Implementation of Electrokinetic Based Soil Desalinization

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Current Remediation Technologies for Brine Spills

- Dig and Haul
- Amend and/or Flush

  Protective of an aquifer ? Chloride?
- Cap

  Generally not acceptable to land owner
- Others??

Electrokinetic Remediation ?

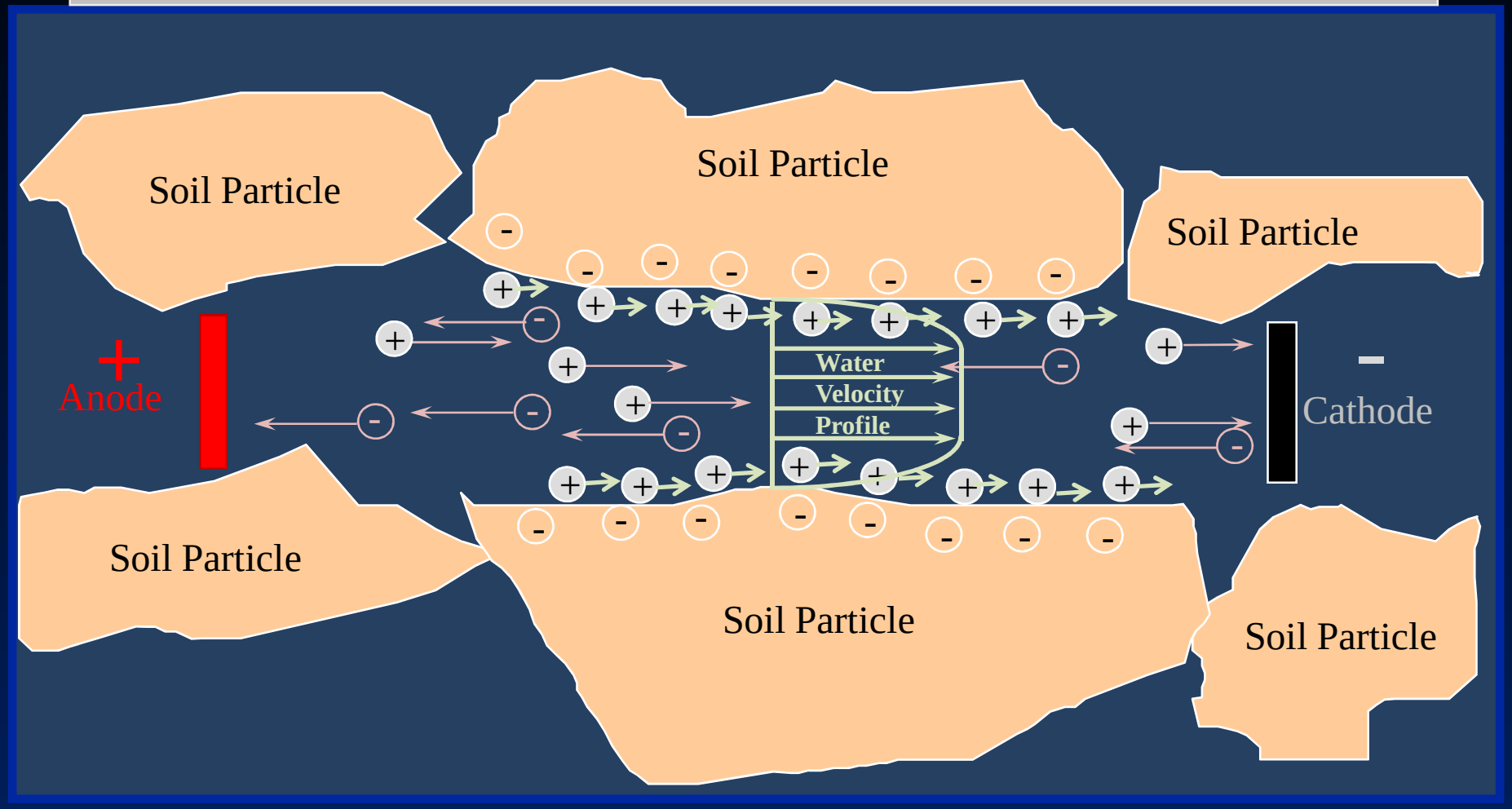
- Application of direct current (DC) electricity to the soil
- Polarized electrodes invoke movement of pore water and ions contained in the pore water, even in low permeability soils

Electrokinetics

- Electroosmosis – Movement of pore water and contaminants toward the cathode
- Electromigration – Migration of ionic species toward respective electrodes (anions toward anode, cations toward cathode) by electrical attraction

Principles of Electrokinetics

Electroosmosis = Water Transport from anode to cathode
Electromigration = Ion Transport to the opposite electrode



