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Vertical Distribution, Attenuation, and Remediation of Brine Releases, Wichita County, Texas

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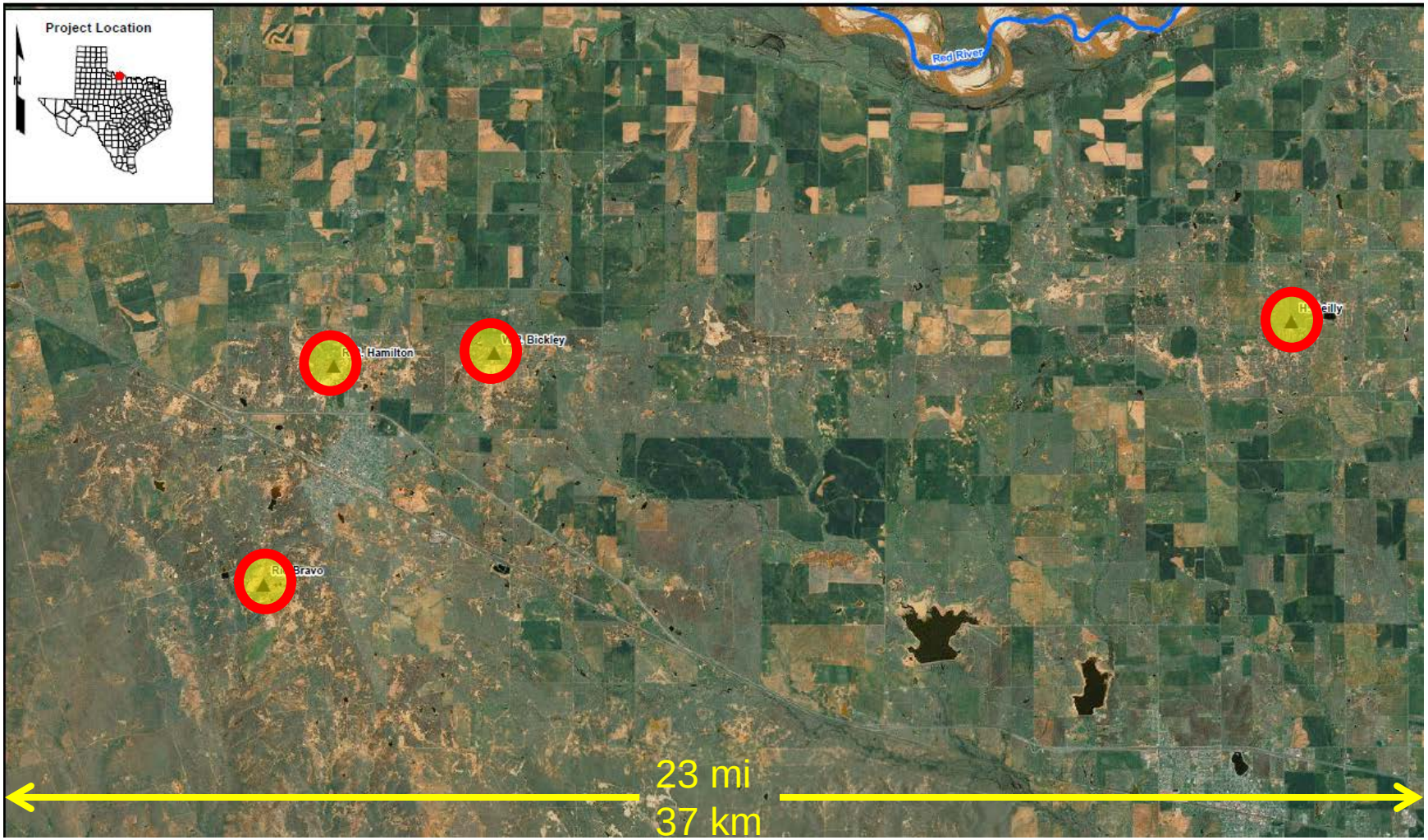
Study Location and Setting



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Setting and Conditions

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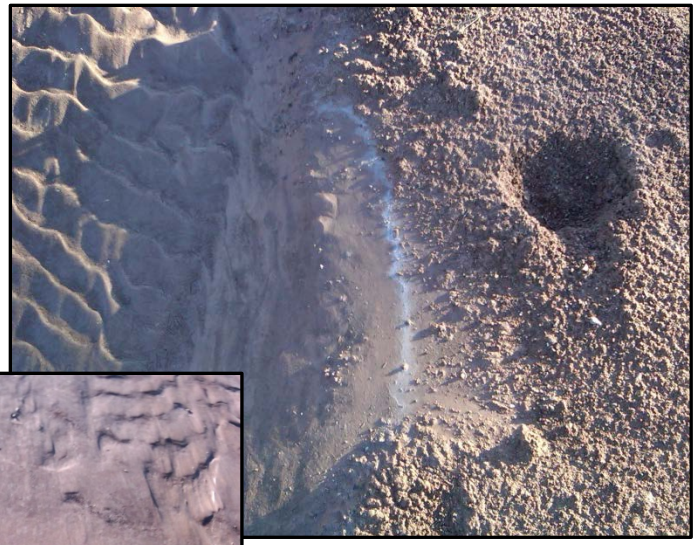
Soil Condition Summary

- Surficial salt staining / precipitation
- Stressed / damaged vegetation
- Impaired soil structure
- Reduced infiltration



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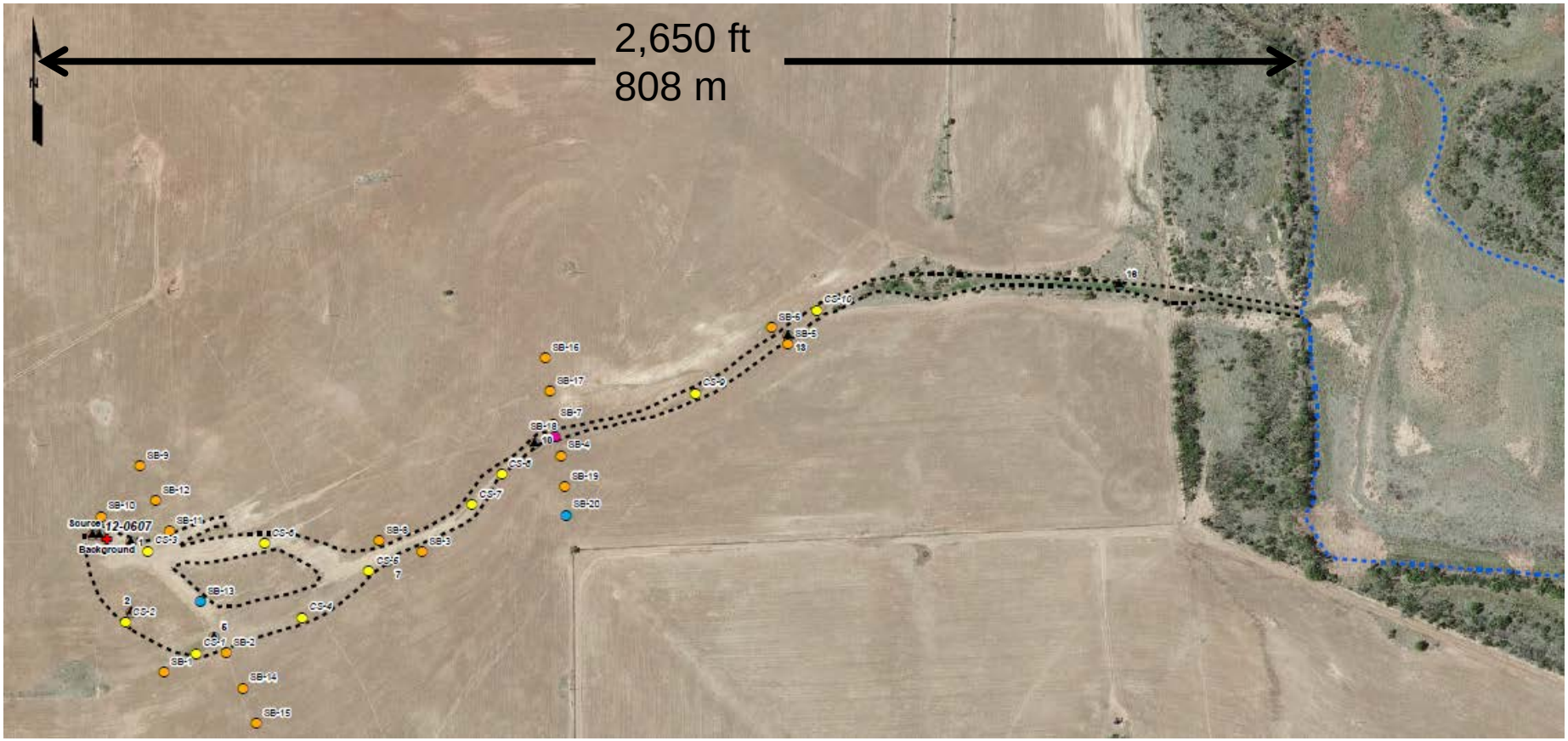
Investigation Sampling Approach



