Implementation of Electrokinetic Based Soil Desalinization Year 2 Update

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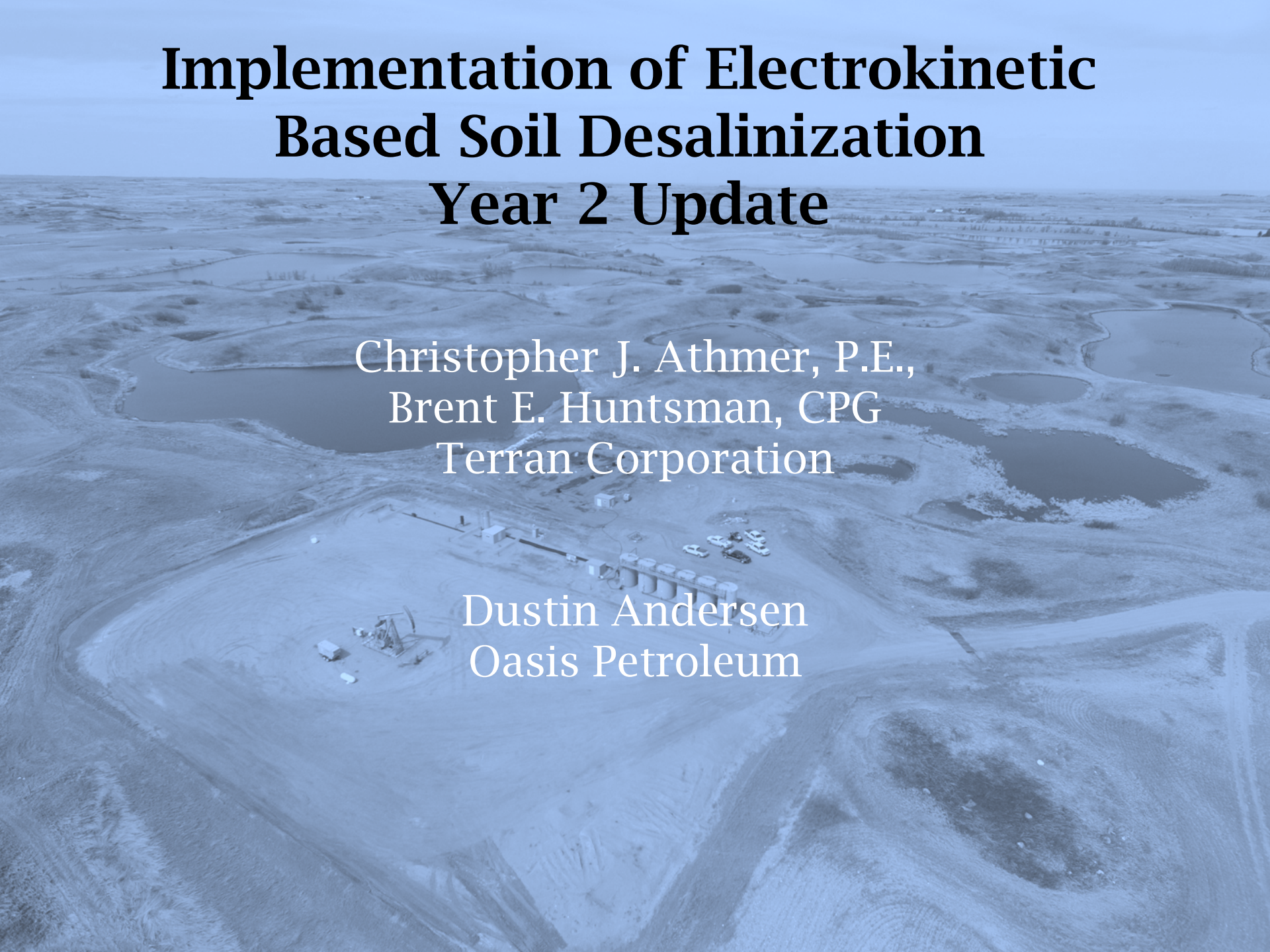


Current Remediation Technologies for Brine Spills

- 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 (saturated or vadose)

- Polarized electrodes invoke movement of pore water and ions contained in the pore water, even in low permeability soils