Electrokinetic Applications

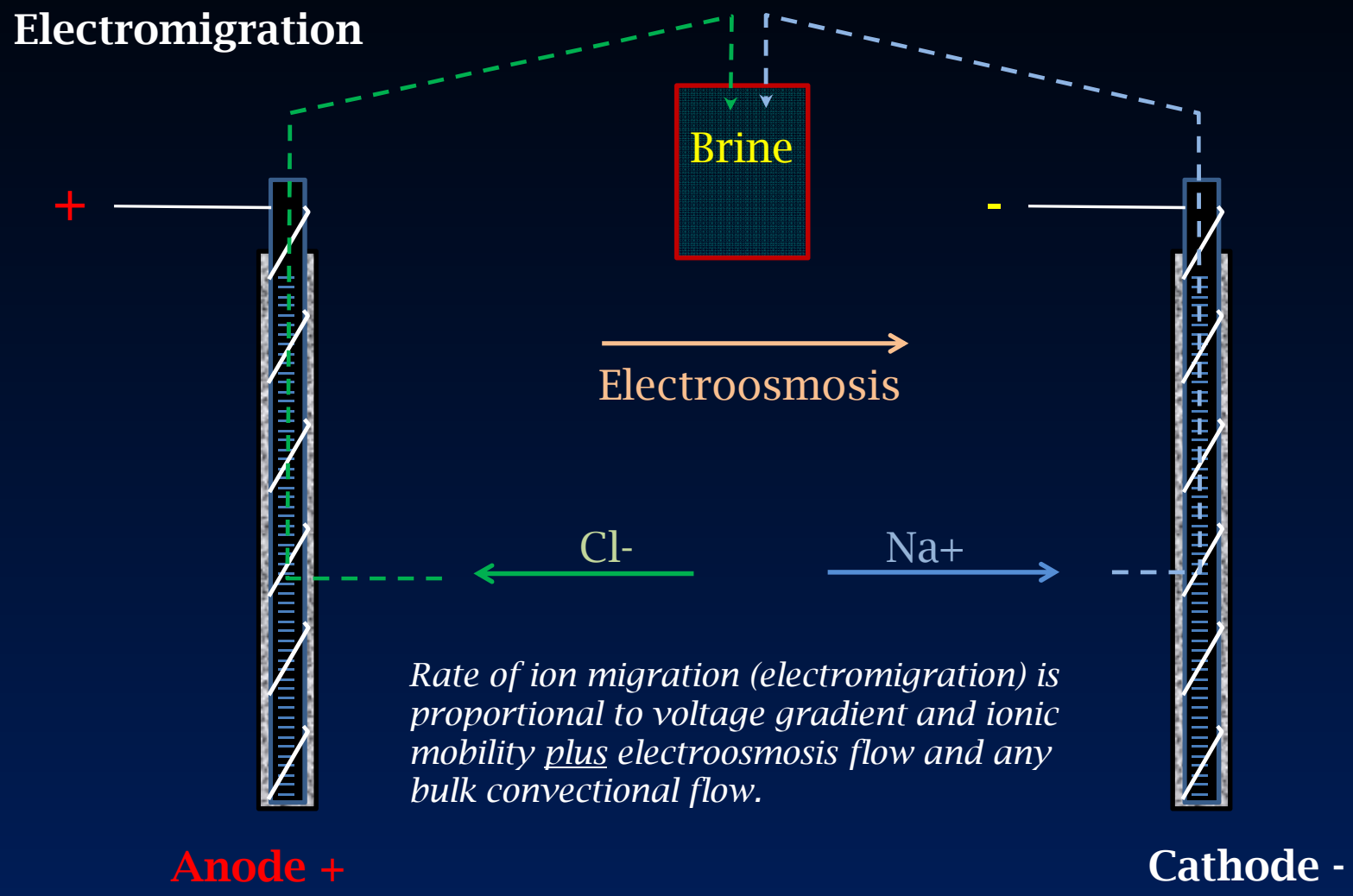
- Environmental Remediation
  - Heavy Metals (lead, chrome)
  - Organic Solvents (with in-situ ZVI)
  - Others (arsenic, nitrate, ISCO, bio-amendments)
- Dewatering/Stabilization
- Desalinization

- EK works in saturated & unsaturated zones

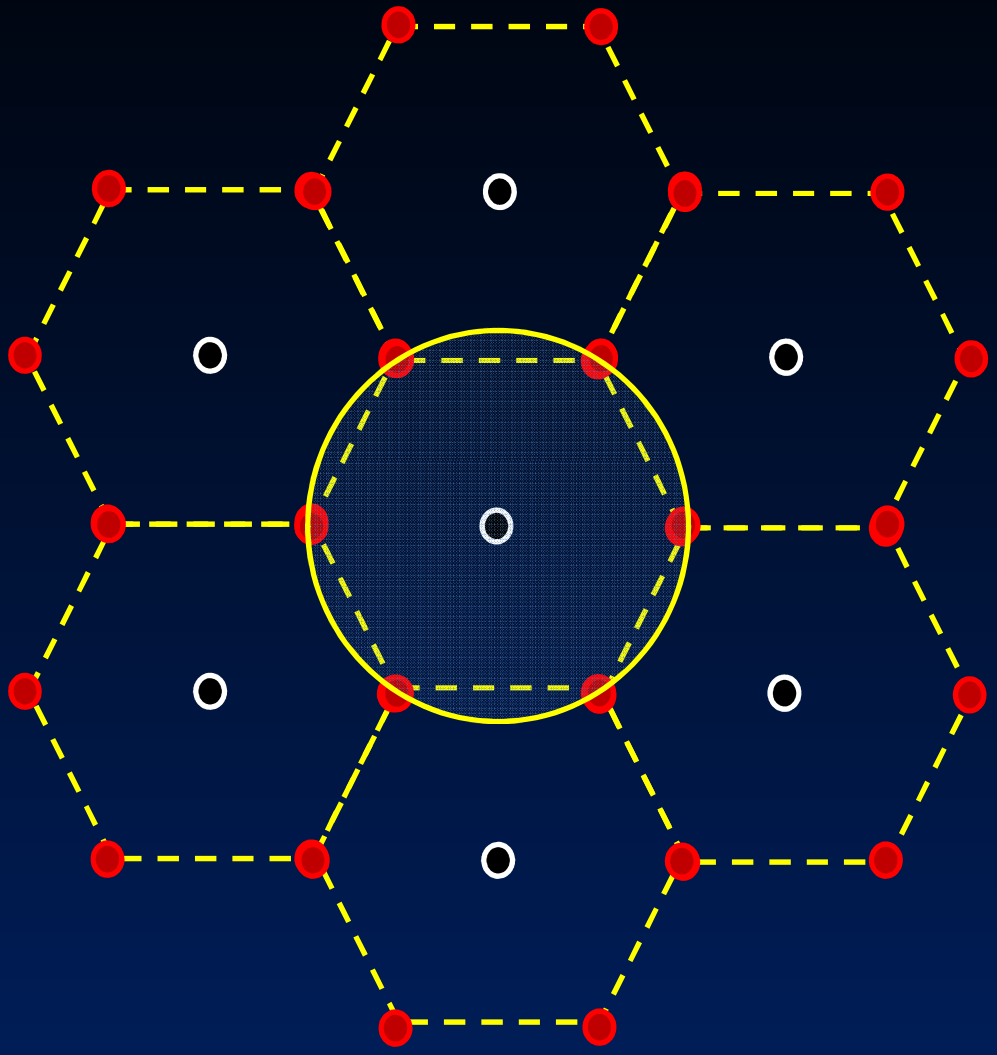
How EK Desalinization Works

- Sodium ions migrate toward the cathode by electromigration and electroosmosis where they are removed
- Chloride ions migrate toward the anode by electromigration, where they are removed or oxidized to chorine
- The removed cathode and anode streams are combined as brine and disposed/injected or beneficially reused

