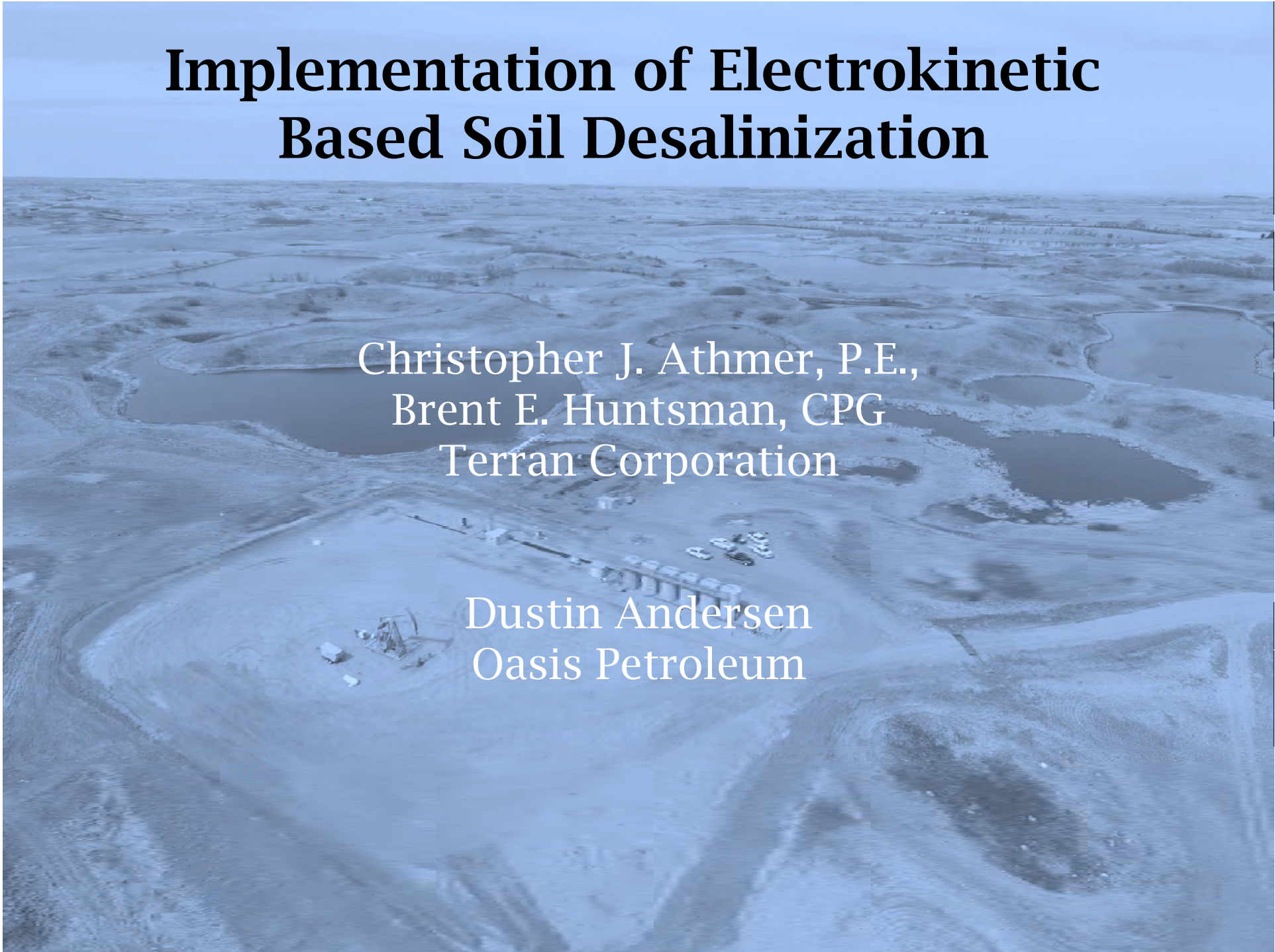


# Implementation of Electrokinetic Based Soil Desalinization

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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 ?