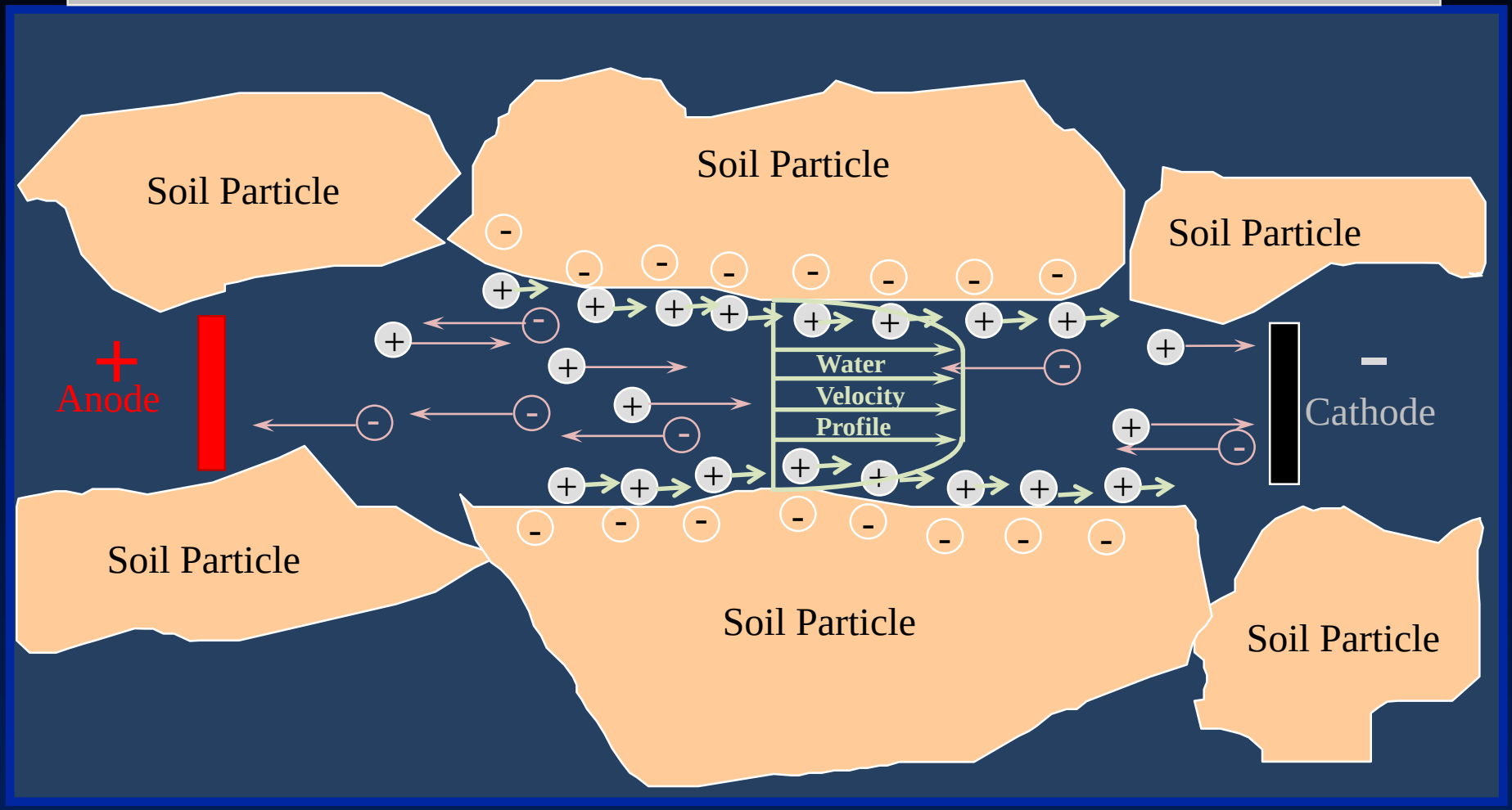
Electrokinetics

- Electroosmosis – Movement of pore water and dissolved non-polar 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