EK Desalinization Application



Electrode Pattern

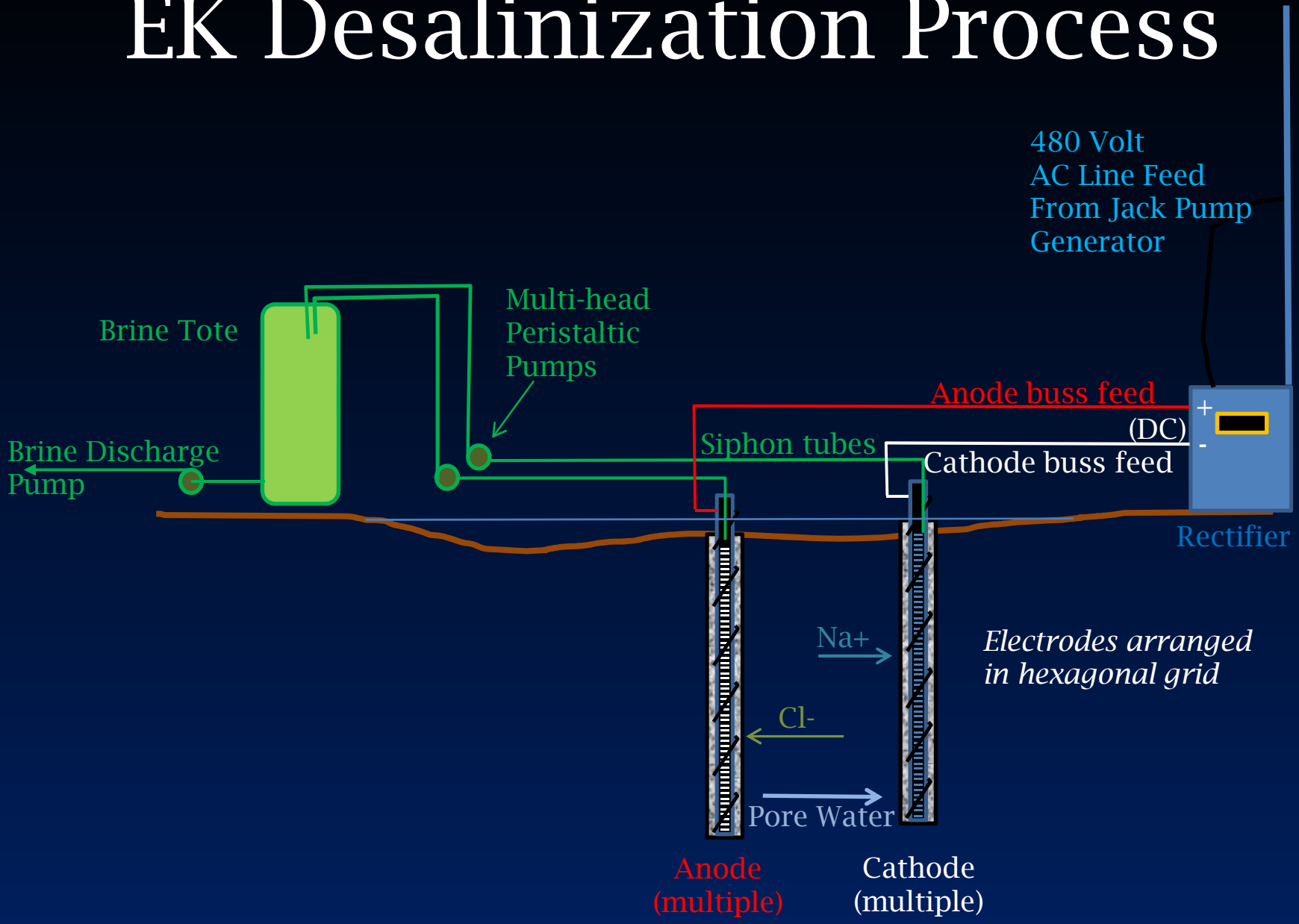


Model simulates removal from a cylinder with no flow boundary and central sink

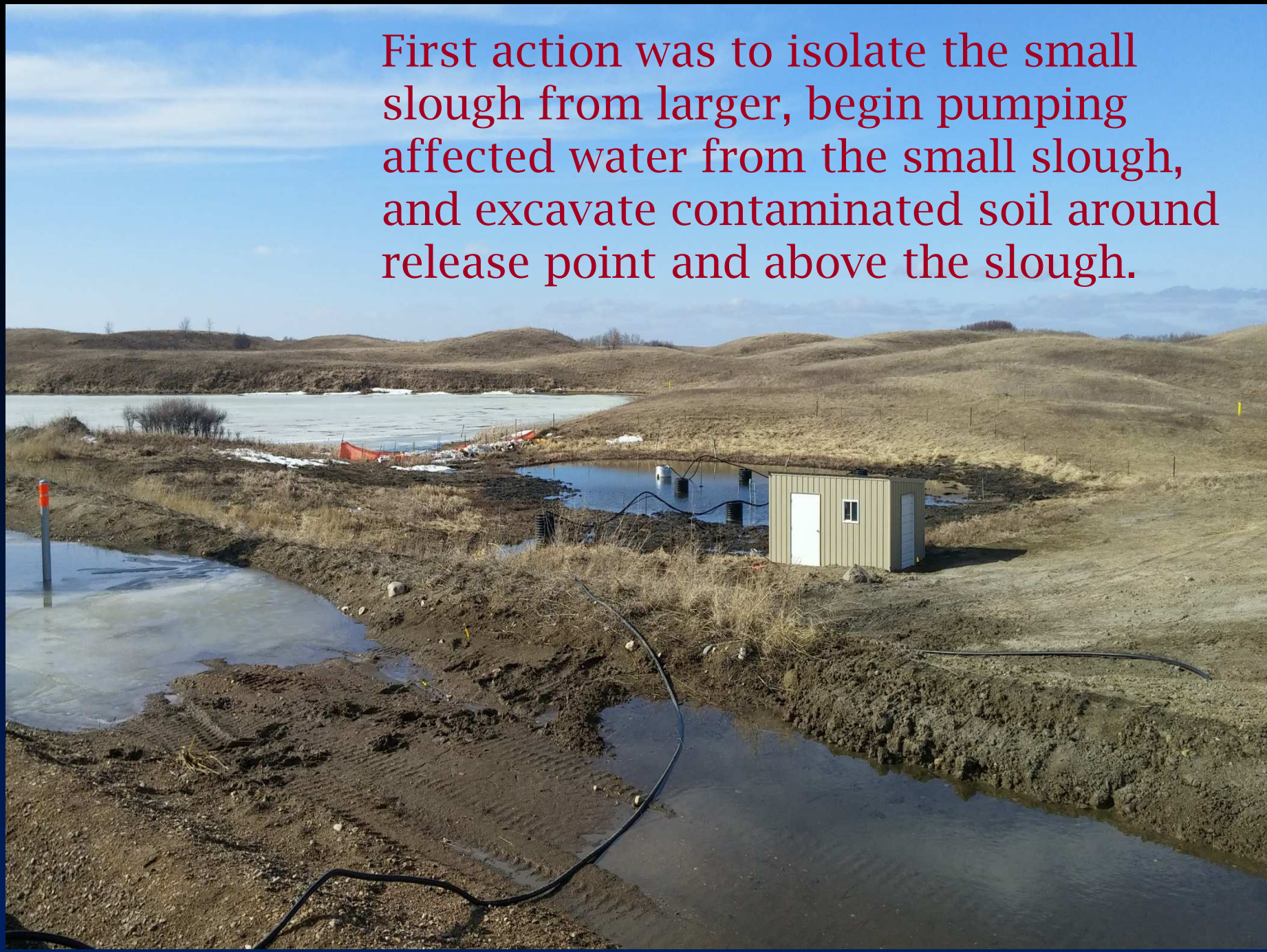
Field Scale Design

- Readily available equipment and parts (lowest costs)
- Electrodes are installed like miniature wells
  - Slotted 1” PVC well screen (24 cathodes, 69 anodes)
  - DSA wire wrapping as primary electrode
  - Backfill annulus with cathodic backfill material (example-Loresco SWS®)
  - Installed with hydraulic push (Geoprobe®) or small drill rig
- Extraction equipment is multi-head peristaltic pumps (peristaltic) operated on a timer