Legend

- Spill Location
- Titan Sample Locations (10/02/2012)
- Kleinfelder Composite Sample (3/29/2013)

Kleinfelder Soil Boring (3/28/2013)

- 0-2'
- 0-3'
- 0-4'

- Estimated Disturbance Boundary
- Seasonal Pond

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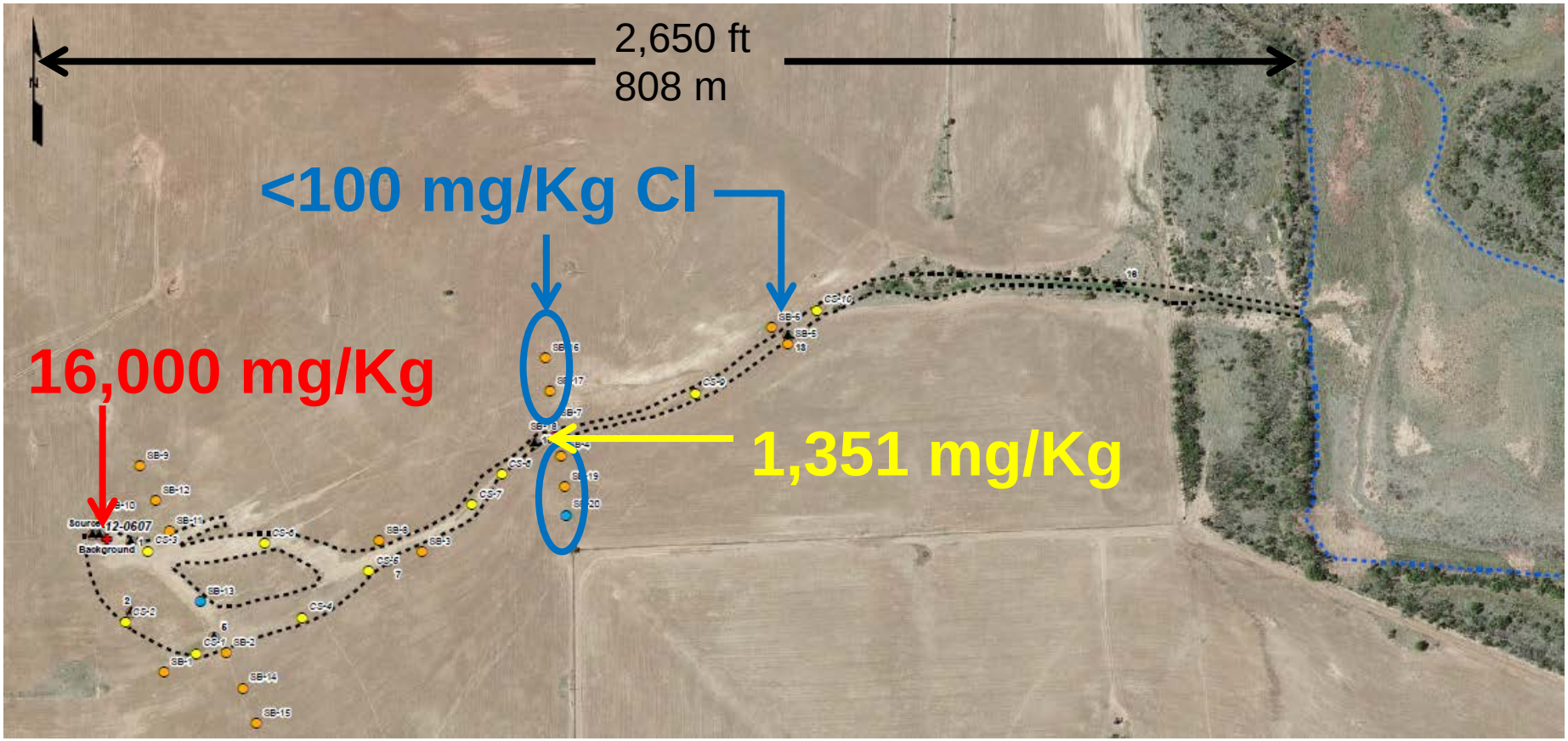
Chloride Concentration Summary



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Vertical Data Evaluation

- Vertical distribution of chloride evaluated by combining data from multiple nearby leases with similar climate, soil, receptor, and depth to groundwater conditions
- Combined data provide more robust data set
- Data evaluated correspond to max surface soil concentration for each lease with 2 or more subsurface samples
- Analysis is conservative / protective as max results are extrapolated to broader area
- Data extrapolated with depth
- Evaluate data in context of regulatory criteria, prevailing groundwater levels, API modeling study, recommended remediation depths

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Soil Data Summary

Chloride (mg/kg)	Depth (ft-bgs)	Lease	Sampling Date
30,000	0	Bickley	October 2011
6,700	4		
5,300	6		
27,932	0.5		March 2013
18,395	2		
12,947	4		
15,660	0.5	Reilly	
6,805	2		
2,814	4		
52,357	0.5	Hamilton	
23,522	2		
15,637	4		
15,735	0.5	Rio Bravo	
14,393	2		
11,004	4		

