rickets)
- Exacerbated by inadequate calcium levels
- Substitutes for calcium during bone calcification or displaces calcium from existing calcified matrix

Image source: aurorahealthcare.org/yourhealth/healthgate/images/exh4511a.jpg



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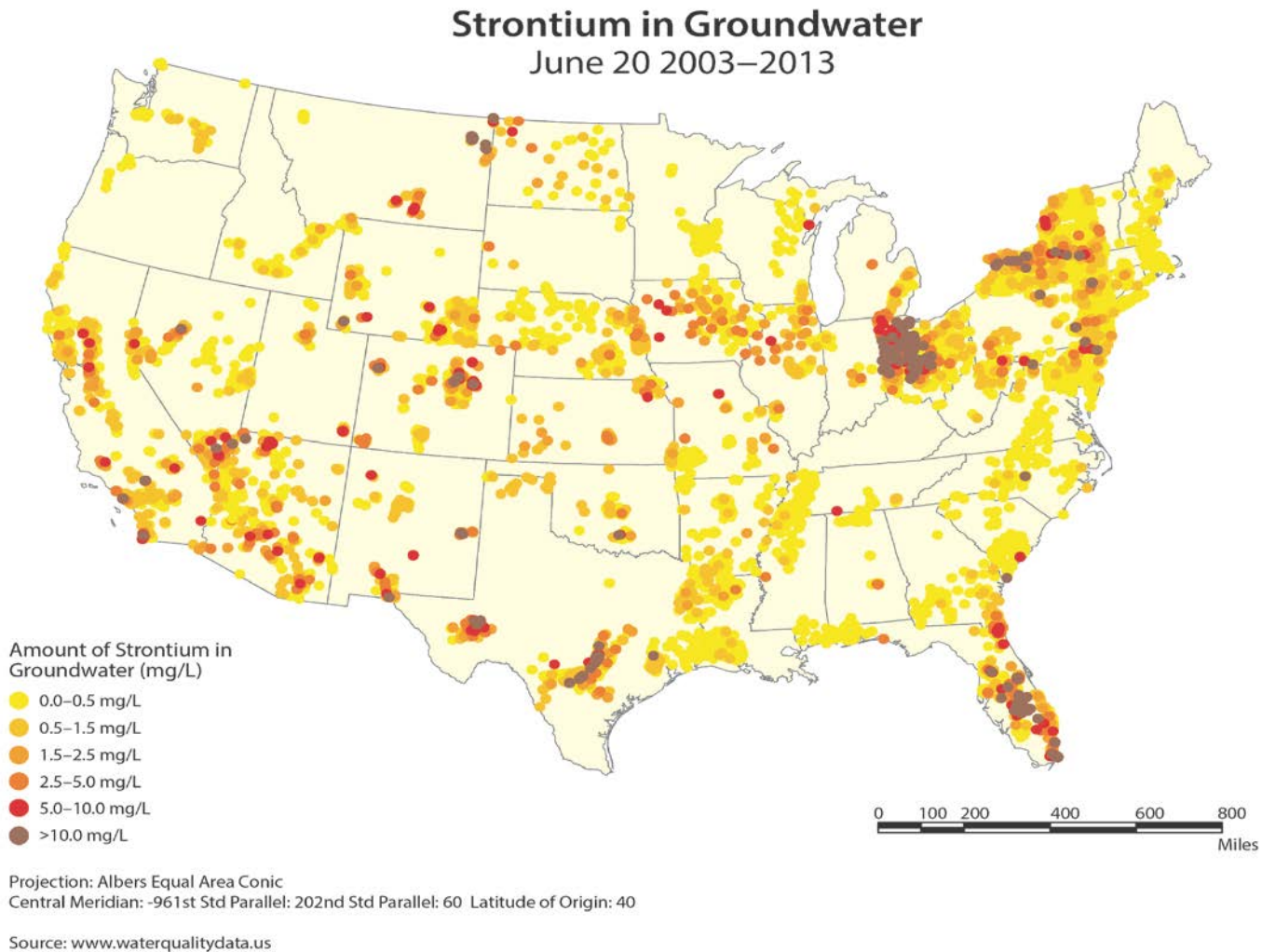
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Regulatory Relevance

- **Contaminant Candidate List 3**
- **Unregulated Contaminant Monitoring Rule 3**
 - Non-cancer Health Reference Level (HRL) of 1500 µg/L
- **Preliminary Regulatory Determination (10/2014)**



Strontium Occurrence in US Ground Waters (USGS NWIS & USEPA STORET)



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Current Water Treatment Options for Strontium

- **Drinking Water**
 - Very little information available
- **Industrial Wastewater**
 - Adsorption
 - Ion exchange
 - Biological treatment
- **Radioactive Isotope, Strontium-90**
 - Regulated since 1977
 - Sorption
 - Nanofiltration
 - Biological Treatment



Objectives

- **Present a brief overview of past bench-scale research to evaluate the impact of lime softening on strontium removal from drinking water.**
- **Present full-scale drinking water treatment studies regrading the impact of lime softening and ion exchange softening on strontium removal.**