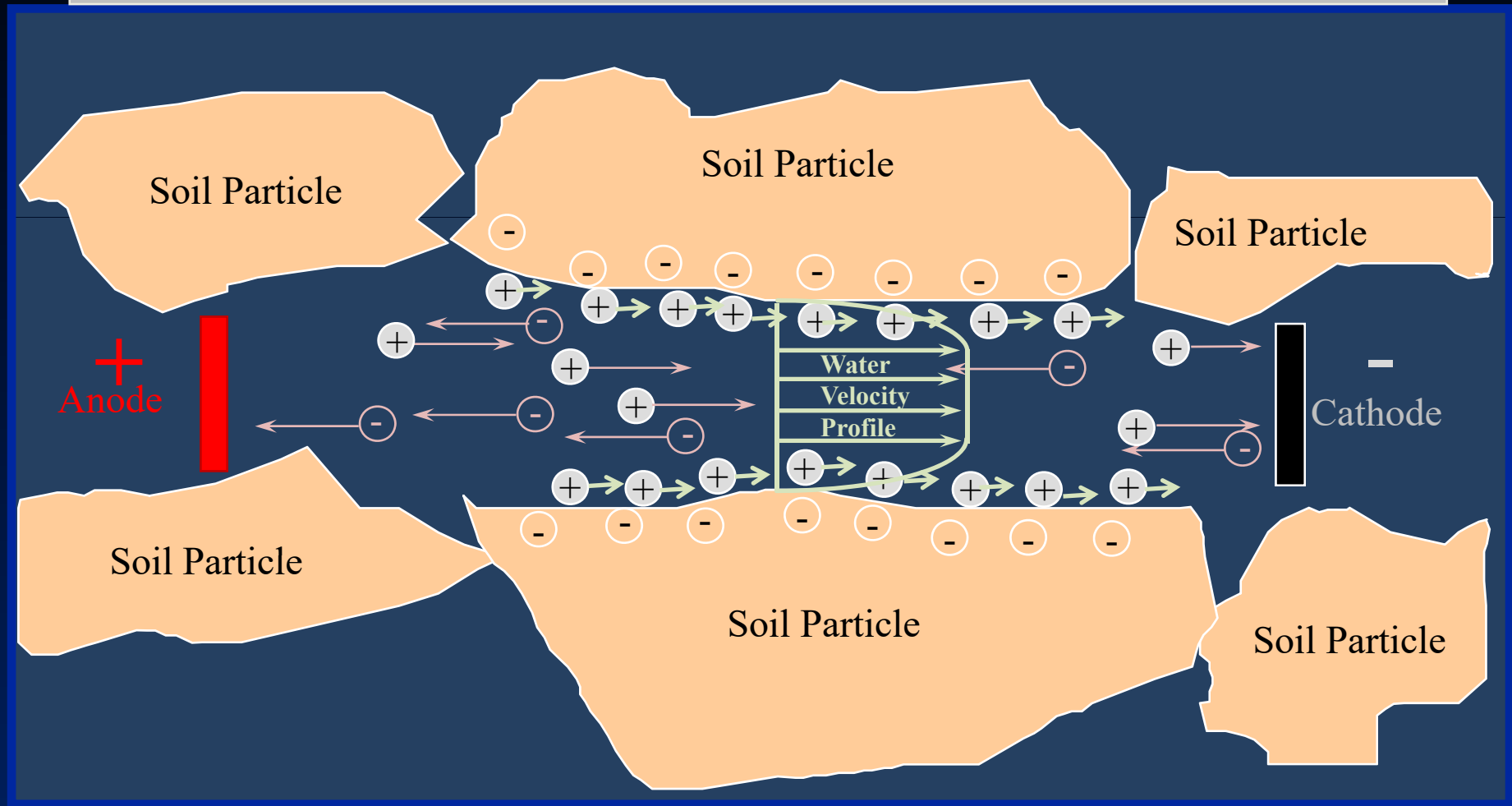
- Application of direct current (DC) electricity to the soil
- Polarized electrodes invoke movement of pore water and ions contained in the pore water, even in low permeability soils