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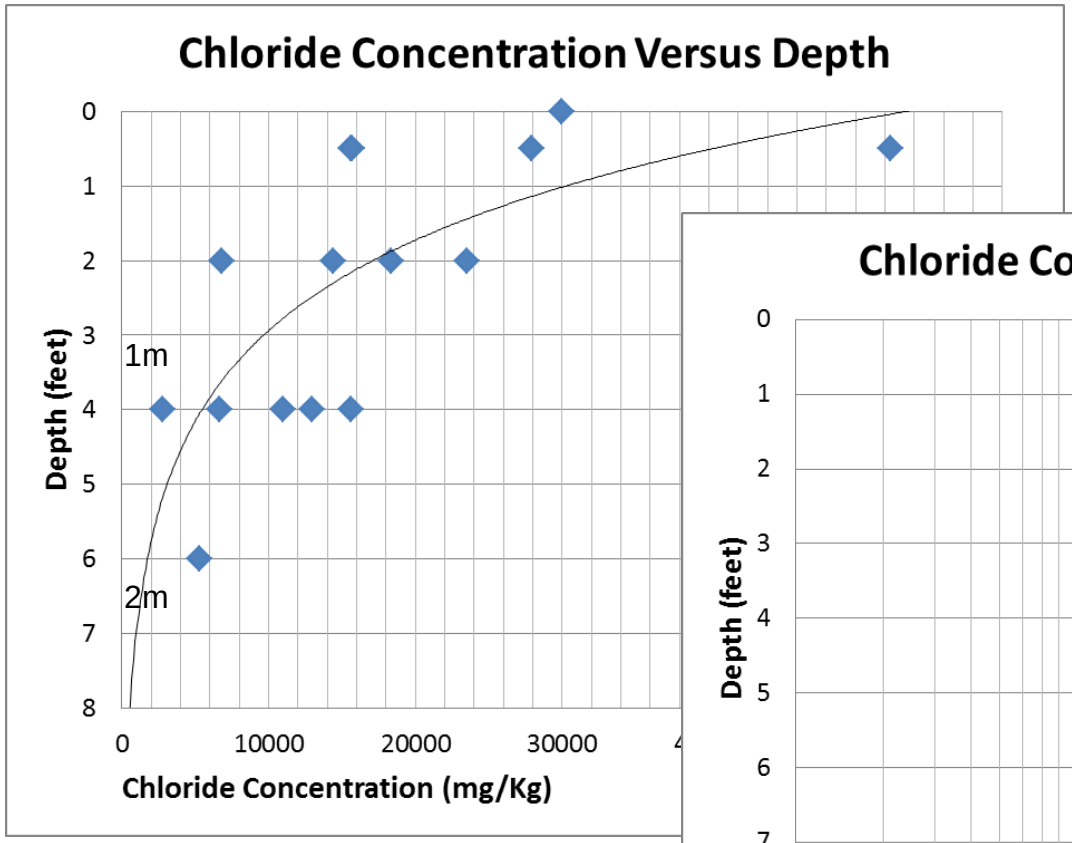
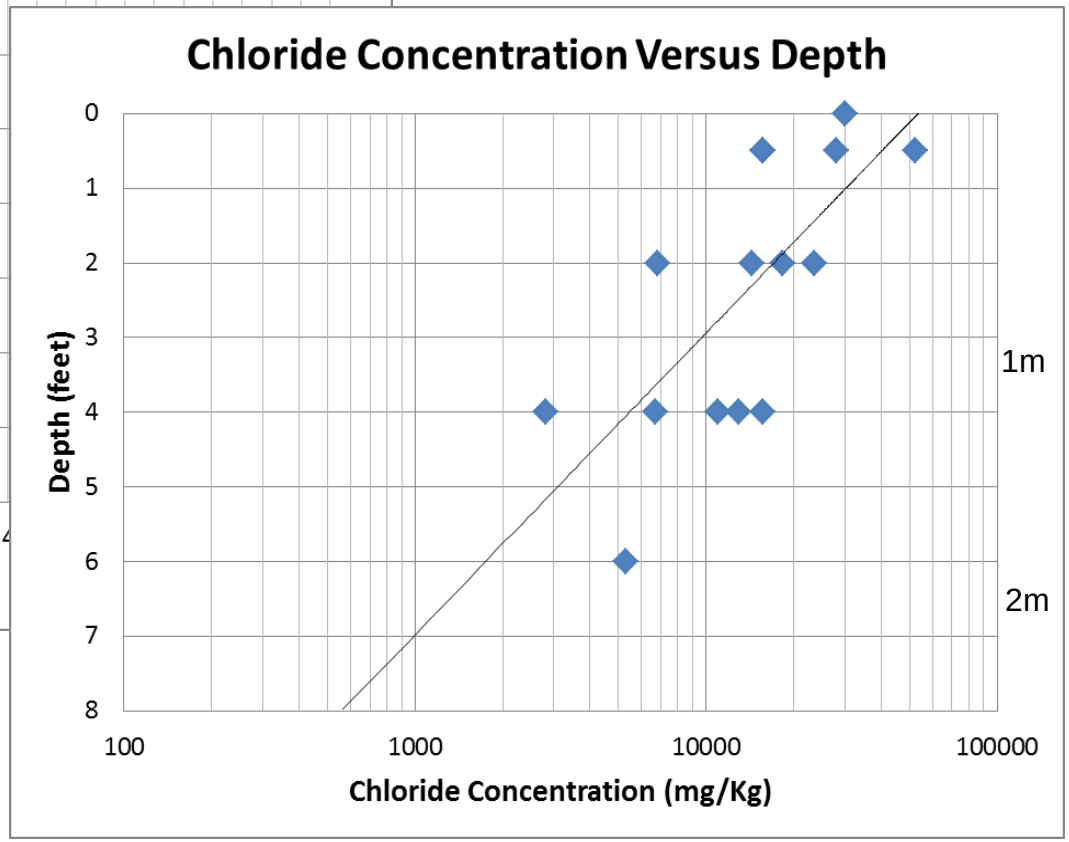
Vertical Soil Data Distribution





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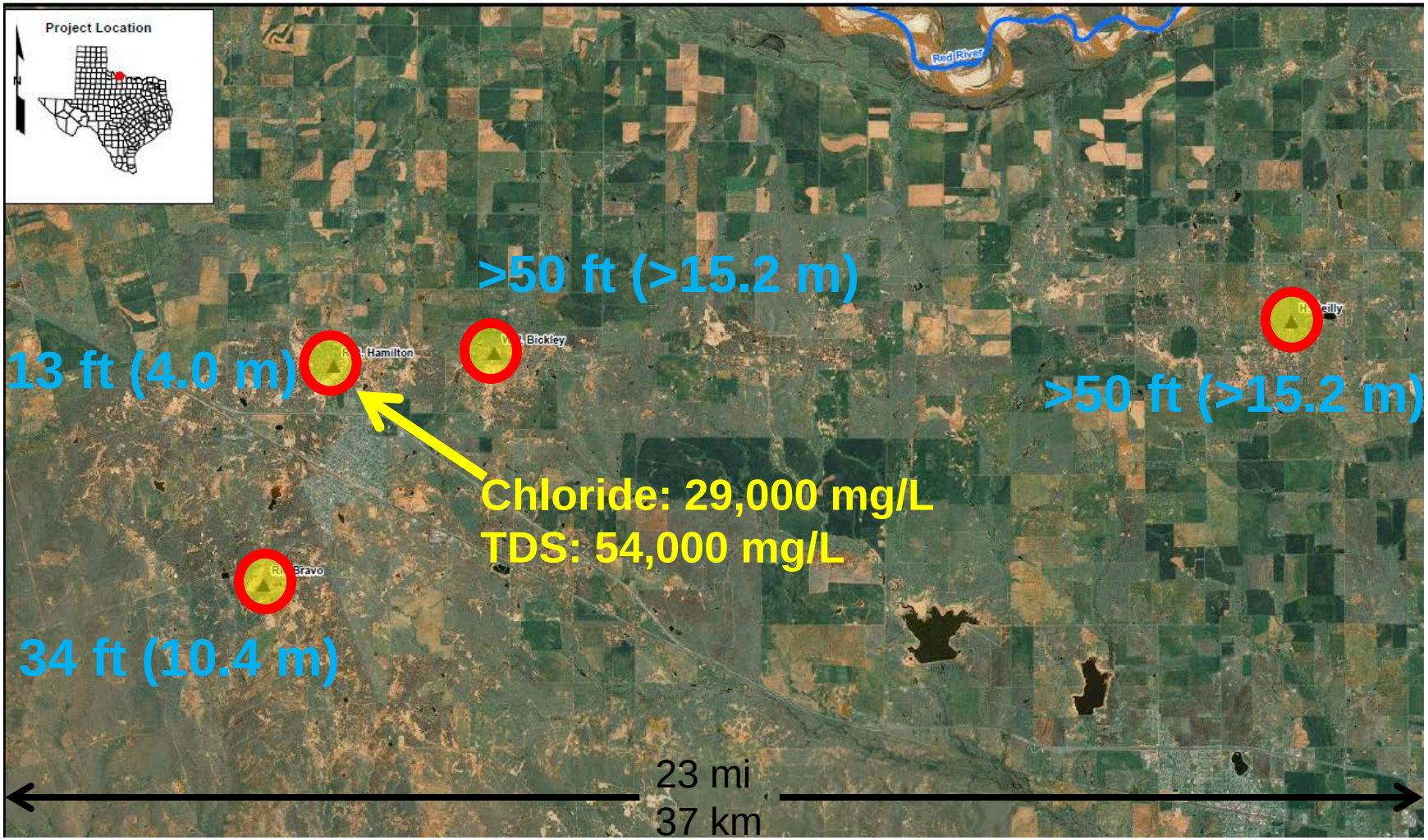
Groundwater Conditions