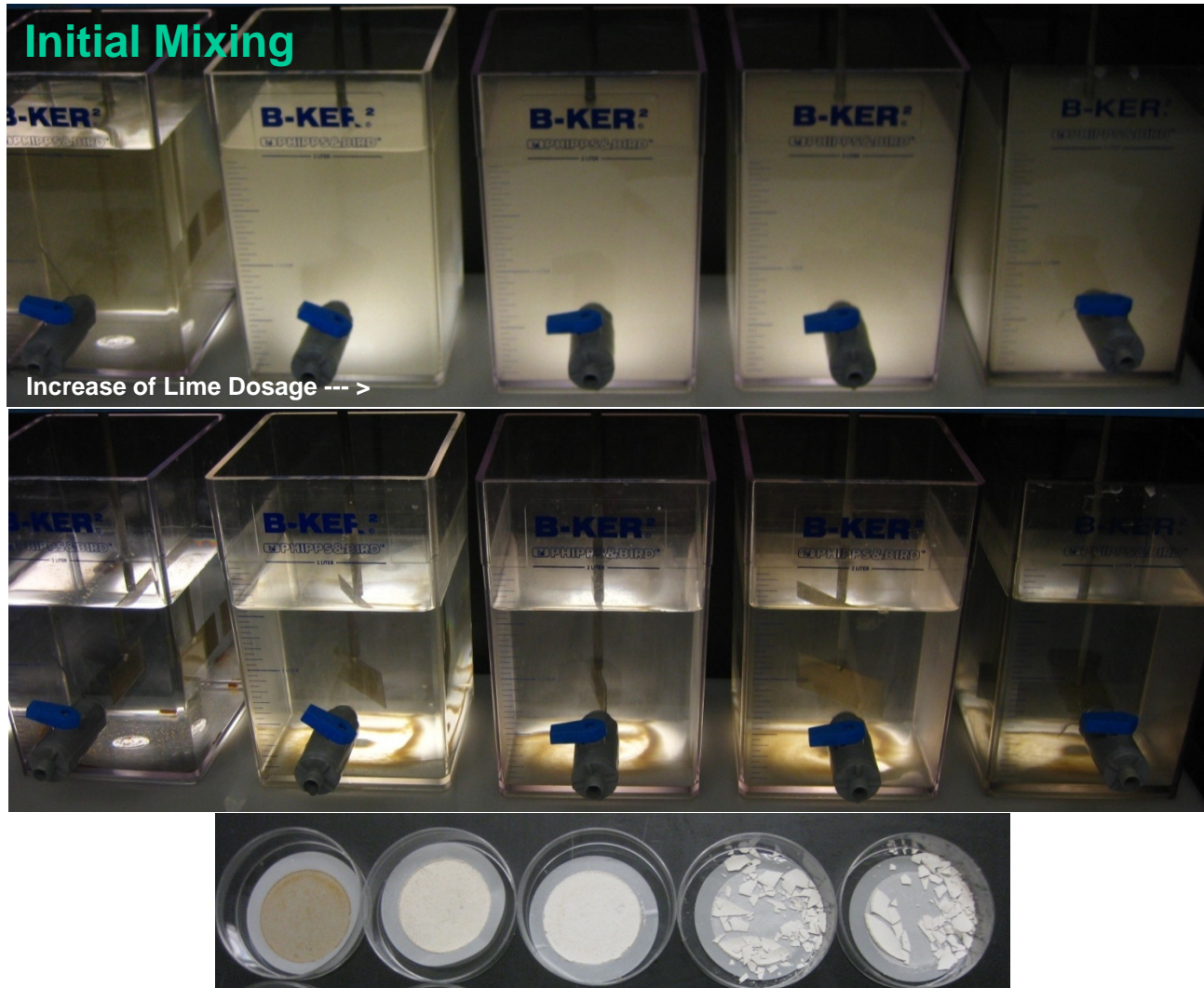


Lime (soda ash) Softening Jar Tests

- Perform jar tests on three ground waters that contained between 4.2 and 21.8 mg/L natural strontium (hardness 414 to 451 mg CaCO_3 /L).
- Perform jar tests on strontium-spiked ground water
- Perform jar tests on laboratory prepared waters.
- Examine the impact of pH, calcium concentration, strontium concentration and DIC on strontium removal.
- Evaluate solid precipitate properties.



Lime Softening Jar Testing – Ground Water



Lime & Soda Ash - 0.2 μ m Filtration

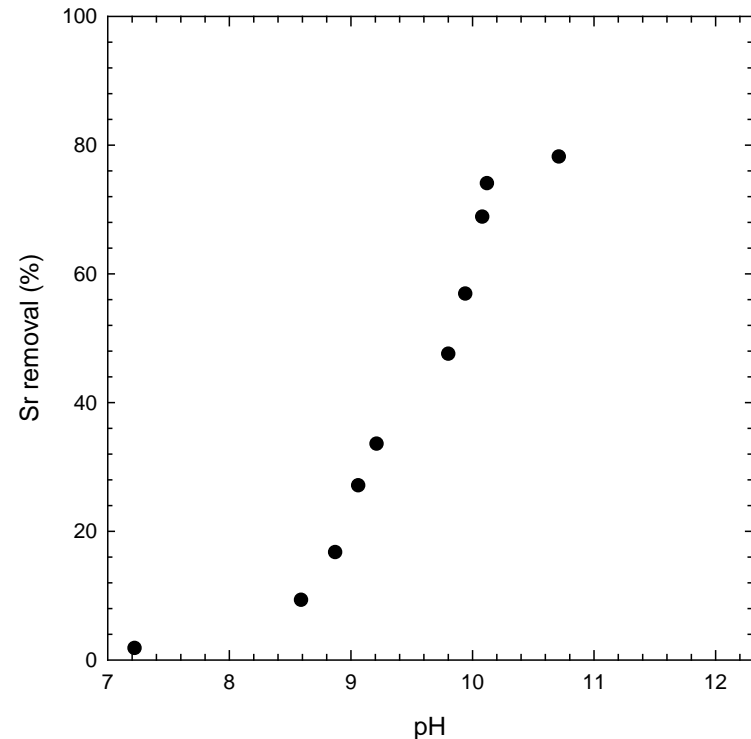
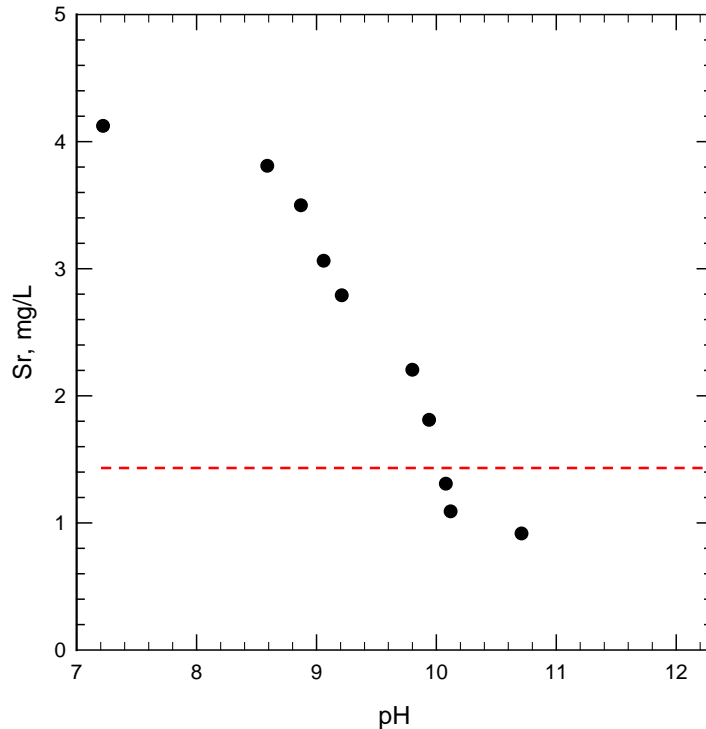