# 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

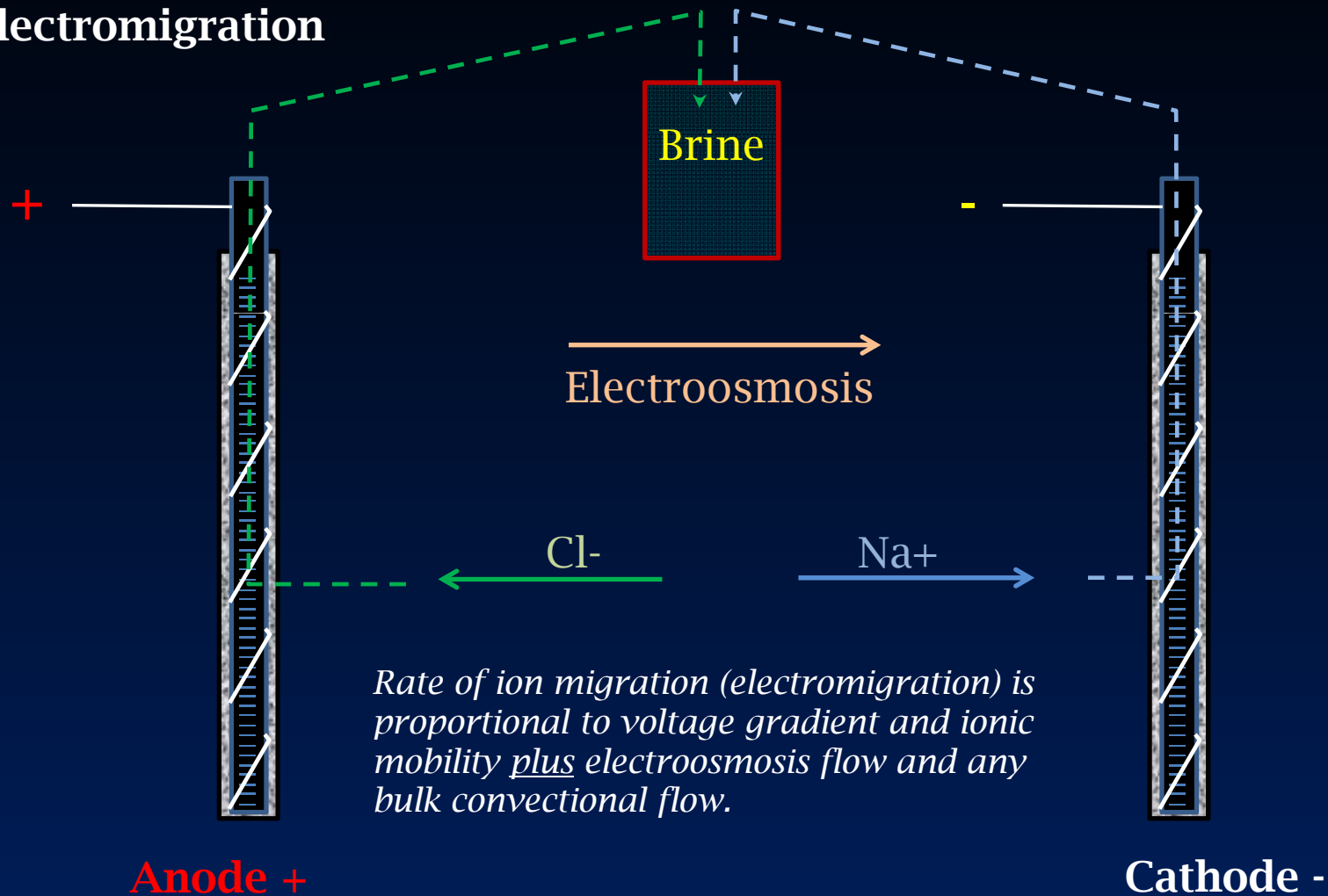
- Environmental Remediation
  - Heavy Metals (lead, chrome)
  - Organic Solvents (with in-situ ZVI)
  - Others (arsenic, nitrate, ISCO, bio-amendments)
- Dewatering/Stabilization
- Desalinization
  
- EK works in saturated & unsaturated zones

# How EK Desalination 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 chlorine
- The removed cathode and anode streams are combined as brine and disposed/injected or beneficially reused