- Passive as possible operation
- Site remained saturated with precipitation providing enough water (some mild flooding)

EK Desalinization Process

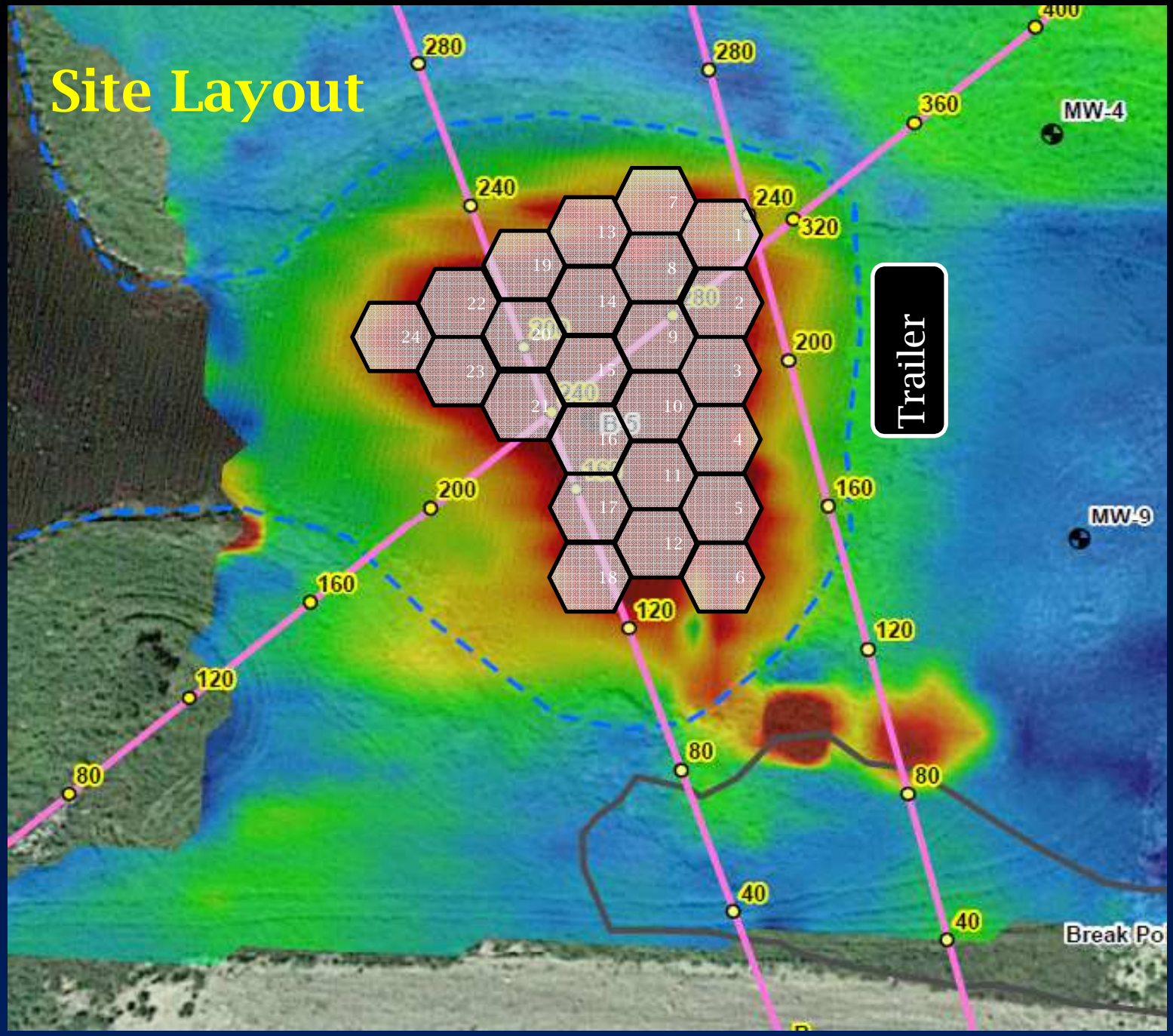


Demonstration Site Description:
Prairie pothole region in North Dakota
Saturated clay/silt (10^{-8}) high organic, Fe, Mn, Mg, SO_4
~500 bbl process water release
Environmentally sensitive area
Elevated chloride to 10 feet deep


First action was to isolate the small slough from larger, begin pumping affected water from the small slough, and excavate contaminated soil around release point and above the slough.