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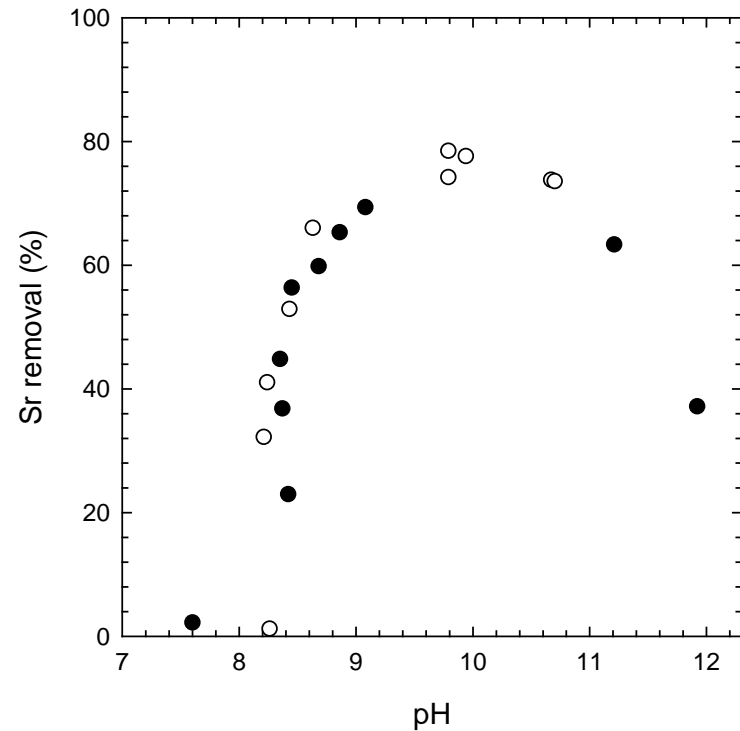
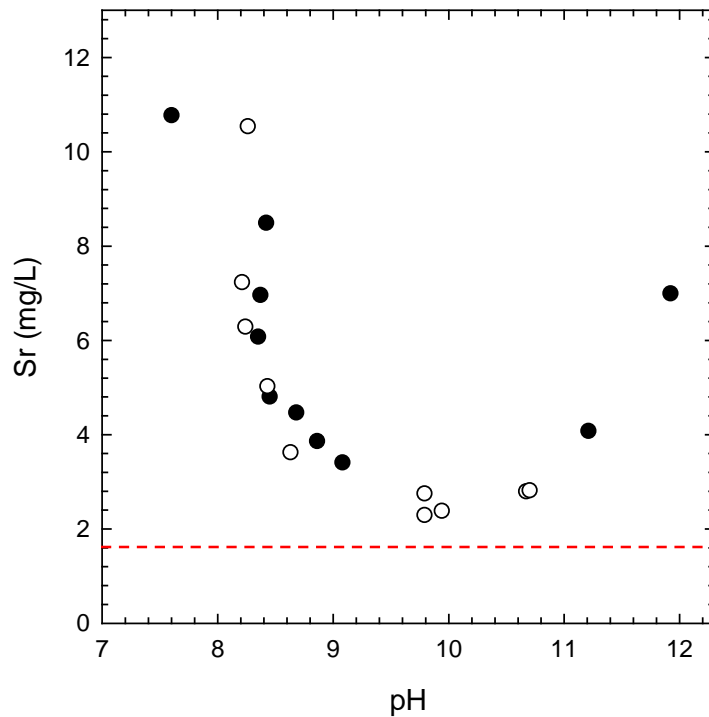
Strontium Removal during Lime Softening Jar Test: Site A (Private Well)