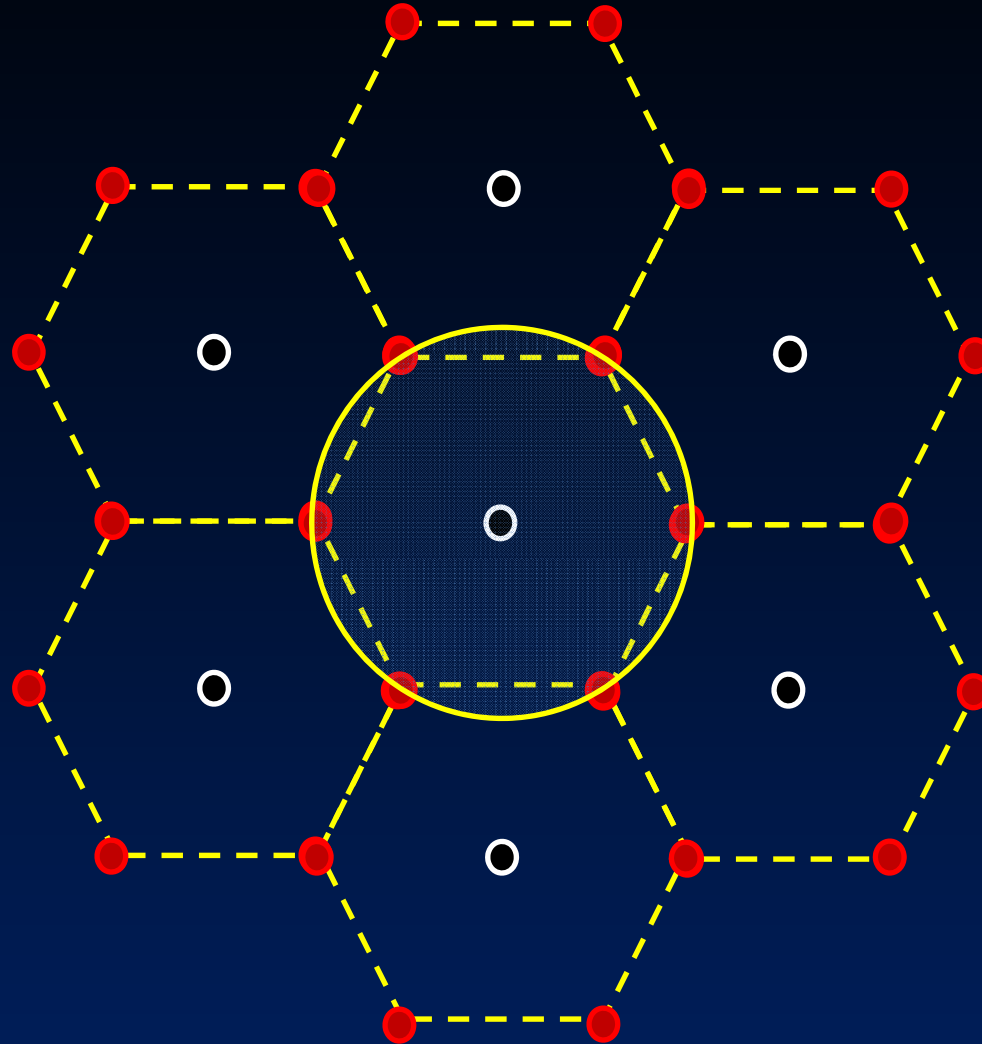
# EK Desalination Application

Electromigration





# Electrode Pattern

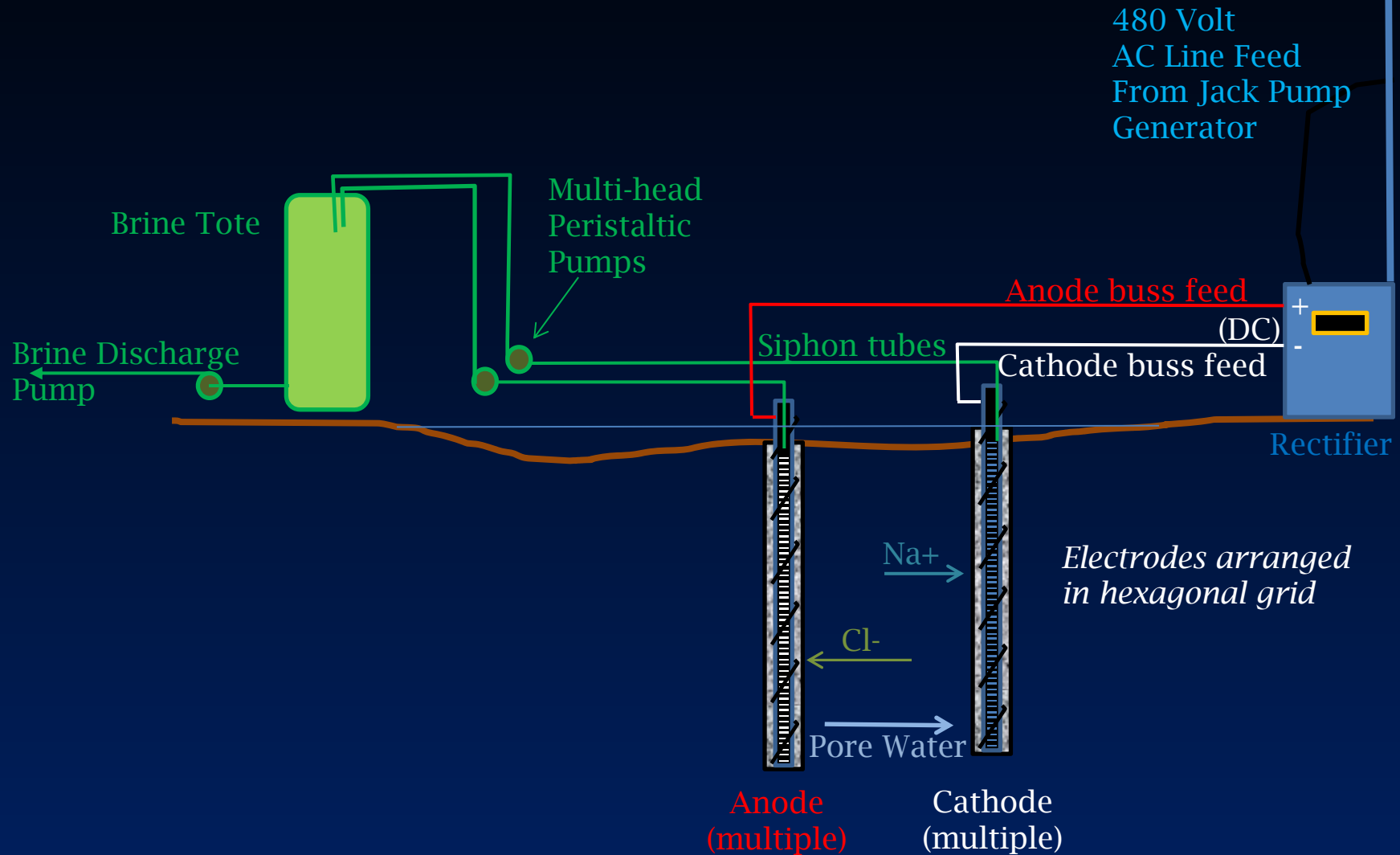


Model simulates removal from a cylinder with no flow boundary and central sink

# 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,  $\text{SO}_4$

~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)