DTW (mode) Wichita County = 23 ft (7 m)

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Evaluation Criteria and Constraints

- *Draft Field Guide for the Assessment and Cleanup of Produced Water Releases* (Railroad Commission of TX)
  - **3,000 mg/kg** chloride generally protective of groundwater, assuming complete soil leaching or runoff pathway with a 10 fold dilution of leachate in the receiving aquifer or surface water body
  - **300 mg/L** groundwater chloride concentration criterion
- *Groundwater Database Report for Wichita County* (Texas Water Development Board)
  - **23 feet (7 m)** modal depth to groundwater in Wichita County
  - Modal depth represents most typical occurrence
- *Secondary Drinking Water Regulations Guidance for Nuisance Chemicals* (U.S. EPA)
  - **250 mg/L** secondary MCL for chloride due to salty taste

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Evaluation Criteria and Constraints

- *Basic Guidelines for Remediation of Brine Spills* (Sublette Consulting, Inc.)
  - "*Rule of thumb: Salt must be pushed down at least **6 ft (1.8 m)** to prevent capillary suction from drawing the salt back up into the root zone.*"
- *Modeling Study of Produced Water Release Scenarios* (American Petroleum Institute [API])
  - Presents modeled depth of produced water infiltration for a pore water chloride concentration of **250 mg/L**
  - Model simulations based on six variables
    - Climate
    - Depth to groundwater
    - Soil type
    - Dispersion length
    - Release concentration
    - Height of release

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Evaluation Criteria and Constraints

- Selection of comparable API produced water release scenario
  - Humid Climate – more applicable and conservative; Wichita County is in a region classified as Subtropical Subhumid
  - Depth to Groundwater Table = 9.8 feet (3 m) – most representative of site conditions relative to alterative scenario (98 feet [30 m])
  - Sand Soil Type – consistent with field observations / most conservative soil type
  - Brine Release Height = 2 feet (0.6 m) – corresponds to depth of drainage channels in which produced water release could accumulate / conservative height relative to unconstrained surface release
  - Dispersion Length = 0.3 feet (0.1 m)
  - Duration since release = 50 weeks – maximum duration modeled

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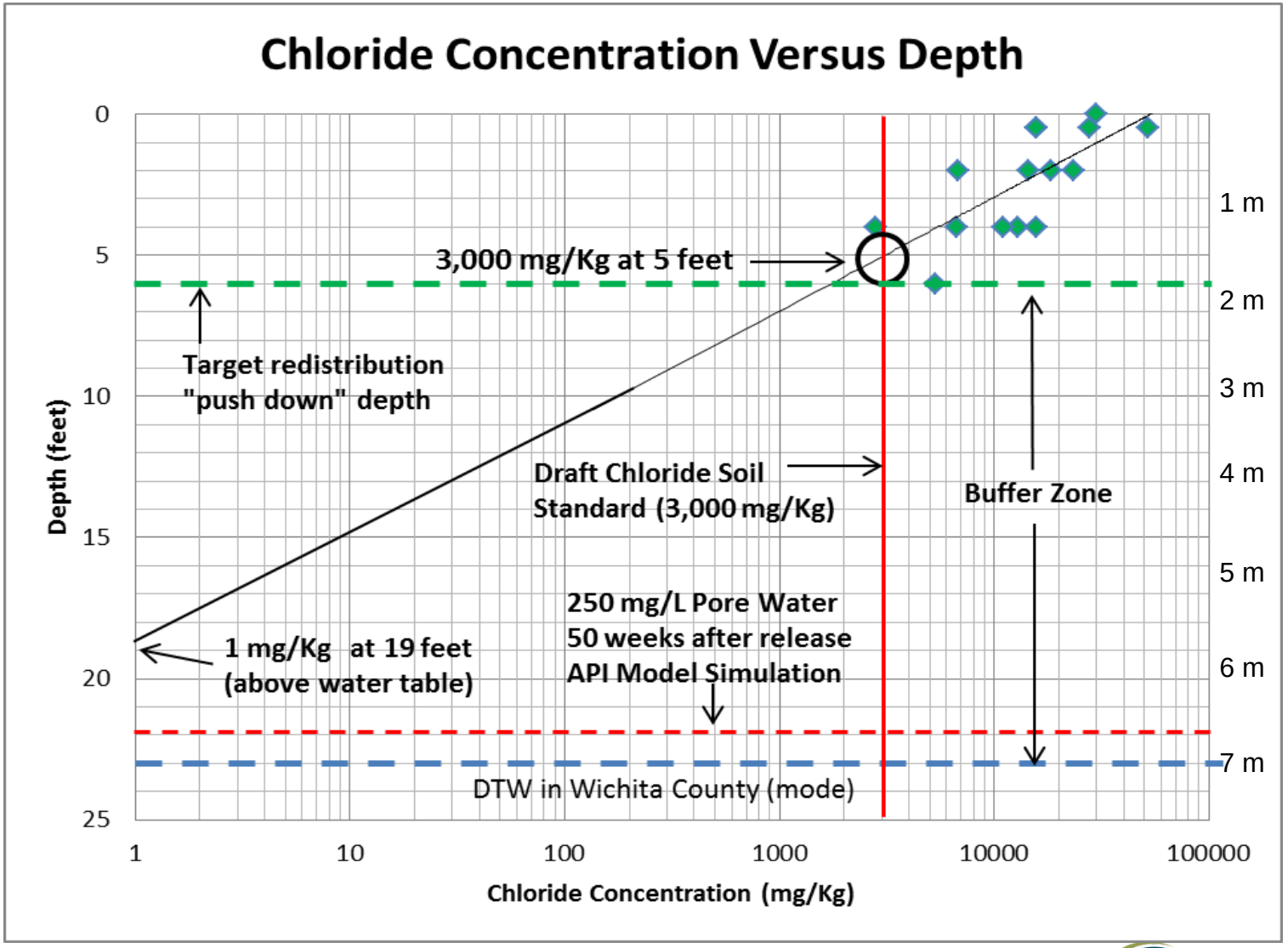
Soil Data, Criteria, and Constraints