Source Water Quality: 4.20 mg/L Sr, 127 mg/L Ca, 9.88 mg/L Mg, pH 7.22

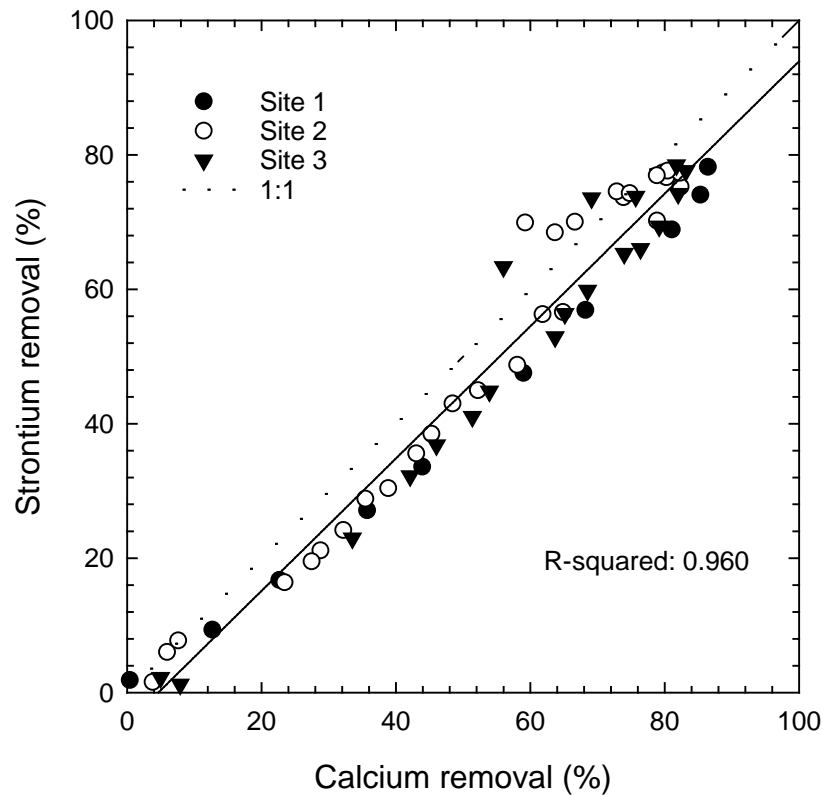


Strontium Removal during Lime Softening Jar Test: Site B

Source Water Quality: **10.9 mg/L Sr**, 112 mg/L Ca, 32.5 mg/L Mg, pH 7.30



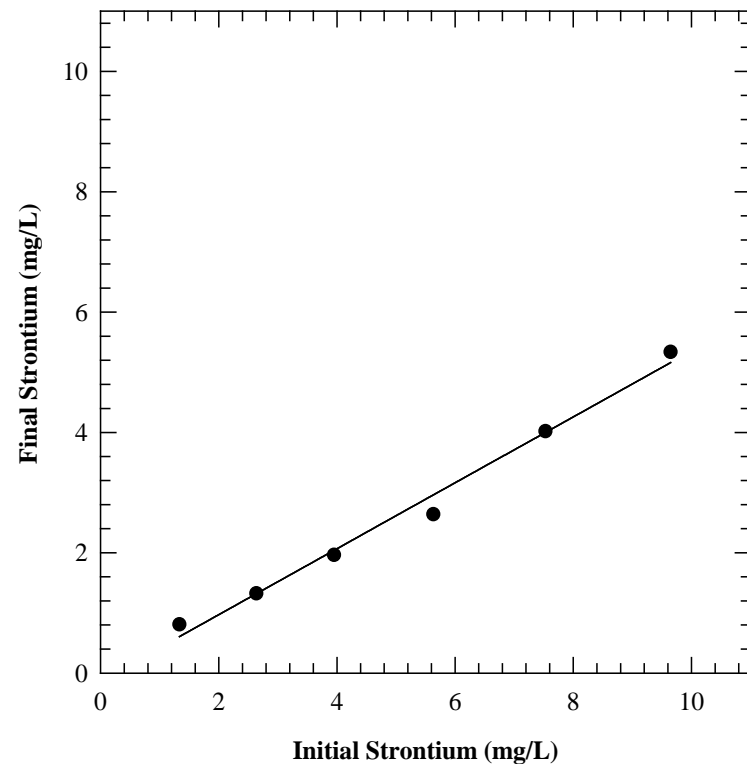
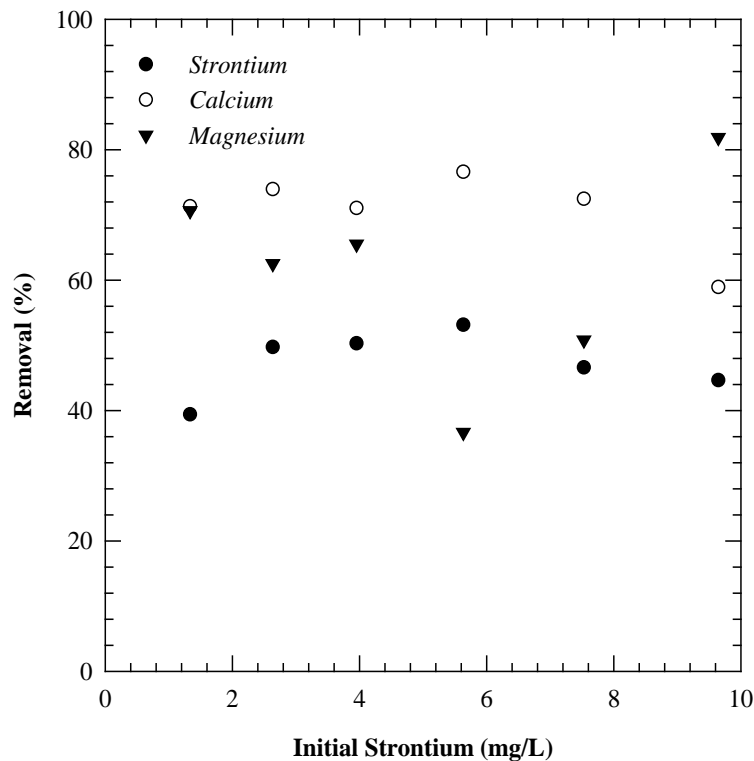
Percent Removal Strontium vs. Percent Removal Calcium (naturally elevated strontium waters)



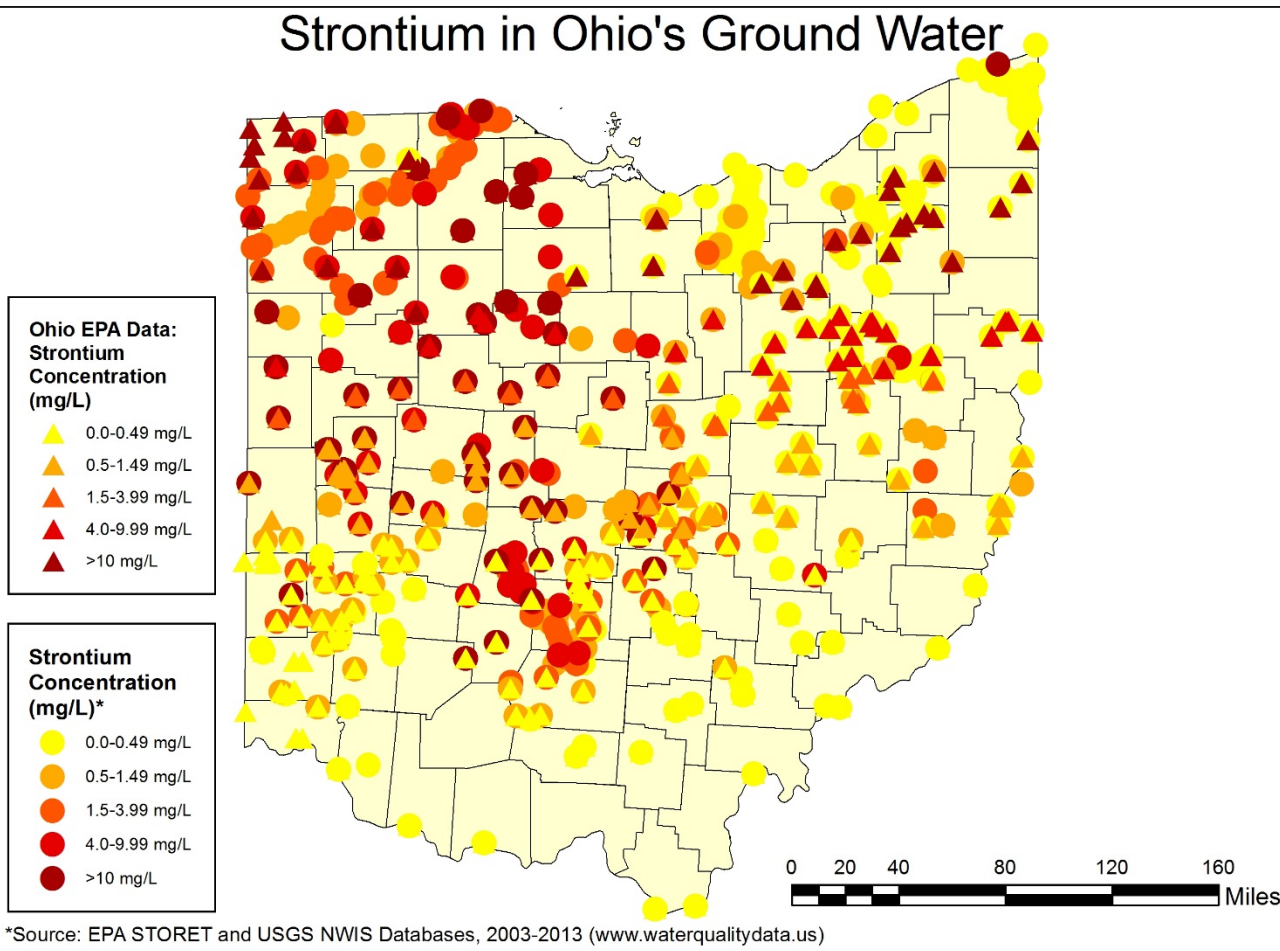
Strontium Removal during Lime Softening Jar Test: Site 4

Impact of Initial Strontium Concentration

Source Water Quality: 0.417 mg/L Sr, 61.9 mg/L Ca, 23.6 mg/L Mg, pH 6.72 (Spiked)



Strontium in Ohio's Ground Water



Source Water

Site (sampling events)	Sr (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg CaCO ₃ /L)
1 (11) IX	16.5	94	38	396
2 (11) IX	13.3	126	36	446
3 (10) IX	18.1	85	36	350
4 (11) IX	27.3	140	49	517
5 (10) LS	2.69	59	23	237
6 (8) LS	15.0	87	37	370
7 (9) LS	1.09	79	28	305
8 (7) LS	3.74	82	30	339



Ion Exchange



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Full Scale Study of Strontium Removal