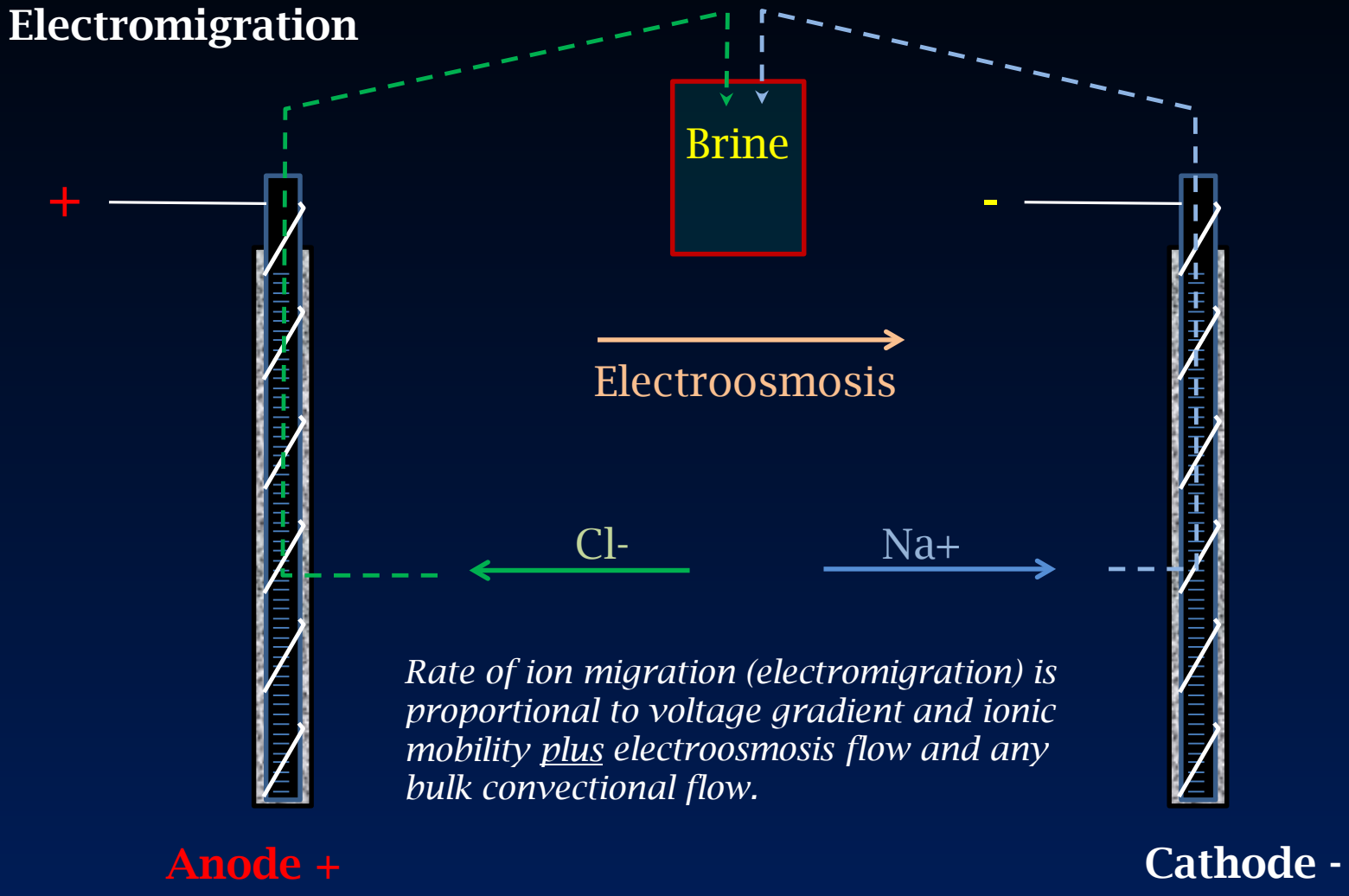
Electrokinetic Applications

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

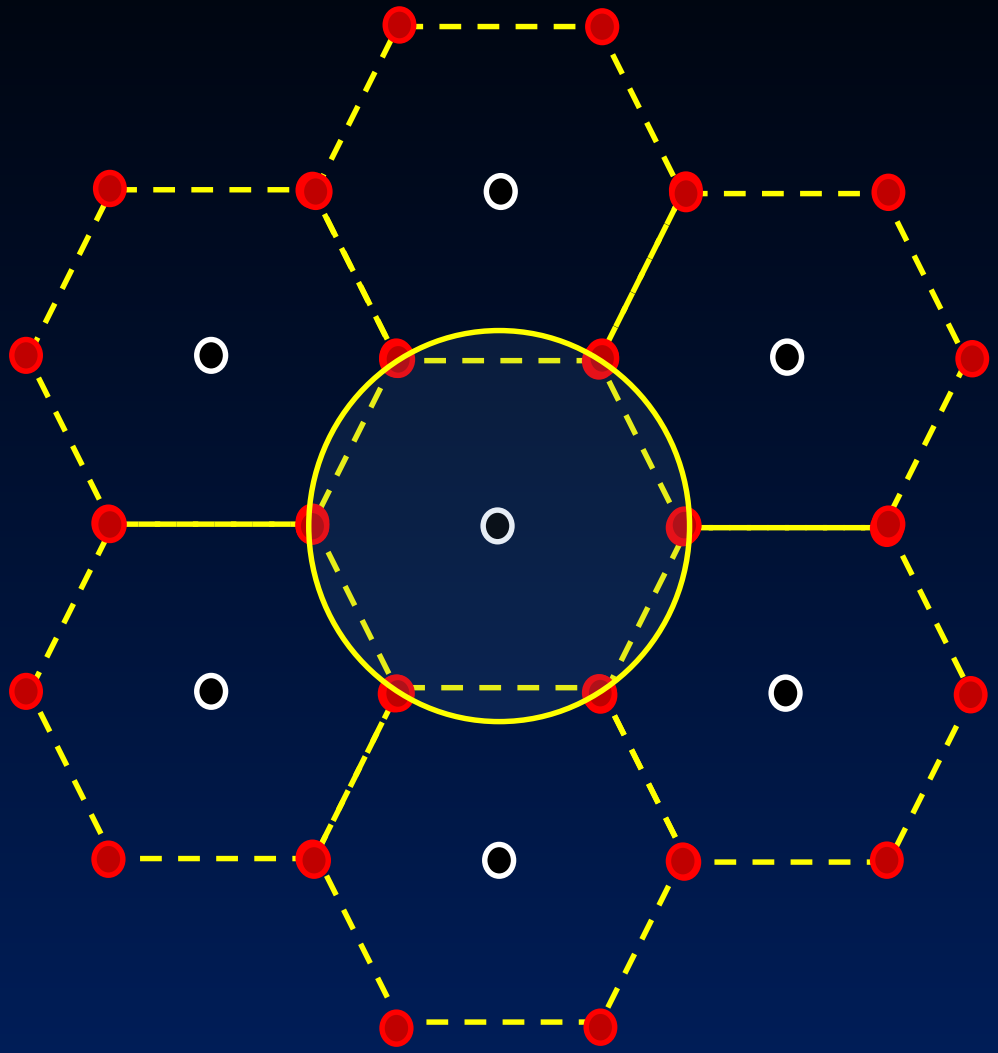
How EK Desalinization Works