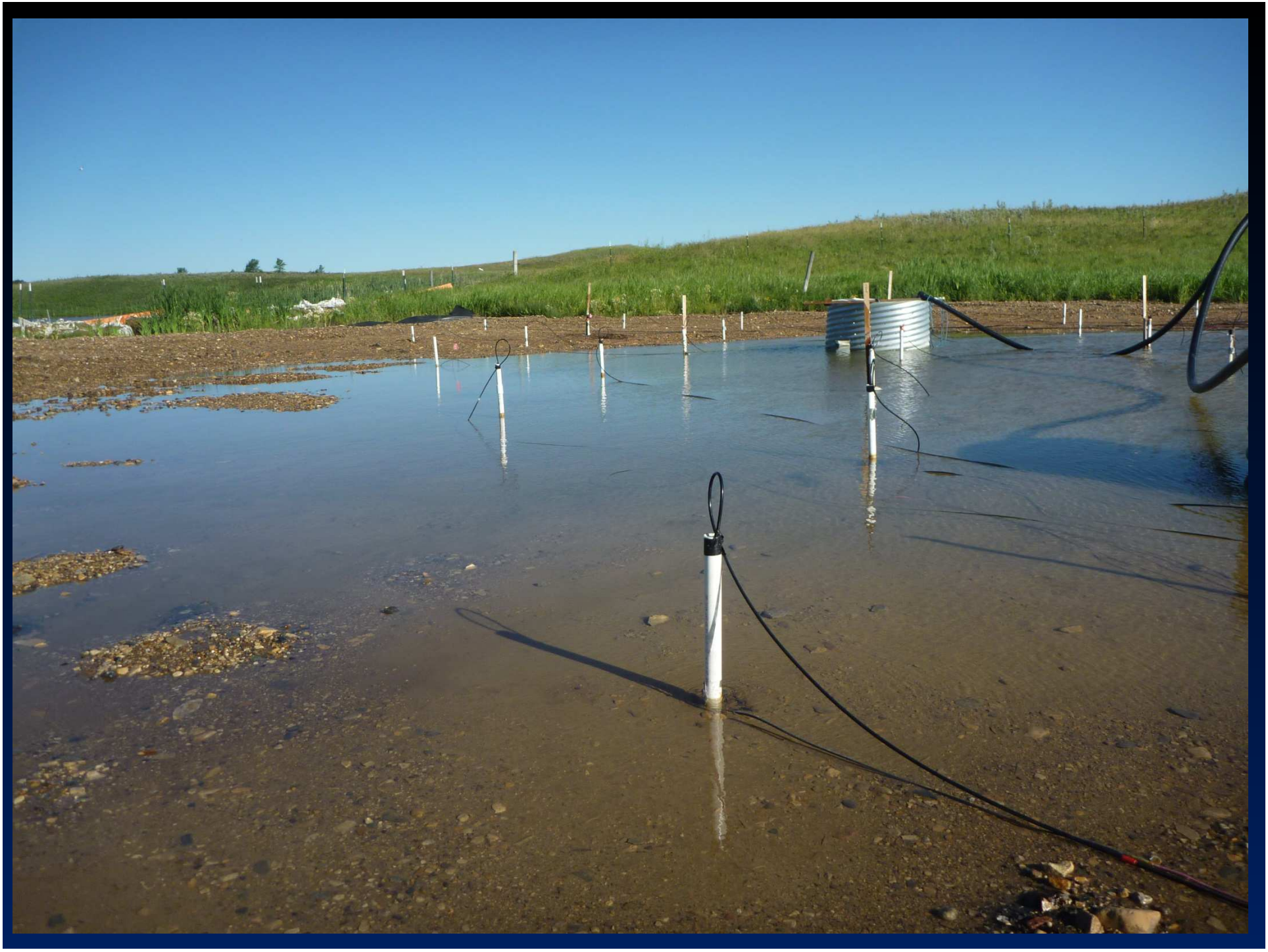

What a muck hole !
(effectively a swamp)

Area was covered with geofabric, geogrid, and cover rock to confine the contaminated soil and create a firm working surface. Surface materials will be removed at completion


Site Layout
280
280
360
MW-4
240
240
320
Trailer
200
200
160
MW-9
160
120
120
80
80
80
40
40
Break Po