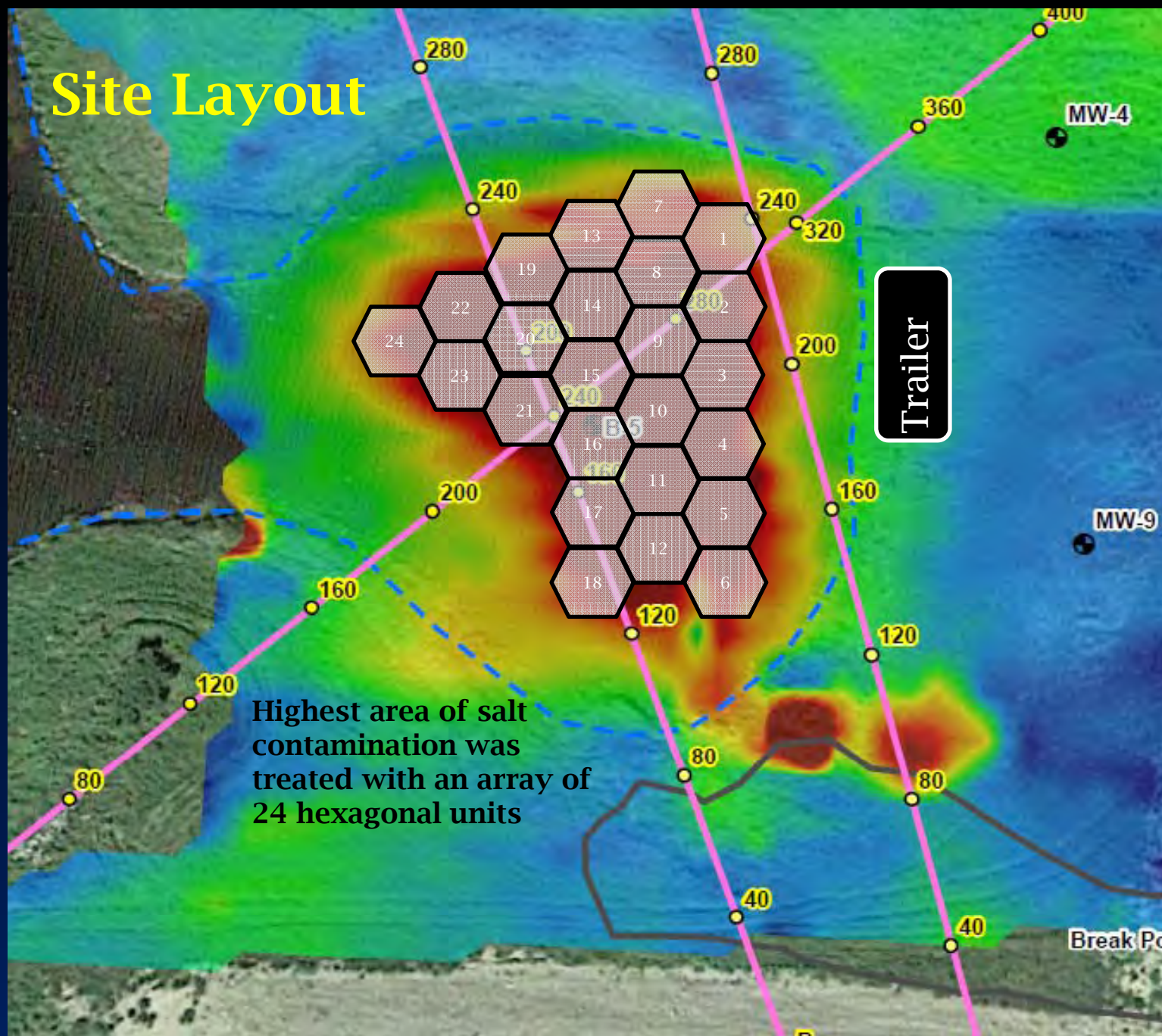




Area was covered with geofabric, geogrid, and cover rock to confine the contaminated soil and create a firm working surface. Surface materials will be removed at completion.