Photos from **Ion Exchange** Softening Plant Visits



Site 1



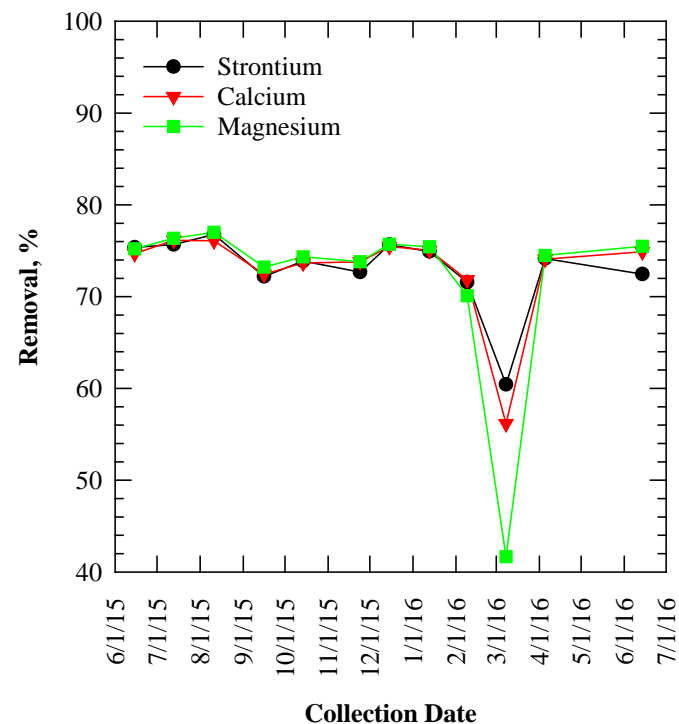
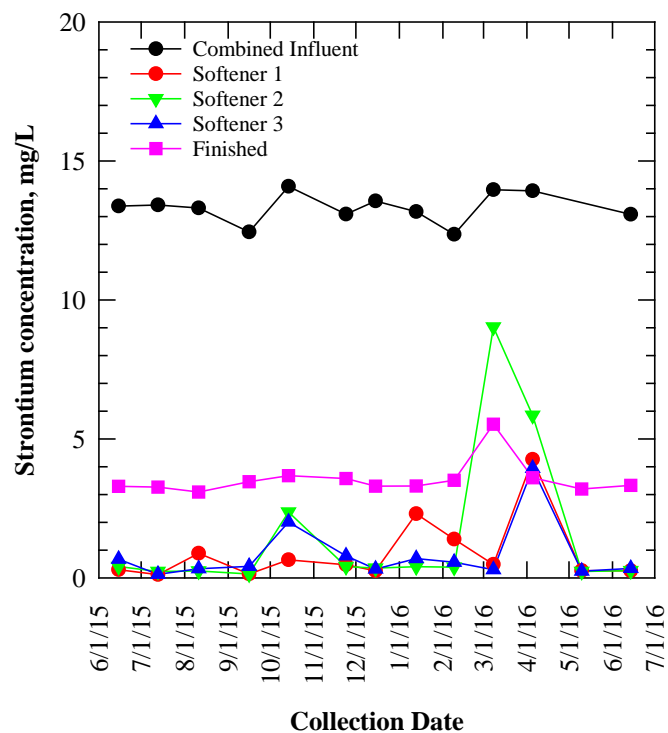
Site 2



Site 3

Strontium Removal during Ion Exchange Full-Scale: Site 2

Source Water Quality: **10.9 mg/L Sr**, 124 mg/L Ca, 34 mg/L Mg

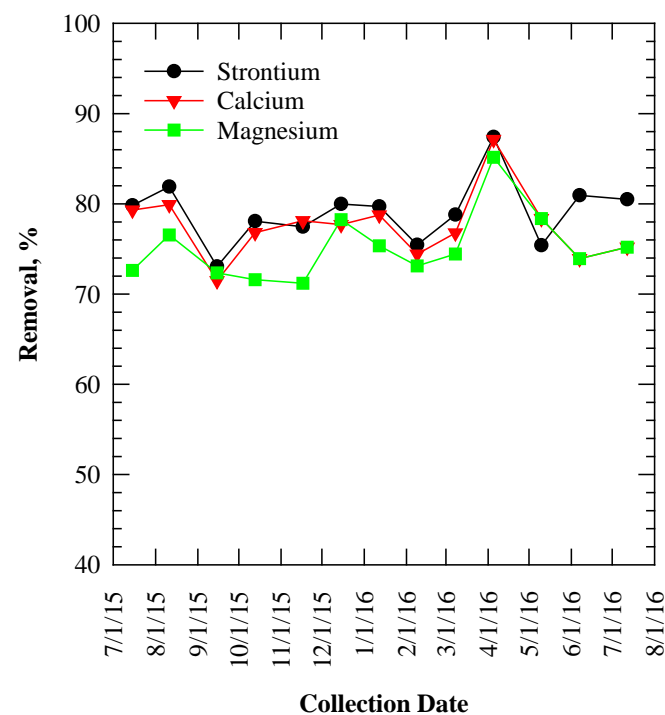
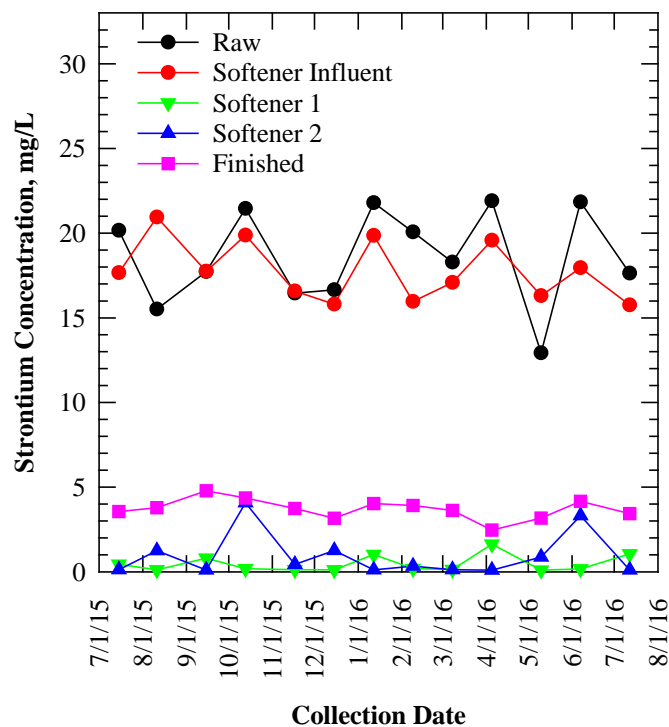