- 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

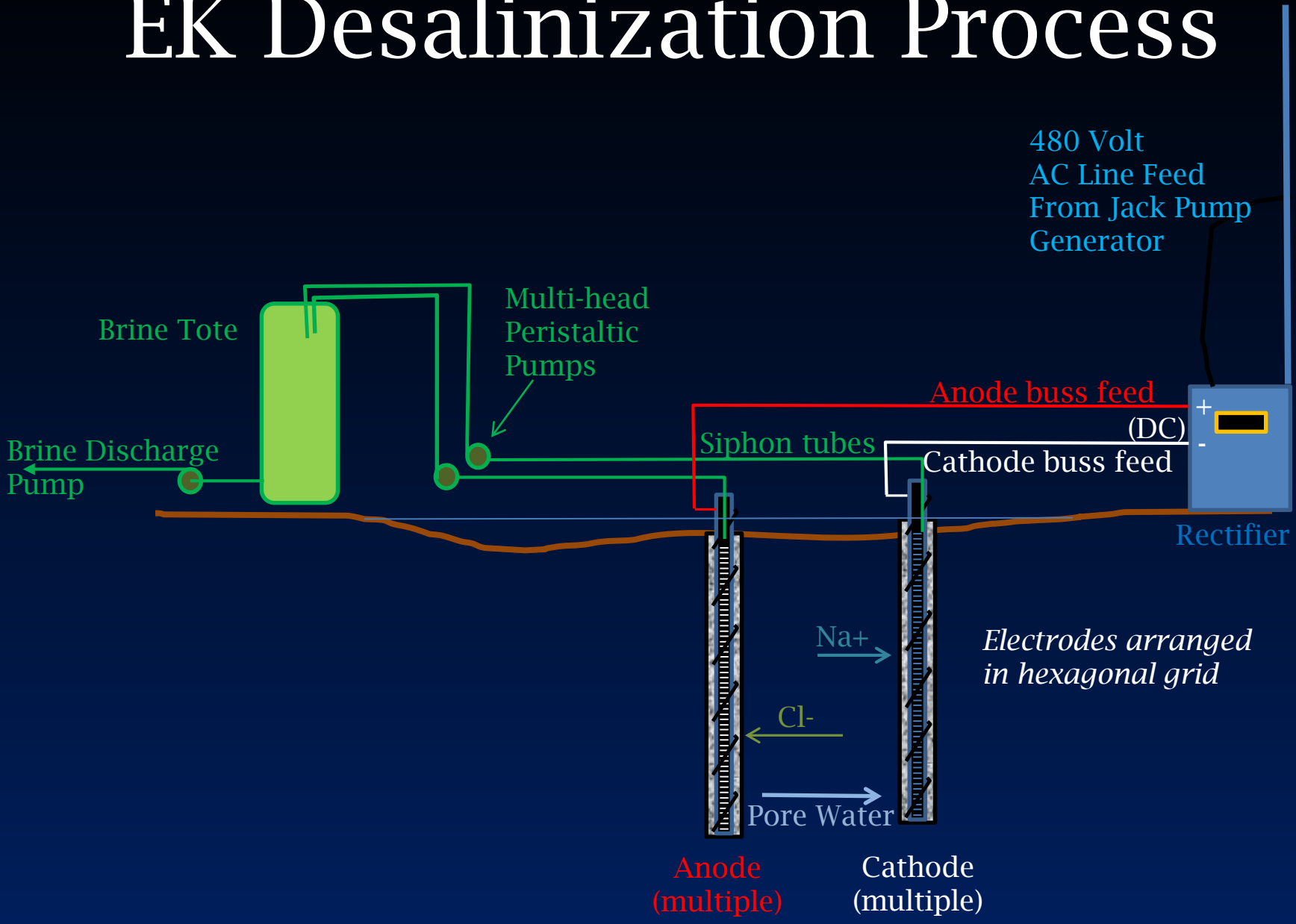


Model simulates removal from a cylinder with no flow boundary and central sink

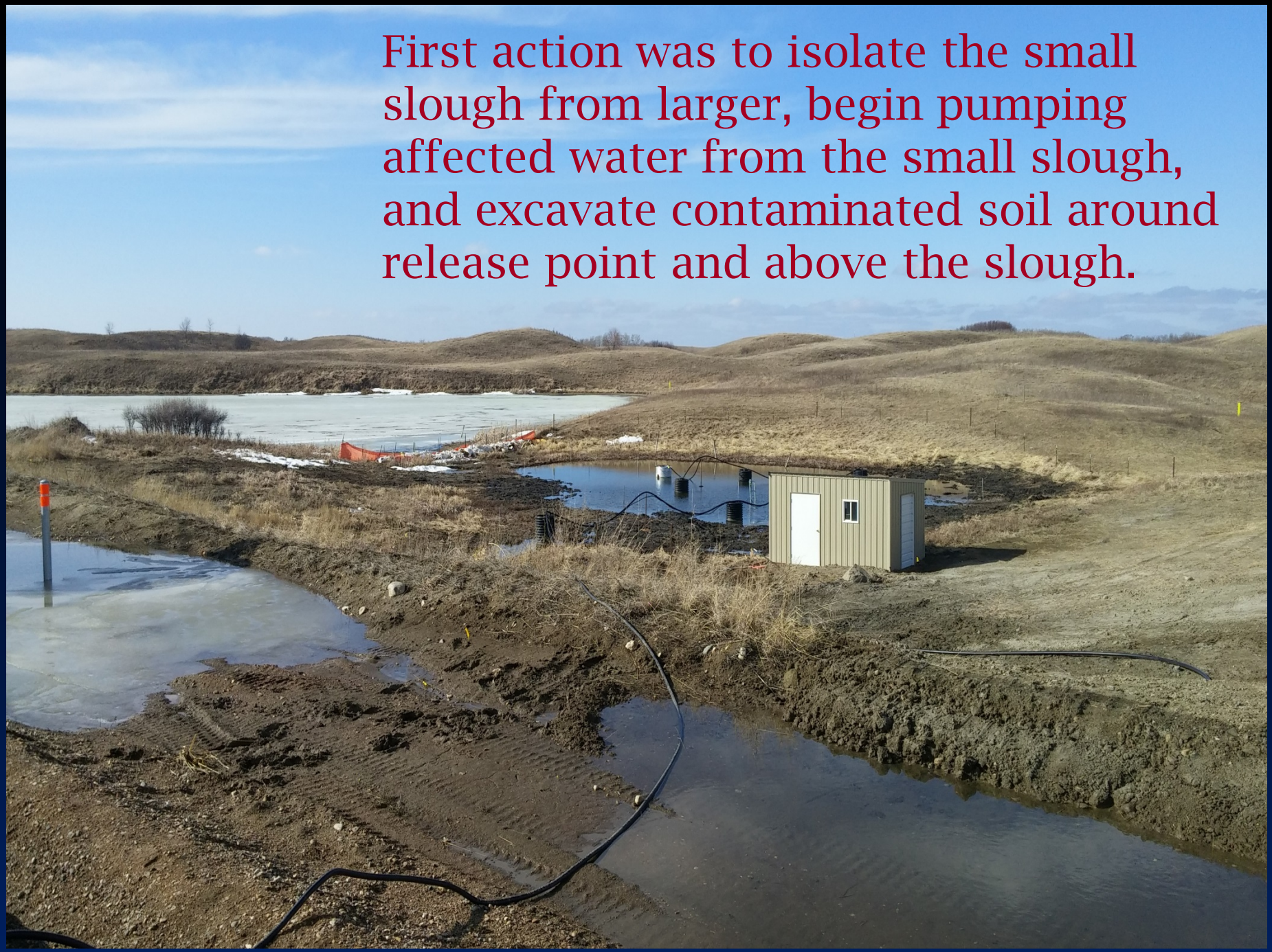
Field Scale Design

- 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 timers
- Site remained saturated with precipitation providing enough water (some mild flooding) in year 1
- However, site showed signs of drying in year 2