# Site Layout








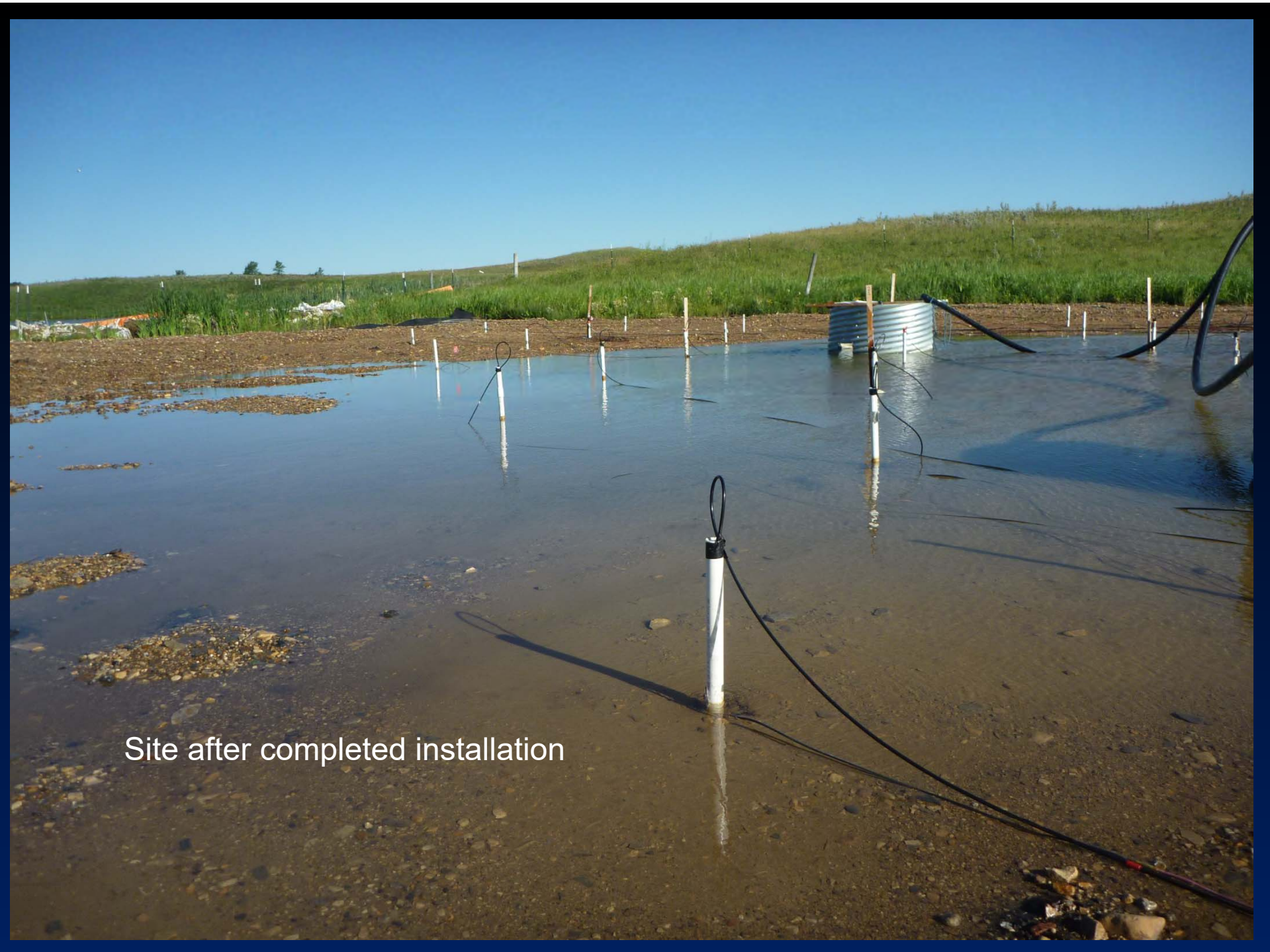
Installation was accomplished  
using a Geoprobe rig