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Results of Evaluation

- Soil chloride concentrations attenuate logarithmically with depth
- Extrapolated concentration attains 3,000 mg/Kg at 5 feet (1.5 m)
- 18-foot (5.5 m) buffer distance from 3,000 mg/Kg concentration to typical depth to groundwater (23 feet [7 m])
- Chloride concentrations in soil are extrapolated to attenuate to 1 mg/Kg at a depth of 19 feet (5.8 m) above the typical depth to water
- Comparable and conservative API modeling scenario indicates that chloride concentration in pore water is expected to attain 250 mg/L at a depth of 22 feet (6.7 m), above the typical depth to groundwater
- Feasible to flush salt to depth below capillary suction and root zone without adversely impacting groundwater

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Remedial Approach

- Redistribute salt impact via vertical leaching to buffer zone
  - Below 6-foot (2 m) target capillary suction depth
  - Above water table (23 feet [7 m]) (modal dtw)
  - Reduced concentration in buffer zone via dilution/dispersion
- Leachate recovery for groundwater protection, as necessary
- Promote cation exchange of Ca^{2+} for Na^{+}
- Restore soil nutrients, organic matter, structure, re-vegetate and monitor

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Remediation Methods

- Salt Redistribution
  - Promote infiltration through disking/tilling
  - Add organic bulking agent (weed-free hay)
  - Supplement precipitation with irrigation
- Groundwater Protection
  - Installed drains at shallow groundwater site (13 ft-bgs [4 m-bgs])
  - 5 feet (1.5 m) deep
  - Central drain 250 ft (76 m) connected to recovery sump
  - Three laterals 50 ft (15 m) long
- Cation Exchange
  - Addition of Ca++Nhance™ and marble dust / lime
- Soil Restoration
  - Tilling, ripping, disking of soil.
  - Addition of weed-free hay
  - Re-vegetate

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Remediation Methods

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Application Quantities

- 1,742 lbs (790 kg) Ca++Nhance™ and marble dust per acre (0.4 hectare)

- 5.5 tons (5 metric tonnes) per acre (0.4 hectare) weed-free hay broadcast-spread across each remediation area and worked into the soil to improve drainage and tilth.

Water Applied

Lease Name	Acres	Hectares	March		June	
			Gallons	Liters	Gallons	Liters
R. R. Hamilton	1.4	0.6	12,000	45,4250	12,000	45,4250
	1	0.4				
W. P. Bickley	1.7	0.7	6,000	22,712	6,000	22,712
Rio Bravo	0.4	0.2	2,000	7,571	2,000	7,571
H. Reilly	2.5	1.0	12,000	45,4250	12,000	45,4250
	1.2	0.5				

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Interim Results

Lease Name	R.R. Hamilton Lease			W.P. Bickley			Rio Bravo Lease			H. Reilly Lease		
Sample Name	HAM-CS-0-1	HAM-CS-1-2	HAM-CS-2-3	BIK-CS-0-1	BIK-CS-1-2	BIK-CS-2-3	RB-CS-0-1	RB-CS-1-2	RB-CS-2-3	RIL-CS-0-1	RIL-CS-1-2	RIL-CS-2-3
Sample Depth (ft)	(0 - 1)	(1 - 2)	(2 - 3)	(0 - 1)	(1 - 2)	(2 - 3)	(0 - 1)	(1 - 2)	(2 - 3)	(0 - 1)	(1 - 2)	(2 - 3)
Parameter	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value	Sample Value
Boron (ppm)	0.4	0.4	0.4	0.3	0.3	0.5	0.2	0.1	0.1	0.1	0.6	0.6
Calcium (ppm)	877.3	639.4	405	1,568.7	405.8	920.4	1,858	891	672.2	264.8	928	443.4
Chloride (ppm)	16,402.8	16,522.7	12,125.5	22,669	9,508.4	18,485.3	26,032.5	15,707.8	13836.6	4,960.2	18,966.6	9,826.7
EC (µmhos/cm)	53,610	54,420	40,980	71,400	32,910	60,900	81,000	51,840	45,870	18,600	61,500	33,240
ESP	43.3	49.3	48.2	13.7	44.5	48.6	46.8	45	46.2	37	48	38.2
EPP	6.4	7.1	7.8	6.2	6.4	6.4	7.7	6.4	6.8	7	6.5	5.8
Magnesium (ppm)	466	354.5	245.2	642	161.6	387.9	538.8	327.6	234.6	65.5	436.6	311.9
pH	7.8	7.8	7.9	7.9	7.7	7.8	7.5	7.8	7.8	7.1	7.8	7.7
PAR	0.3	0.4	0.5	0.3	0.3	0.3	0.5	0.3	0.4	0.4	0.3	0.2
Potassium (ppm)	78	82	81	90	50	74	146	73	71	45	81	46
SAR	53	67.4	64.6	53.9	55.7	65.6	61	56.9	59.6	41	64.1	43.1
Sodium (ppm)	7,806.1	8,557.3	6,678.4	10,029.9	5,244.9	9,408	11,614.8	7,818.1	7,039.5	2,875.7	9,568.7	4,838.4
TSS (ppm)	35,383	35,917.2	27,046.8	47,124	21,720.6	40,194	53,460	32,214.4	30,274.2	12,276	40,590	21,938.4
Soil Texture	Medium	Fine	Fine	Medium	Fine	Medium	Fine	Fine	Fine	Medium	Medium	Fine