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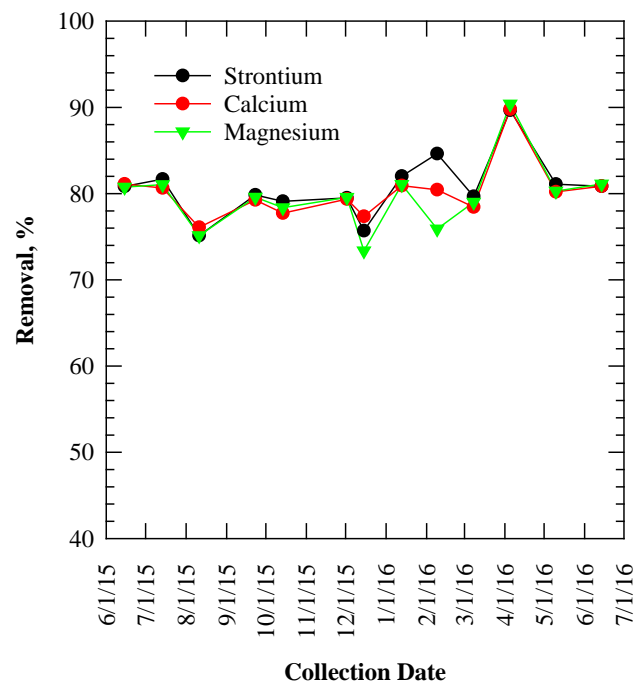
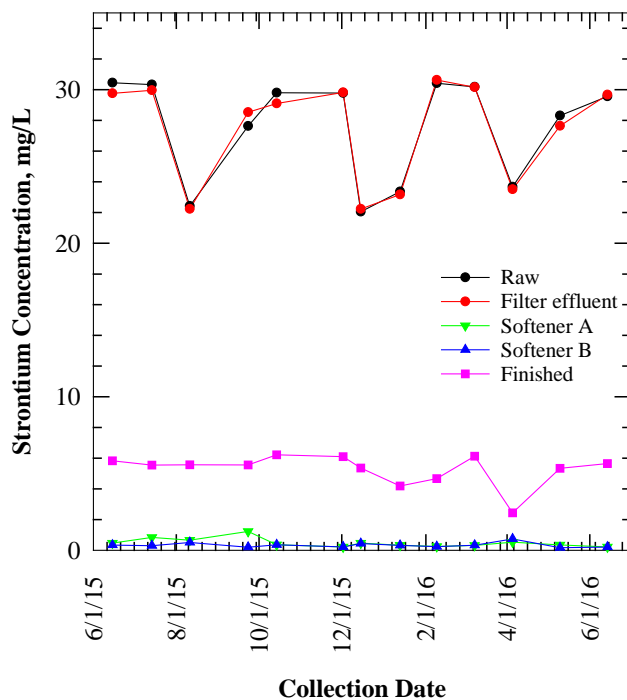
Strontium Removal during Ion Exchange Full-Scale: Site 3

Source Water Quality: **18.7 mg/L Sr**, 86 mg/L Ca, 35 mg/L Mg



Strontium Removal during Ion Exchange Full-Scale: Site 4

Source Water Quality: **27.6 mg/L Sr**, 135 mg/L Ca, 48 mg/L Mg



Lime Softening



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Full Scale Study of Strontium Removal

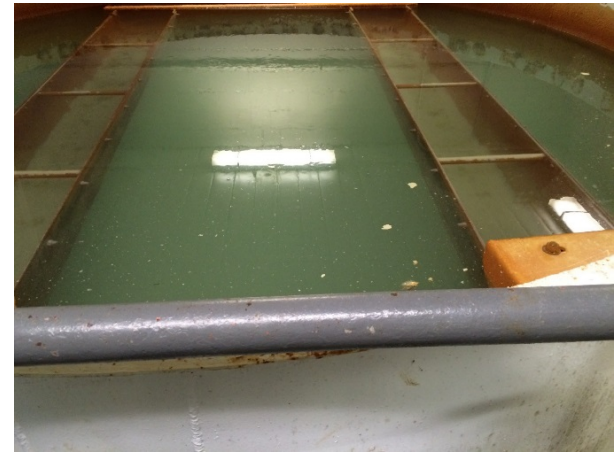
Photos from **Lime Softening** Plant Visits



Site 5



Site 8



Site 6

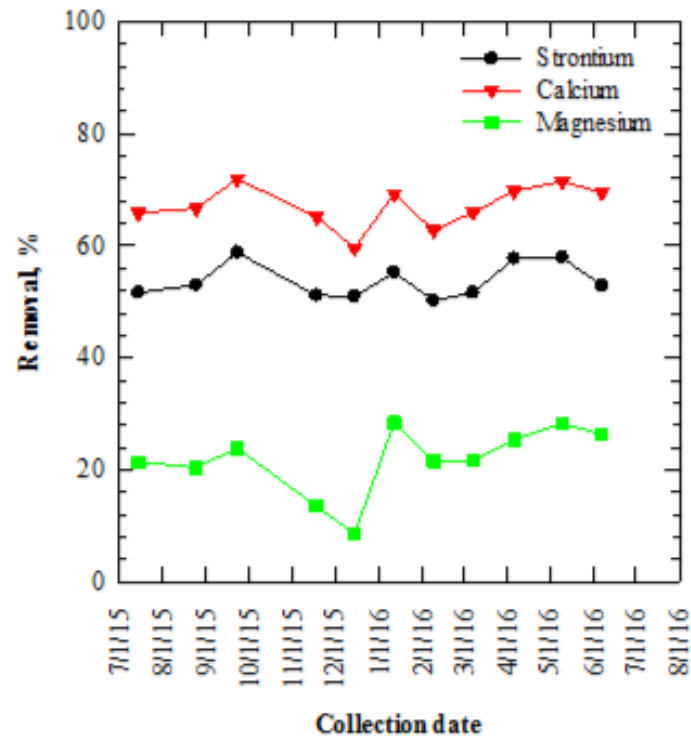
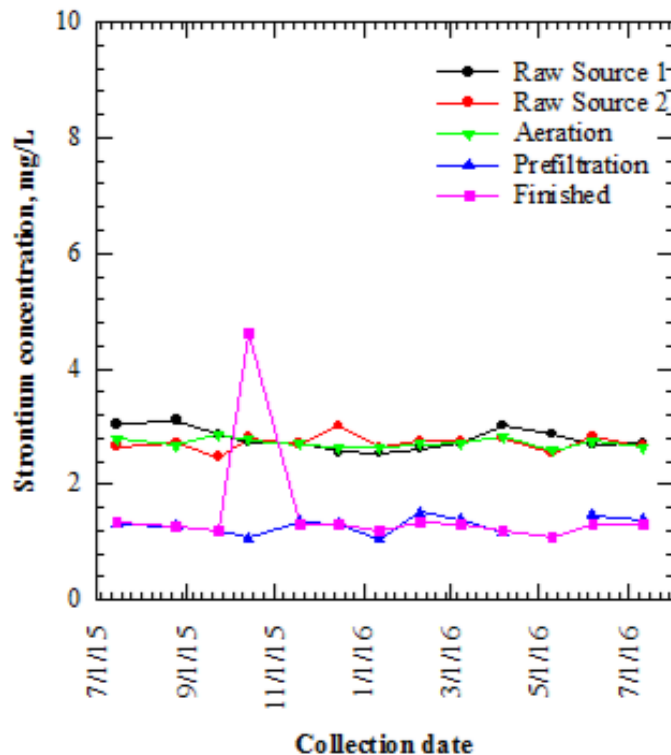