Installing the EK system





Site after completed installation

# Operations To Date

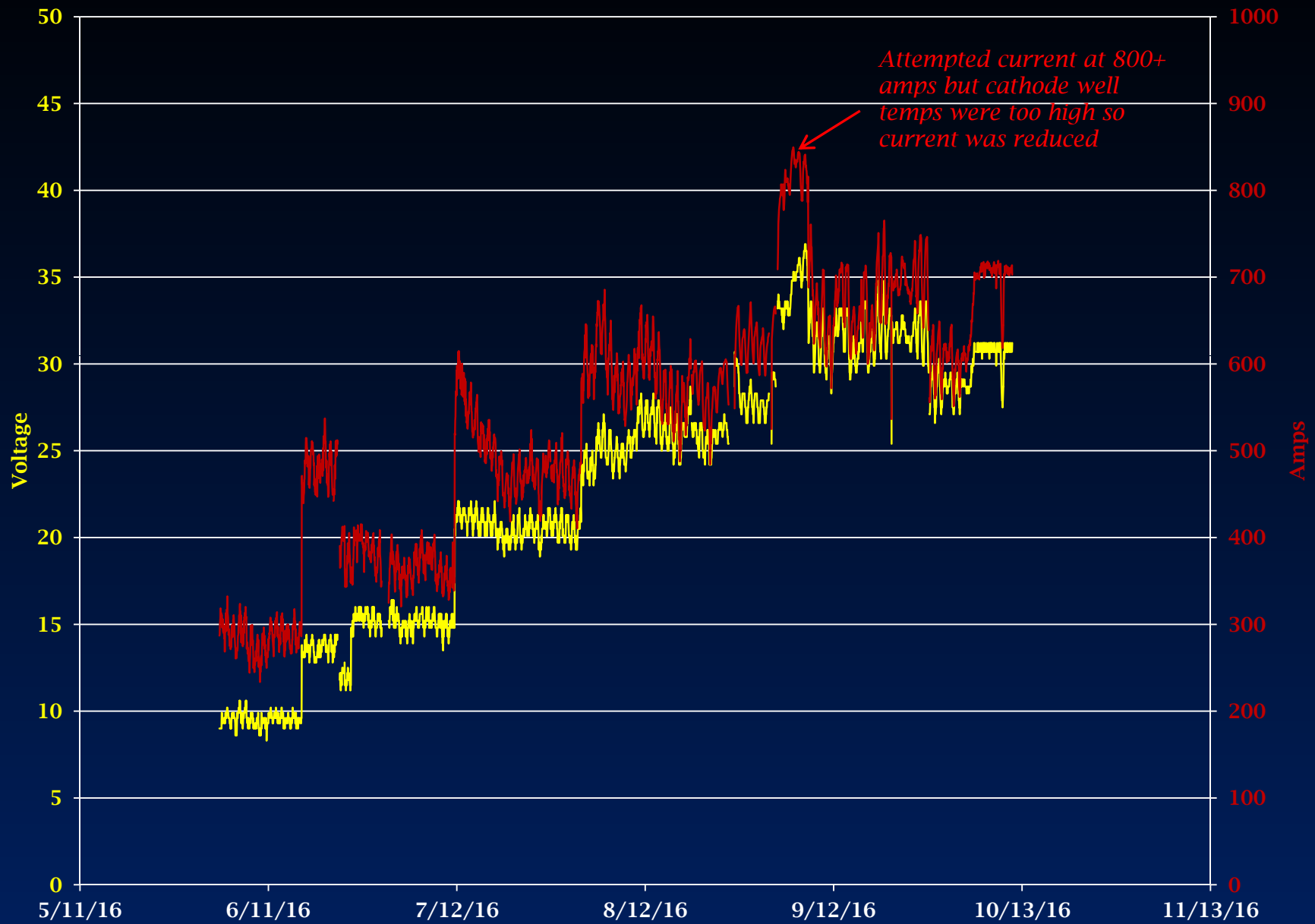
System began operations June 2, 2016

System shut down for winter October 13, 2016