Chloride: 4,960 to 26,000 mg/Kg

EC: >32 mmhos/cm

SAR: >41

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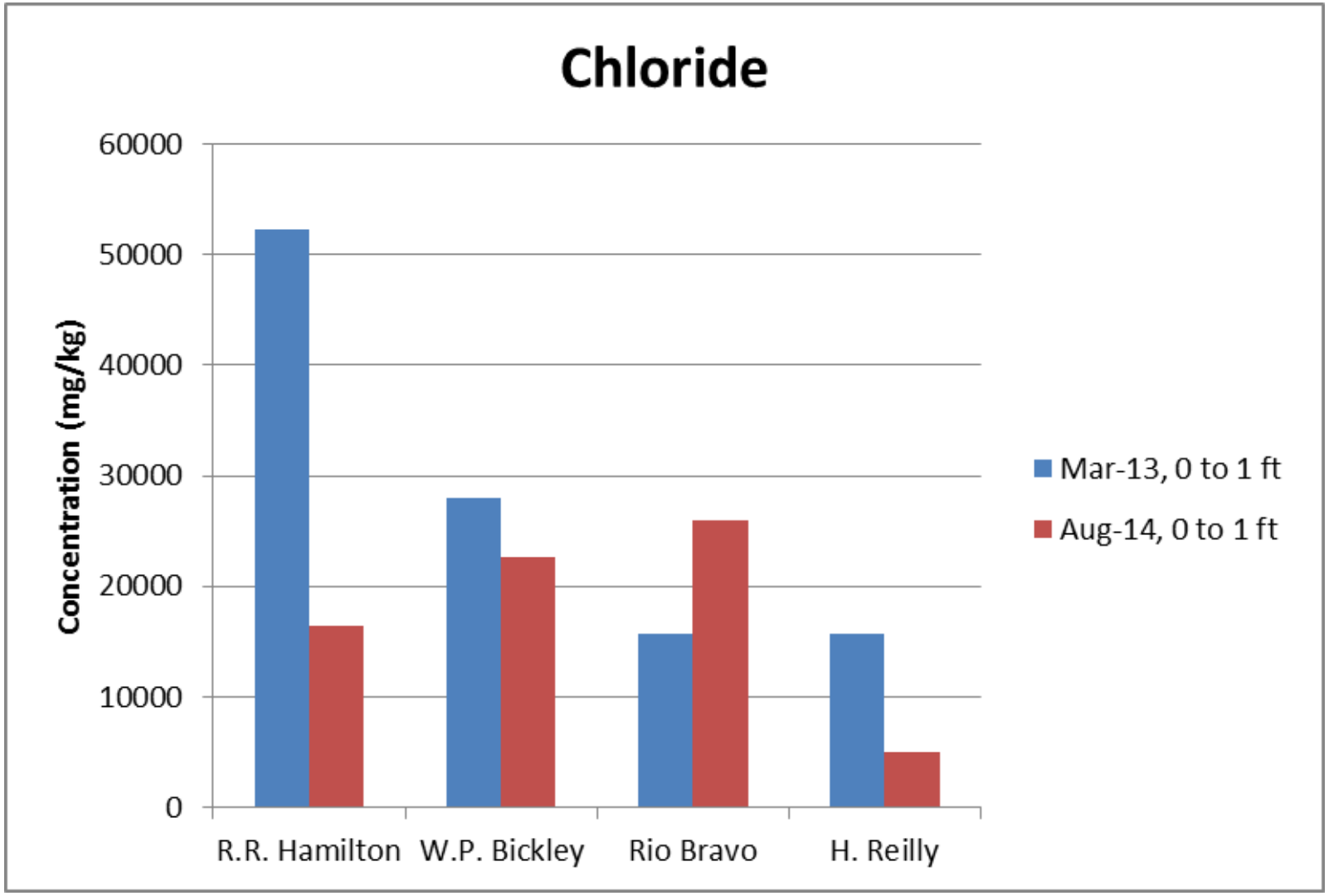
Interim Results



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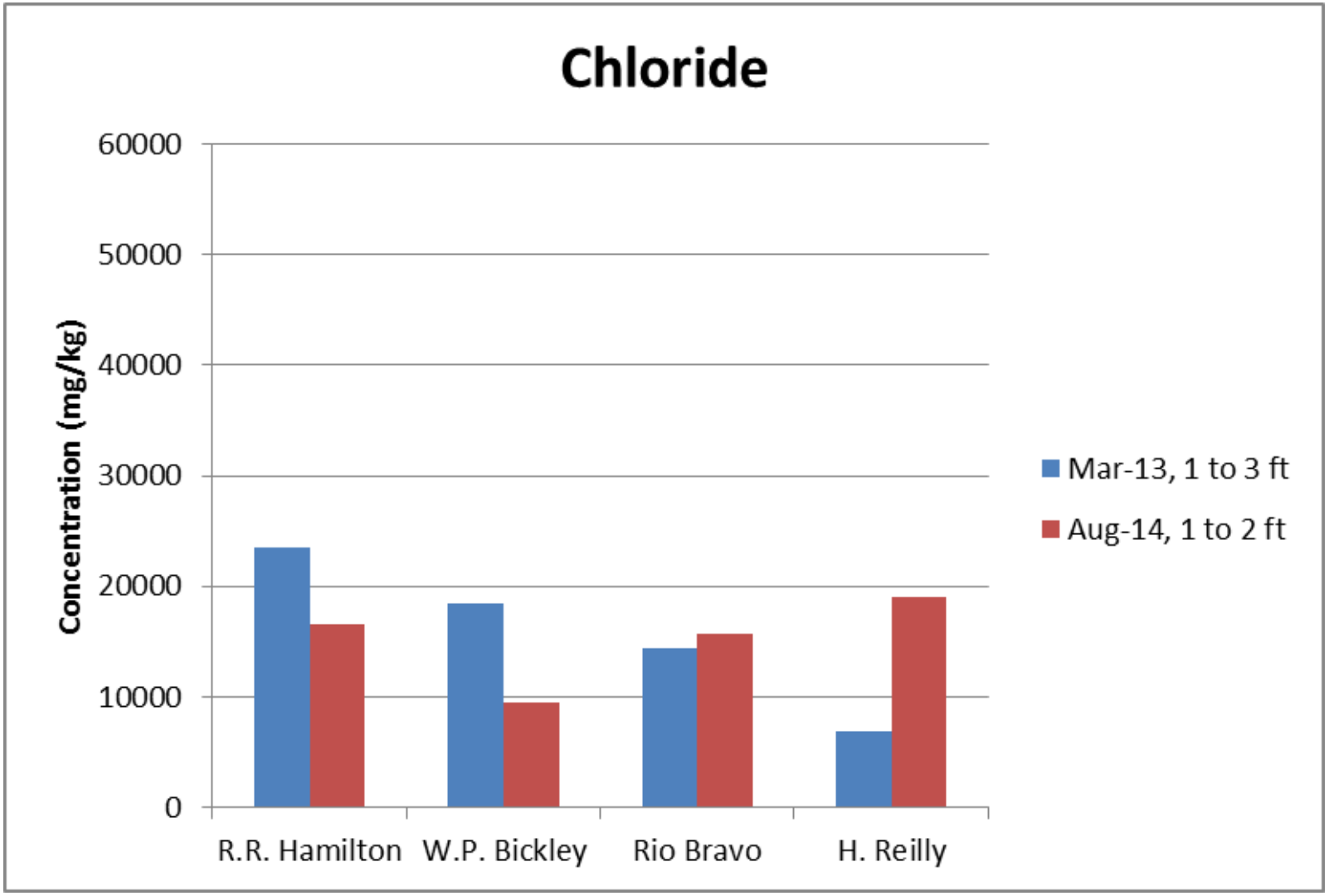