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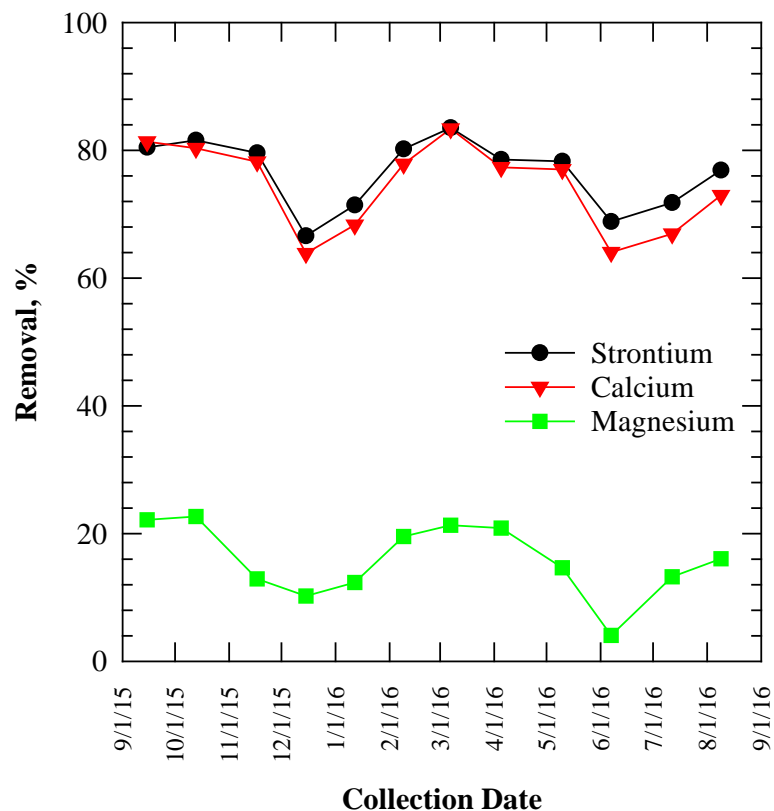
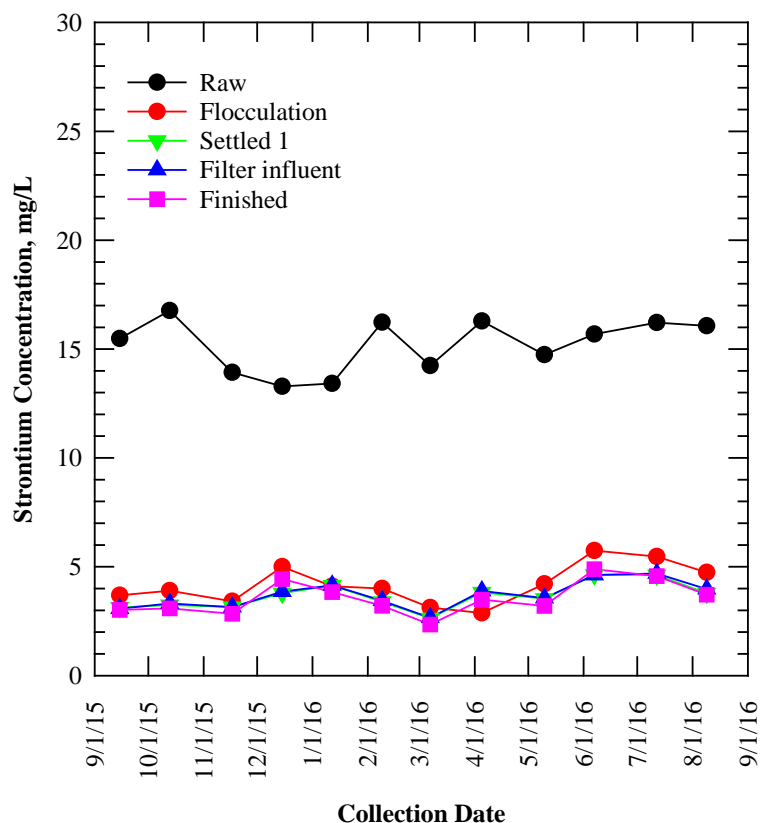
Strontium Removal during Lime Softening Full-Scale: Site 5

Source Water Quality: **2.68 mg/L Sr**, 58 mg/L Ca, 22 mg/L Mg



Strontium Removal during Lime Softening Full-Scale: Site 6

Source Water Quality: **15.2 mg/L Sr**, 85 mg/L Ca, 37 mg/L Mg

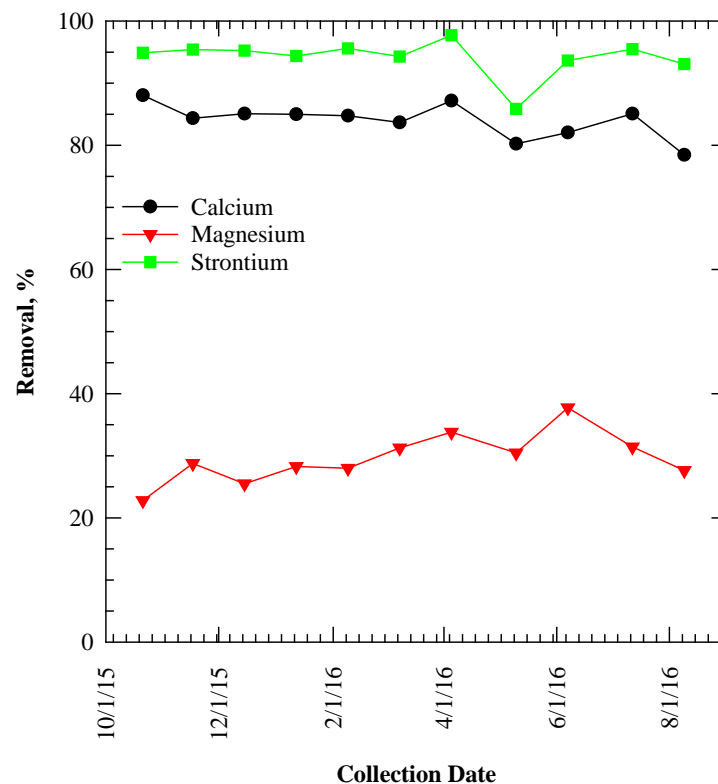
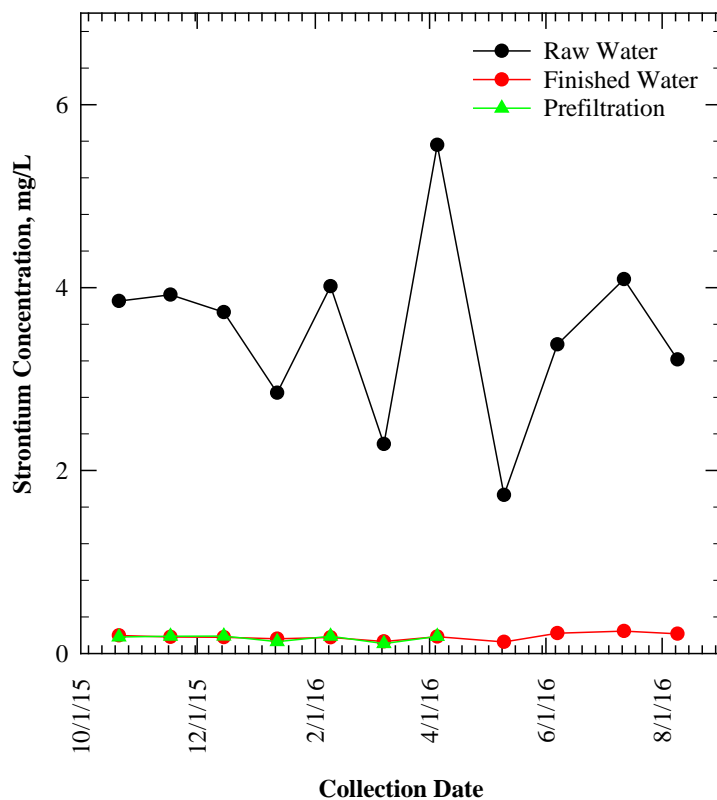