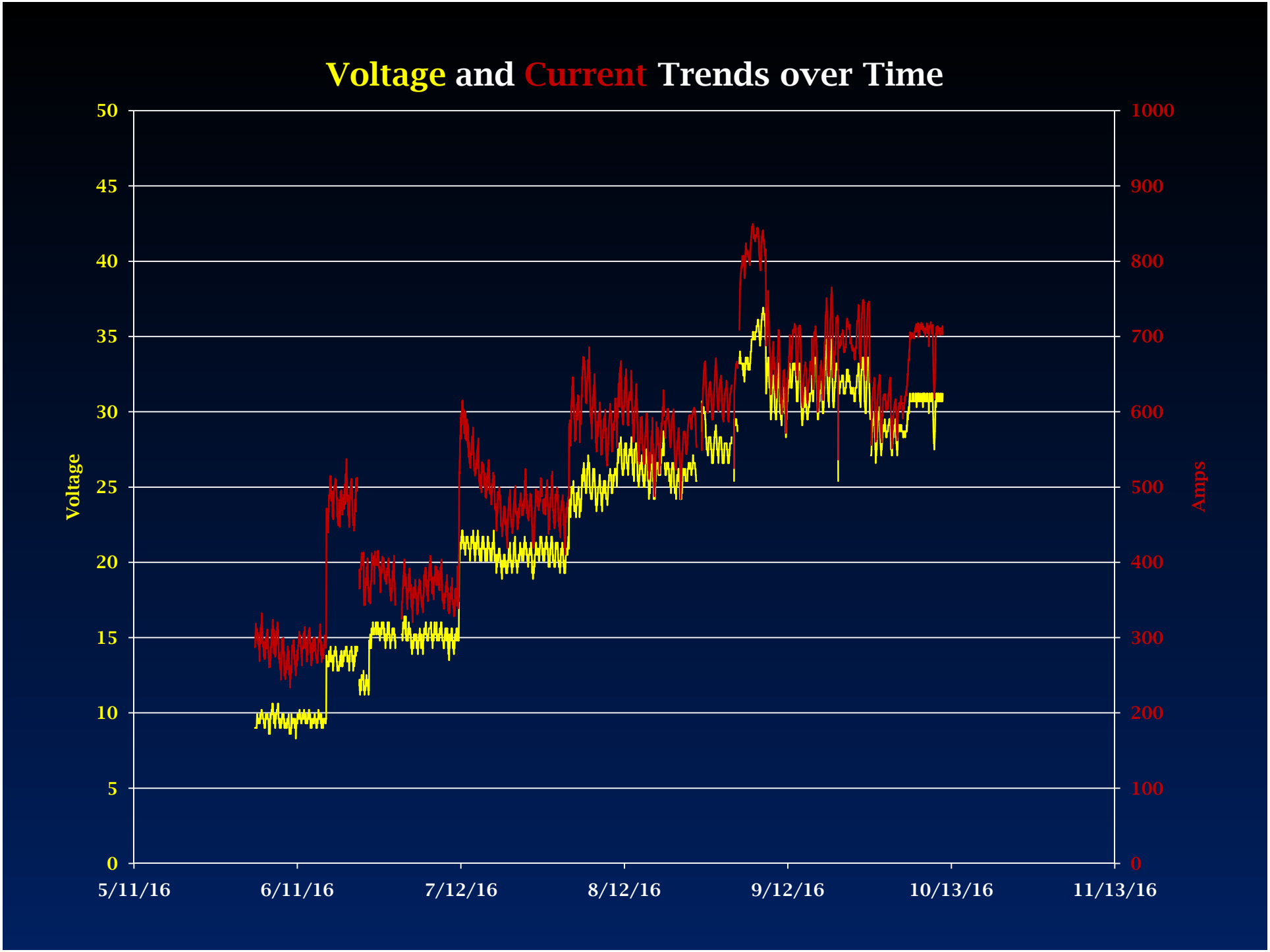

Installation was accomplished
using a Geoprobe rig


Installing the EK system

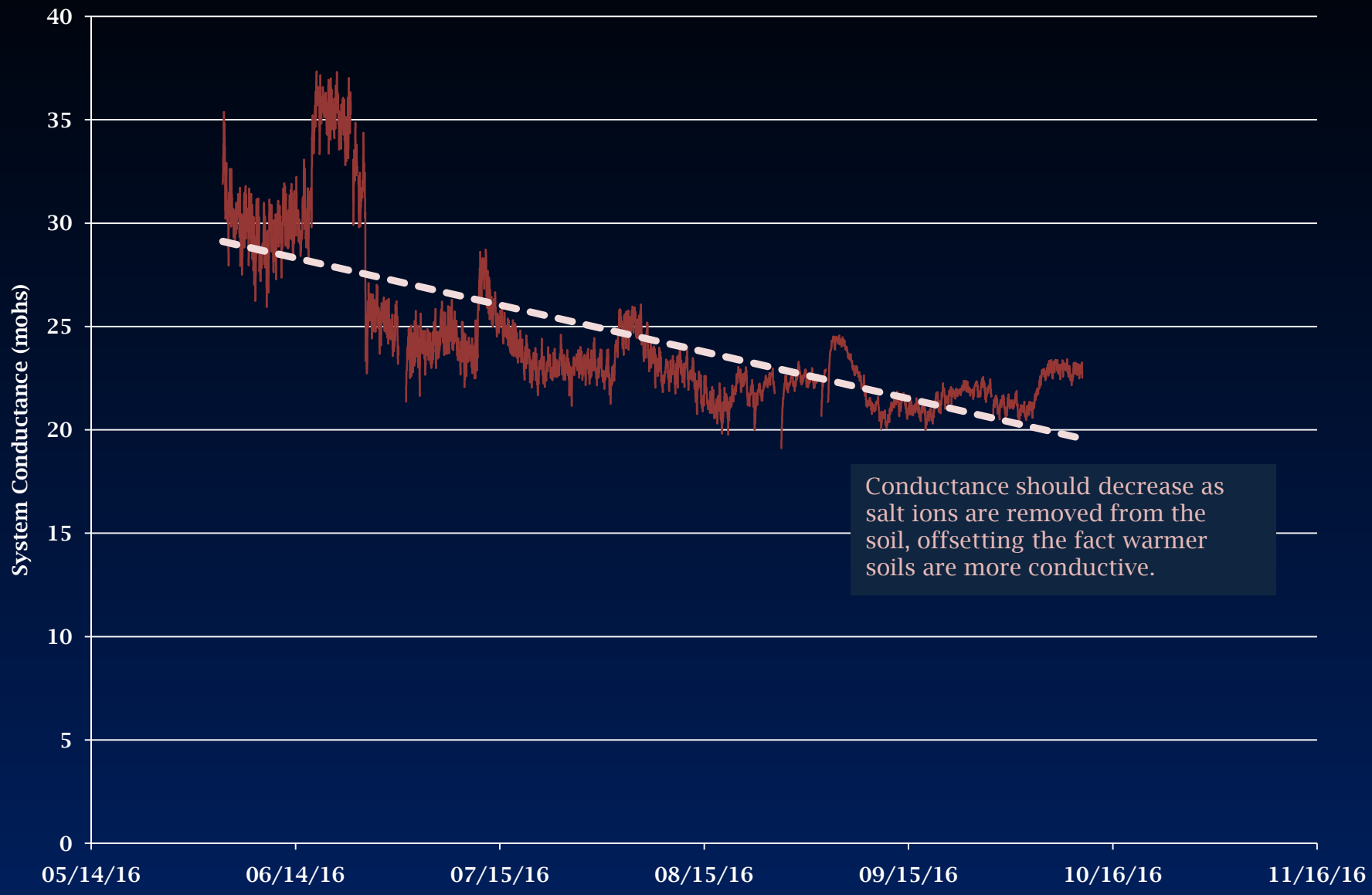


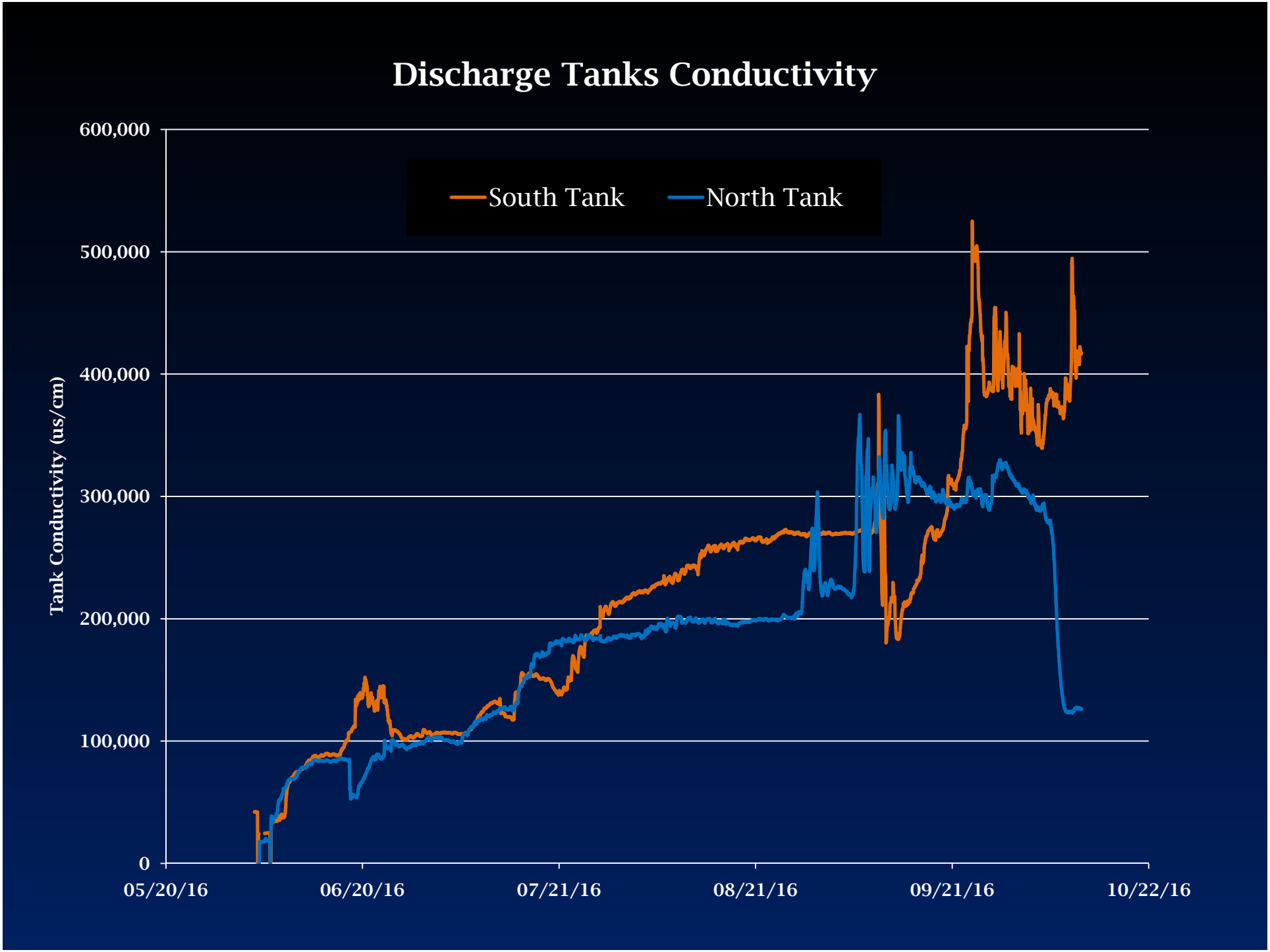
Operations To Date

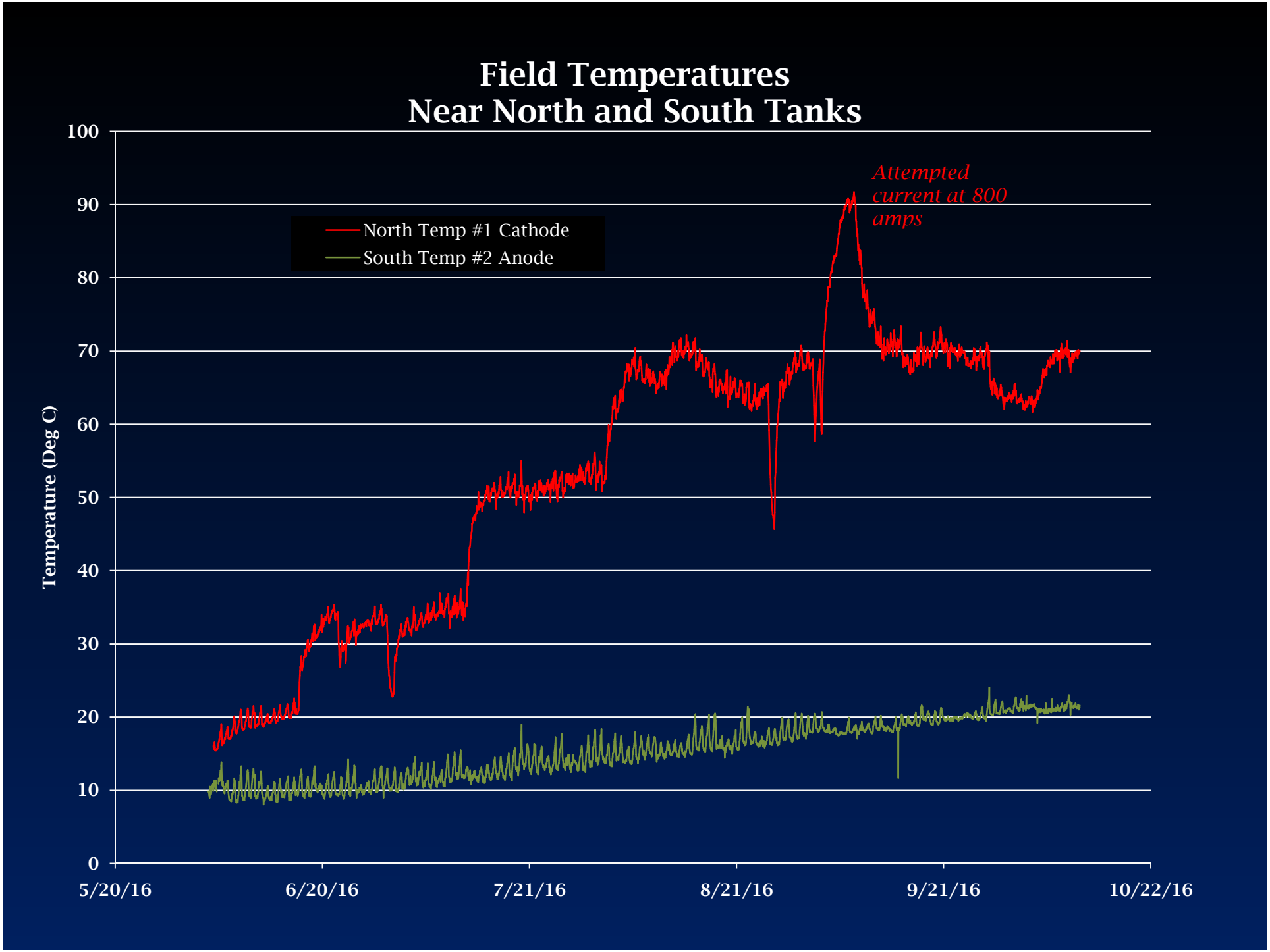
System began operations June 2, 2016
System shut down for winter October 13, 2016


Voltage and Current Trends over Time
Voltage
Amps
50
45
40
35
30
25
20
15
10
5
0
1000
900
800
700
600
500
400
300
200
100
0
5/11/16
6/11/16
7/12/16
8/12/16
9/12/16
10/13/16
11/13/16

Site Overall Electrical Conductance Based on Rectifier Output




Discharge Tanks Conductivity
South Tank
North Tank
Tank Conductivity (us/cm)
600,000
500,000
400,000
300,000
200,000
100,000
0
05/20/16
06/20/16
07/21/16
08/21/16
09/21/16
10/22/16


Field Temperatures
Near North and South Tanks
Temperature (Deg C)
100
90
80
70
60
50
40
30
20
10
0
5/20/16
6/20/16
7/21/16
8/21/16
9/21/16
10/22/16
North Temp #1 Cathode
South Temp #2 Anode
Attempted current at 800 amps

Chloride Removal

- Model predicts 300+ days for the chloride to reach anodes (2D, cylindrical, transient)