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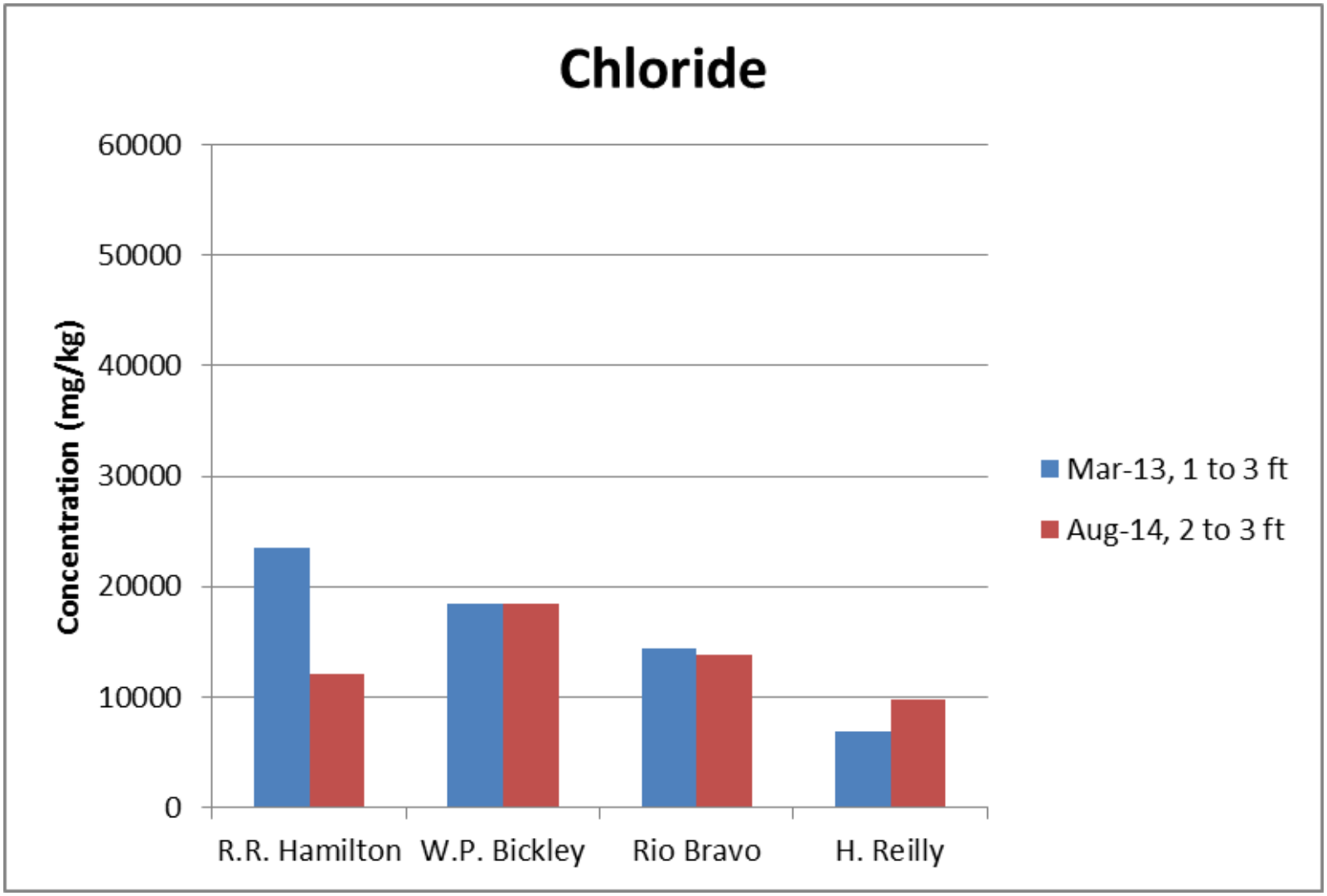

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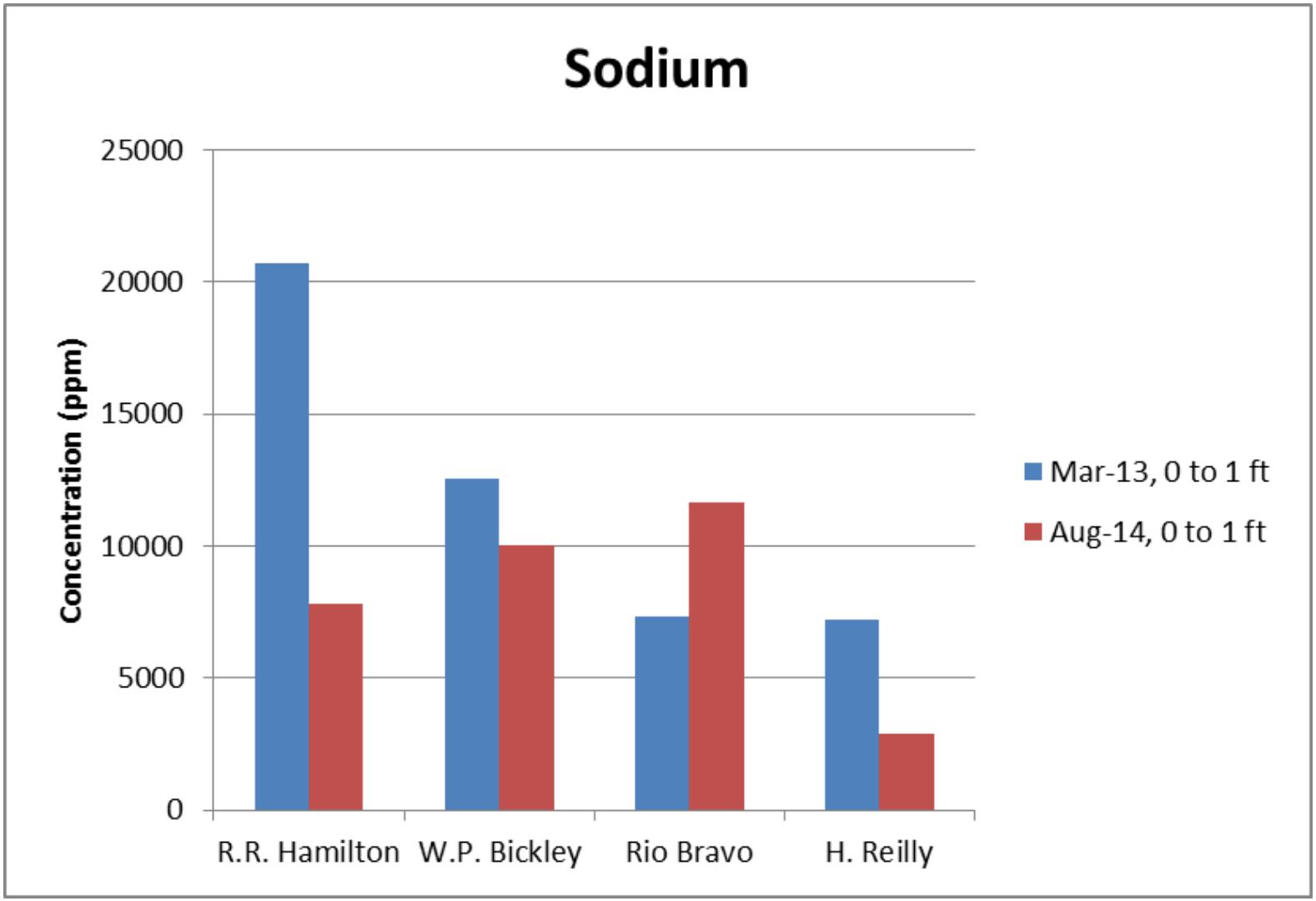