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Strontium Removal during Lime Softening Full-Scale: Site 8

Source Water Quality: **3.51 mg/L Sr**, 84 mg/L Ca, 29 mg/L Mg



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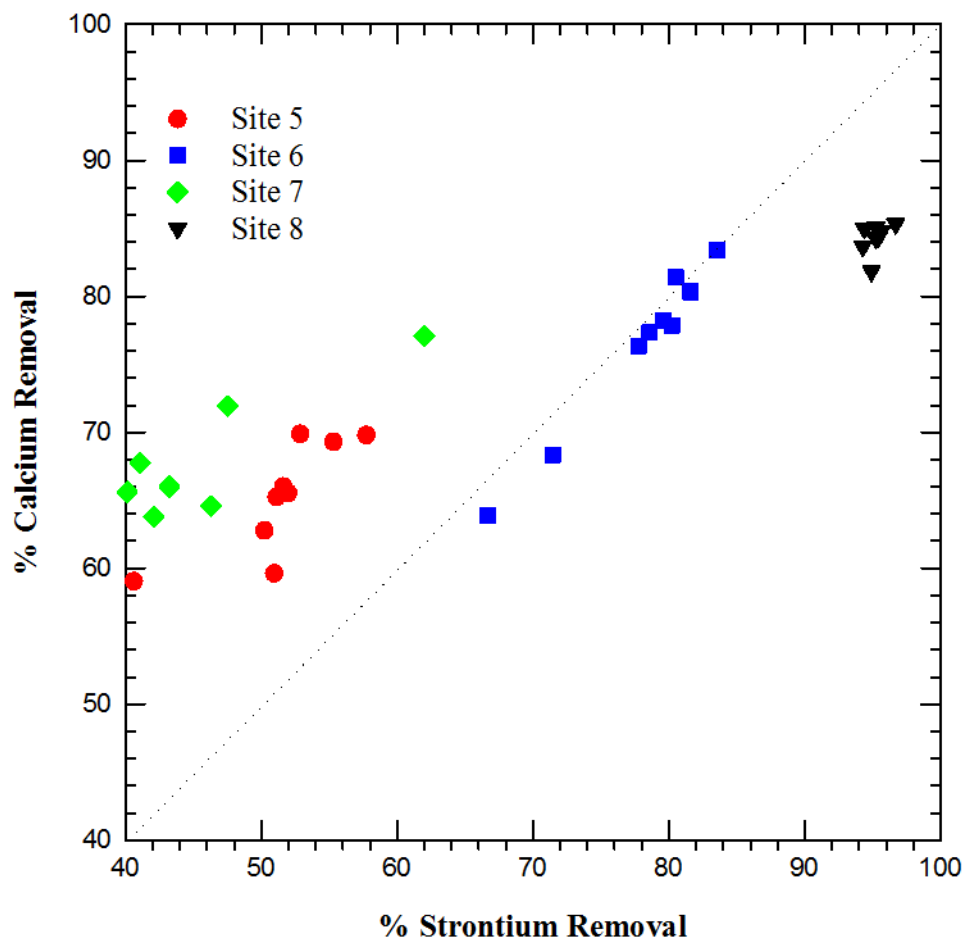
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Treatment Summary

Site	Average (raw) final strontium concentration (mg/L)	Average strontium removed (%)	Average final calcium concentration (mg/L)	Average calcium removed (%)	Average final magnesium concentration (mg/L)	Average magnesium removed (%)	Average percent bypass* (%)
1 (13) IX	(19.71) 4.47	76.4	25.8	72.0	10.6	73.1	30.5
2 (12) IX	(13.24) 3.58	73.0	34.7	72.5	10.3	71.9	25.5
3 (13) IX	(18.65) 3.71	79.8	18.3	78.5	8.8	75.0	22.9
4 (13) IX	(27.56) 5.28	80.8	26.6	80.2	9.8	79.6	21.0
5 (13) LS	(2.68) 1.26	53.1	19.3	66.8	17.6	21.5	--
6 (11) LS	(15.2) 3.55	76.5	21.8	74.3	30.9	15.8	--
7 (13) LS	(1.15) 0.55	49.3	24.7	68.3	15.3	43.8	--
8 (11) LS	(3.51) 0.18	94.2	13.3	84.0	20.6	29.6	--



Lime Softening Summary: Ca vs. Sr Removal



Residuals



Weight %:	Al	Ca	Cl	Fe	Mg	Na	O	S	Si	Sr
Site 5	0.98	38	0.24	0.71	2.3	0.85	21	0.09	1.85	0.64
Site 6	ND	43	0.26	0.53	2.6	0.93	21	0.12	0.61	2.72

Lime Softening Sludge Composition (% by weight)

Conclusions

- Strontium is relatively widely distributed in ground water across the US
- Jar testing showed that strontium is effectively removed during lime/soda ash softening and removal was related to lime dose/pH/calcium
- Final strontium concentration was related to initial concentration
- Full-scale studies showed that lime softening and ion exchange softening effectively reduce strontium but initial strontium concentration and recycle ratio (IX) may limit final level.



Acknowledgements

- **Steve Harmon and Keith Kelty, U.S. EPA**
 - Conducted water and solids analyses
- **Water utility operators and staff**



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