- Soil samples were collected after 110 days of operation
- Matched samples collected before and end of summer operations (8 locations, 2 depths, n=16) show 41% removal
  - Site conductance data confirms chloride removal
  - EM Surveys inconclusive

Chloride Soil Data

Hex	L	Depth	4/19/2016 Chloride ppm	Sodium ppm	pH su	Cond us/cm	9/20/2016 Chloride ppm	Sodium ppm	pH su	Cond us/cm	Chloride Reduction	
												Anode
15	1	3-4	7,310	3,250	7.5	17,600	4,400	1,590	7.77	12,900	40%	
		7-8	9,700	4,860	7.2	21,400	10,000	3,070	7.27	21,400	-3%	
17	2	3-4	5,660	2,470	7.3	14,400	3,110	1,580	7.71	12,400	45%	
		7-8	6,020	3,140	7.4	15,200	4,160	1,470	7.94	16,200	31%	
5	4	3-4	5,300	2,170	7.4	12,600	4,140	1,140	7.84	8,020	22%	
		7-8	6,300	2,970	7.2	14,600	4,490	1,340	7.27	10,200	29%	
2	6	3-4	3,970	1,720	7.4	11,000	2,480	632	8.18	4,450	38%	
		7-8	8,600	3,390	7.4	19,100	5,520	1,810	7.86	12,000	36%	
8	8	3-4	3,200	1,540	7.6	9,170	850	418	8.36	2,640	73%	
		7-8	8,560	3,970	7.6	18,800	1,470	1,650	7.96	15,800	83%	
23	9	3-4	6,040	2,270	7.4	14,500	718	352	8.76	2,270	88%	
		7-8	9,470	3,640	7.3	20,500	5,880	3,760	7.74	24,200	38%	
												Cathode
		Average	6,678	2,949	7.39	15,739	3,935	1,568	7.89	11,873	41%	

Started 6/2/2016 Sampled 9/20/16 110 days

Lessons Learned to Date

- Chlorine gas generated at anode (expected)
- Choose materials and pump equipment wisely
- Needed to upsize wellhead generator to handle jack pump and rectifier

For Consideration

- Use of plastic venturi pumps down hole for fluid management?
- Can the system be operated to convert all chloride to chlorine?
- Reverse-pulse operations may even out the conductivity gradients and increase chloride removal
- Low voltage, high current DC requirements begs solar power

Conclusions

- EK desalinization is working at the demonstration site
- Regulators and Corporate on board
- If it works at this site, it can work at most any site.

Many Thanks!

- To Oasis Petroleum for believing in this process and allowing the trial at this site
- To US Fish and Wildlife Service and the North Dakota Dept of Health for guidance and support
- Habitat Management, American Engineering and Testing, Vertex, Three Forks Environmental for site support