EK Desalinization Process

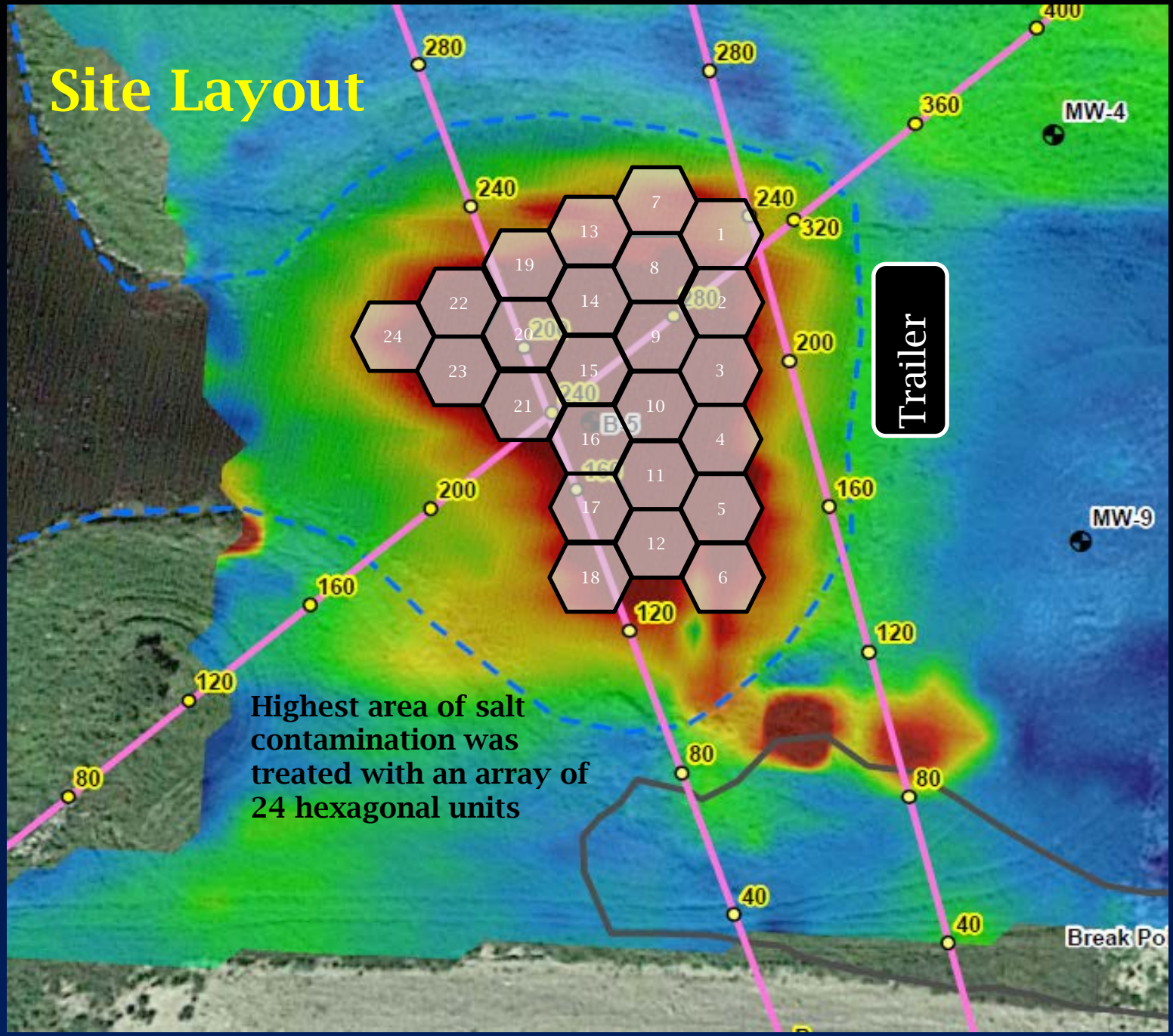


Demonstration Site Description:
Prairie pothole region in North Dakota
Saturated clay/silt (10^{-8}) high organic, Fe, Mn, Mg, SO_4
~500 bbl process water release
Environmentally sensitive area
Elevated chloride to 10 feet deep
EK Desalinization utilized as mass removal option


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.

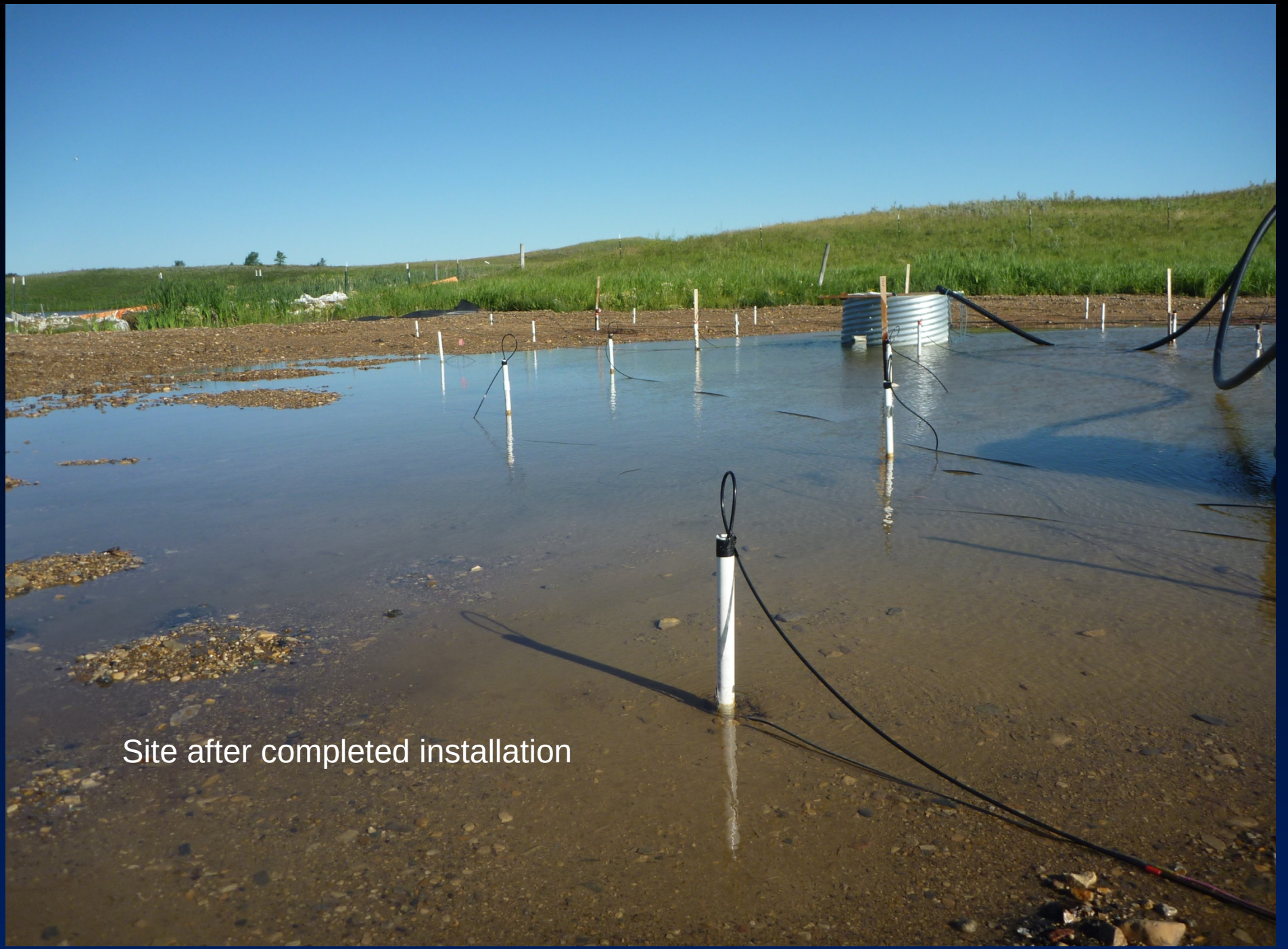

What a muck hole !
(effectively a swamp)

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
400
360
MW-4
240
240
320
7
13
1
19
8
22
14
2
24
20
9
200
23
15
3
21
10
16
4
11
17
5
12
18
6
Trailer
200
160
MW-9
160
120
120
120
80
80
80
Highest area of salt contamination was treated with an array of 24 hexagonal units
40
40
Break Po