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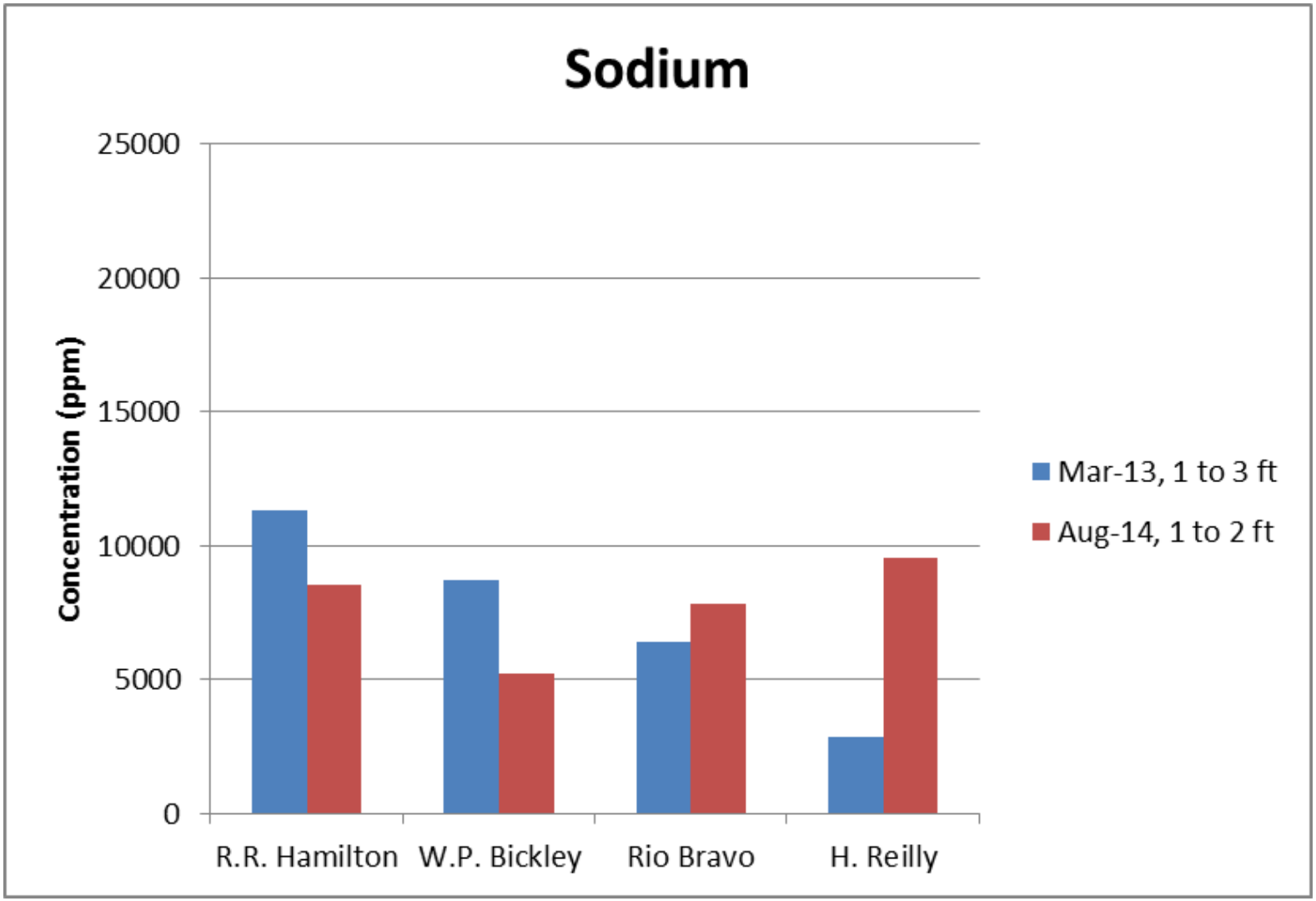

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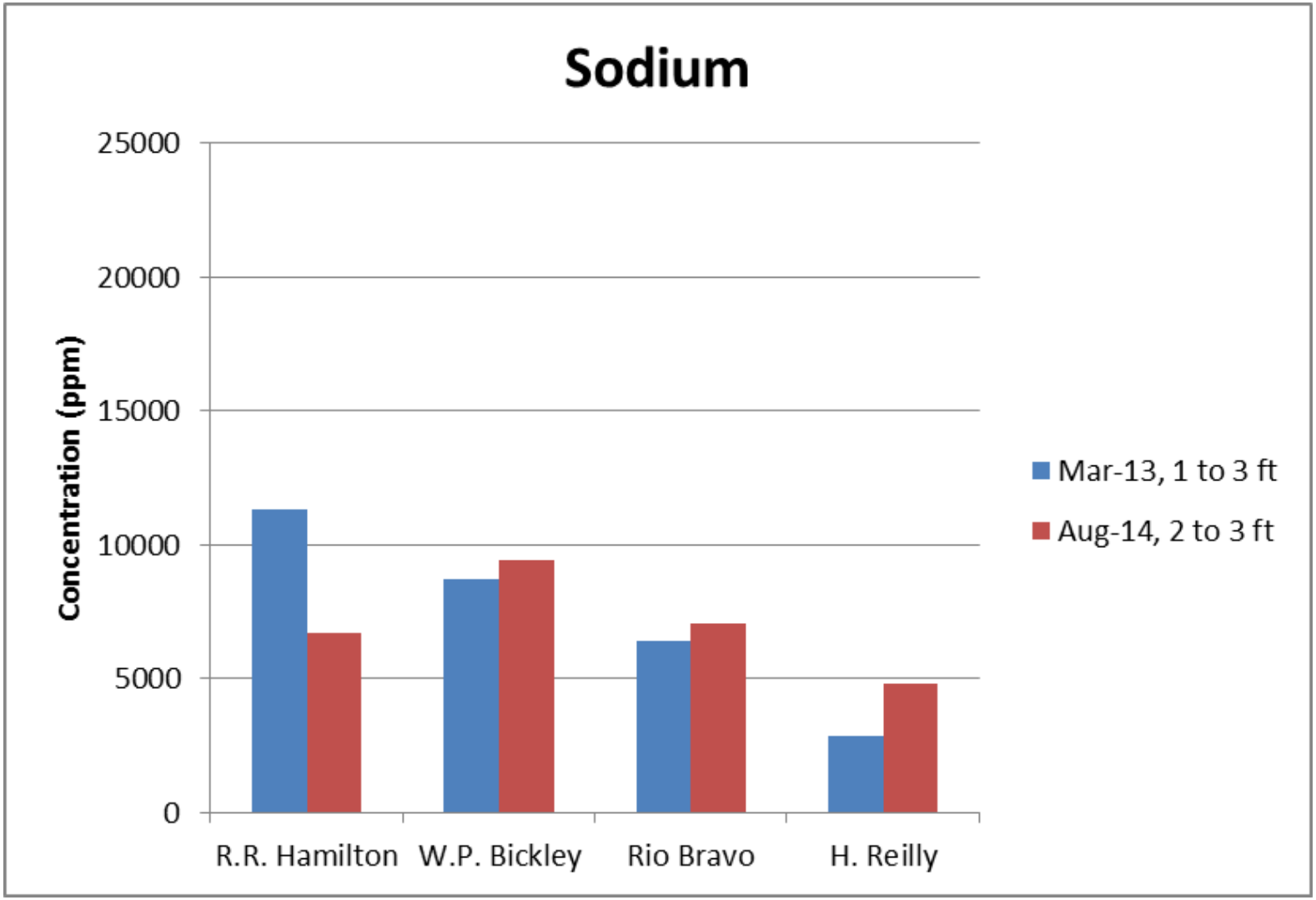

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Conclusions

- Chloride and sodium concentrations have been reduced in shallow interval (one exception)
- Chloride and sodium reduction occurred
  - At every interval beneath R.R. Hamilton
  - At shallow to intermediate depths beneath W.P. Bickley
  - Only in the shallow interval of H. Reilly
  - Not at all at Rio Bravo
- Increased concentrations at depth is attributed to flushing and redistribution of salt ions to these depths
- Deep salt reduction at Hamilton attributed to presence of drainage tiles making water less available for capillary re-mobilization
- Gradual improvement requiring additional application while remaining protective of groundwater

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Thank You