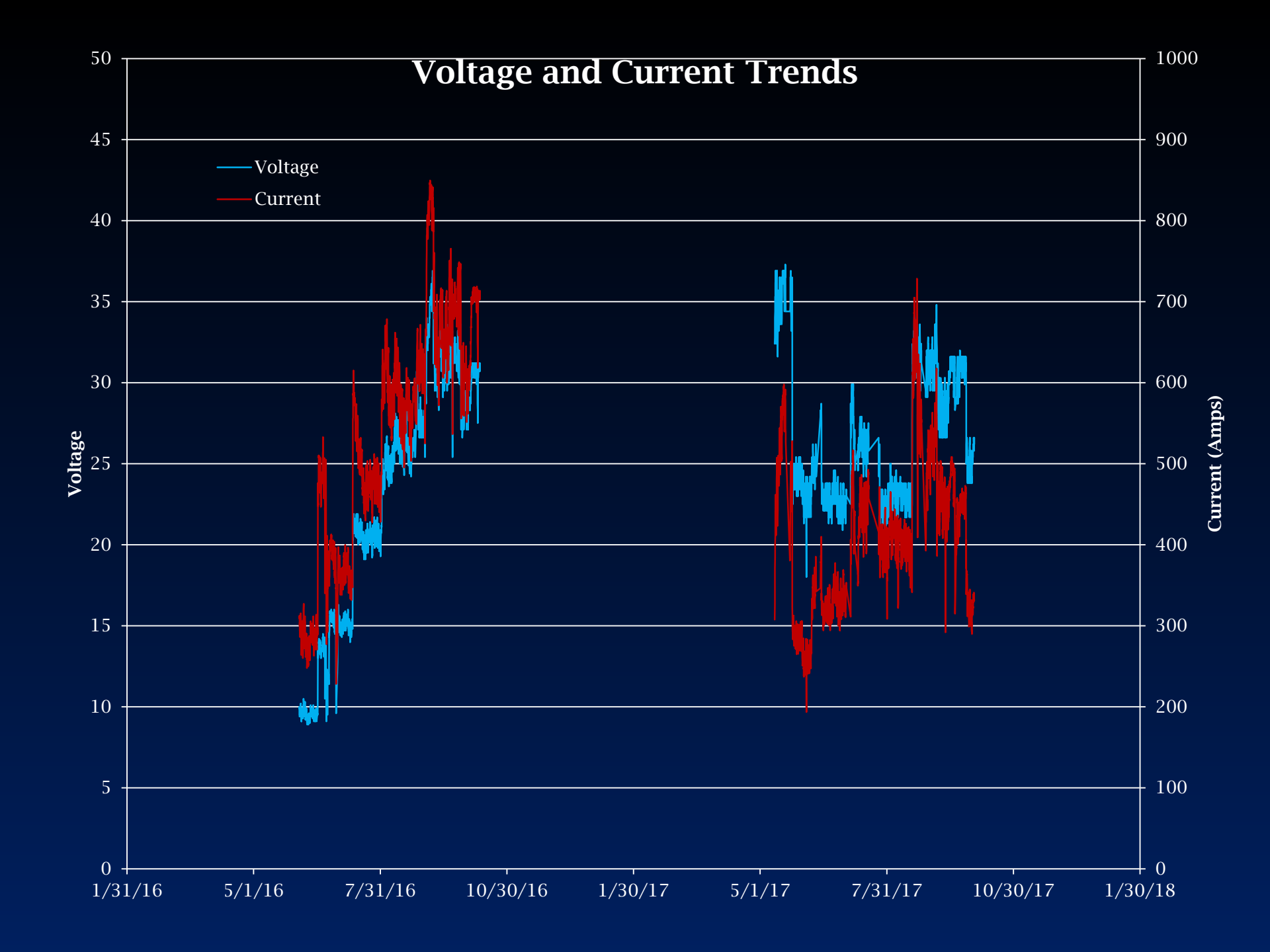

Installation was accomplished
using a Geoprobe rig


Installing the EK system

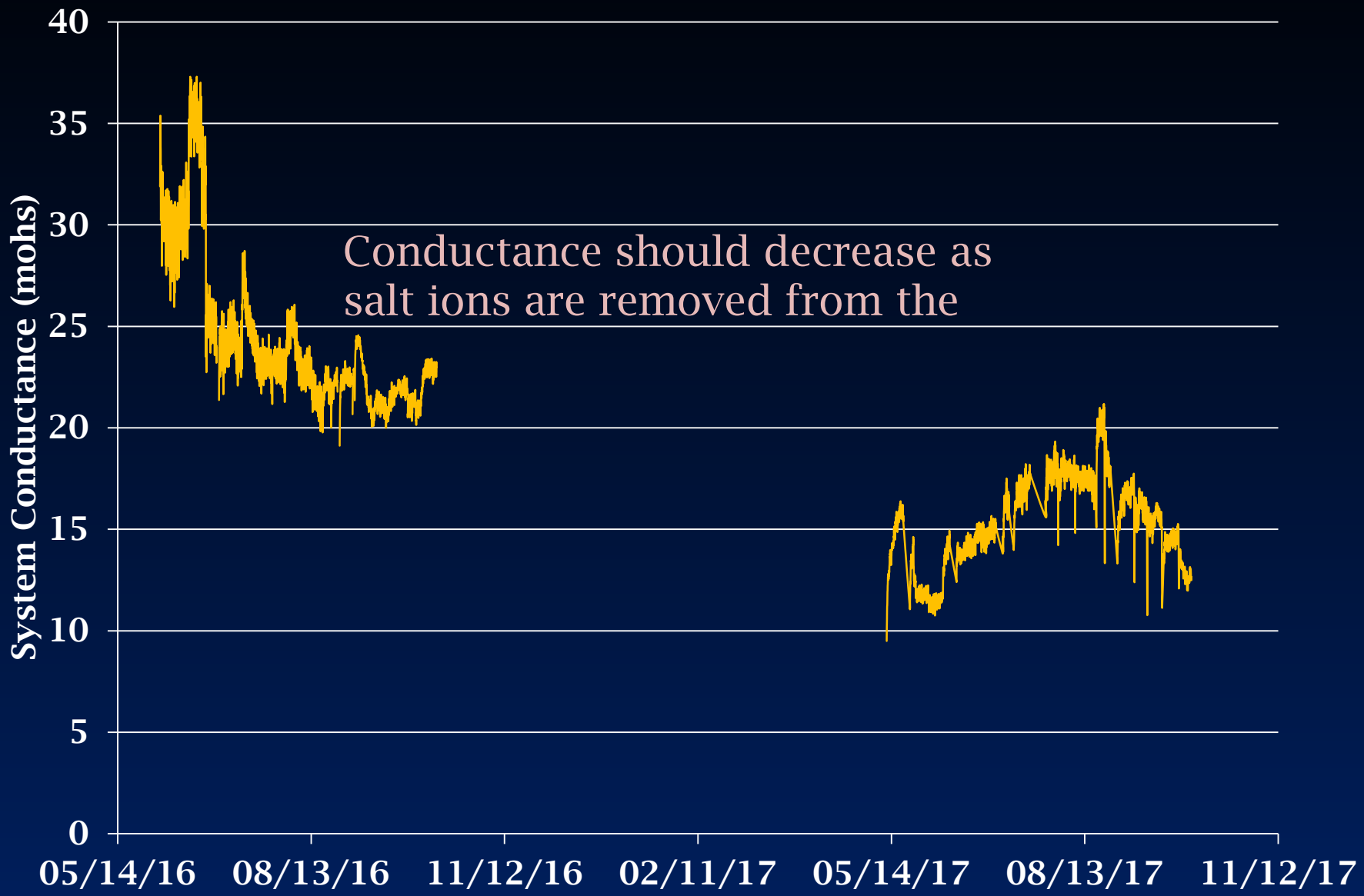

Site after completed installation

Operations To Date

System began operations June 2, 2016
System shut down for winter October 13, 2016
Restarted May 11, 2017
Shut down for winter October 2, 2017


Voltage and Current Trends
Voltage
Current
Voltage
Current (Amps)
50
45
40
35
30
25
20
15
10
5
0
1000
900
800
700
600
500
400
300
200
100
0
1/31/16
5/1/16
7/31/16
10/30/16
1/30/17
5/1/17
7/31/17
10/30/17
1/30/18

Site Overall Electrical Conductance Based on Rectifier Output



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 during operations (8 locations, 2 depths, n=16) show 47% removal as of July 2017.
  - Site conductance data confirms chloride removal
  - EM Surveys inconclusive
- Poor electrode operations this summer contributed to lower rates. Removal after 1st summer was 41%, 1 ½ summers = 47%.
- Results for October 2017 pending

Chloride Soil Data

			4/19/2016			7/31/2017			Chloride
Hex	L	Depth	Chloride	pH	Cond	Chloride	pH	Cond	Reduction
		Anode	ppm	su	us/cm	ppm	su	us/cm	
15	1	3-4	7,310	7.5	17,600	4,040	7.7	10,300	45%
		7-8	9,700	7.2	21,400	6,370	7.1	25,000	34%
17	2	3-4	5,660	7.3	14,400	2,670	7.7	7,320	53%
		7-8	6,020	7.4	15,200	4,140	7.8	9,890	31%
5	4	3-4	5,300	7.4	12,600	4,540	7.5	9,840	14%
		7-8	6,300	7.2	14,600	4,240	7.2	8,350	33%
2	6	3-4	3,970	7.4	11,000	1,260	7.6	3,970	68%
		7-8	8,600	7.4	19,100	2,990	7.4	11,400	65%
8	8	3-4	3,200	7.6	9,170	2,850	7.6	7,160	11%
		7-8	8,560	7.6	18,800	2,820	7.2	5,990	67%
23	9	3-4	6,040	7.4	14,500	2,200	8.1	4,170	64%
		7-8	9,470	7.3	20,500	4,690	7.5	15,100	50%
		Cathode							
		Average	6,678	7.39	15,739	3,568	**7.5**	**9,874**	47%

191 days

Lessons Learned to Date

- Needed to upsize wellhead generator to handle jack pump and rectifier
- Low levels of chlorine gas generated at anode (expected)
- Choose materials and pump equipment wisely (better pump tubing)
- Improved electrode connections
- Water addition at anodes necessary during dry periods

For Consideration

- Low voltage, high current DC requirements begs solar power
- Alternate configurations can be used if groundwater gradients are in play

Conclusions

- EK desalinization is working at the demonstration site but more robust electrode connections are needed
- 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, Stealth Energy Group for site support