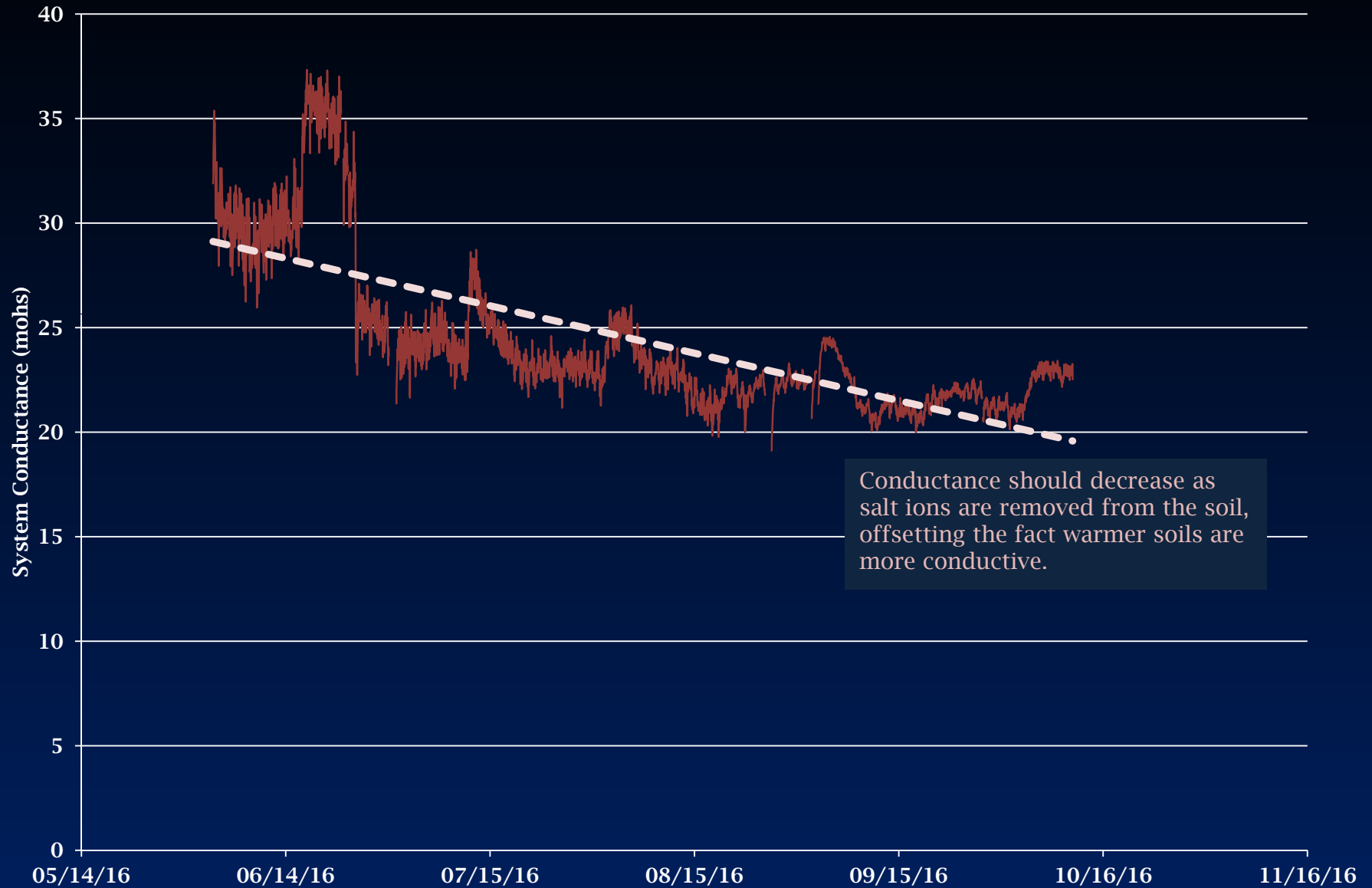




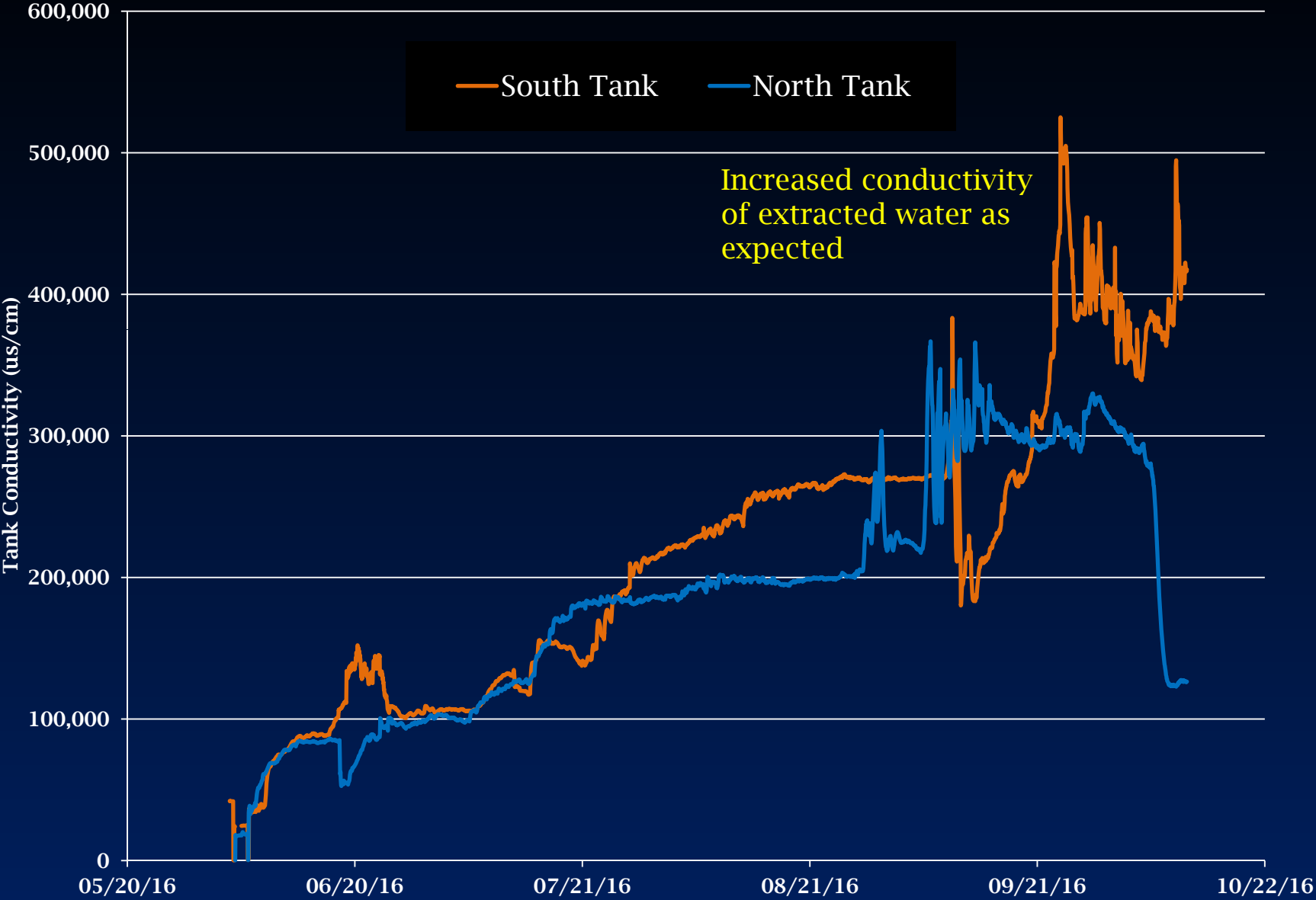
# Voltage and Current Trends over Time



## Site Overall Electrical Conductance Based on Rectifier Output

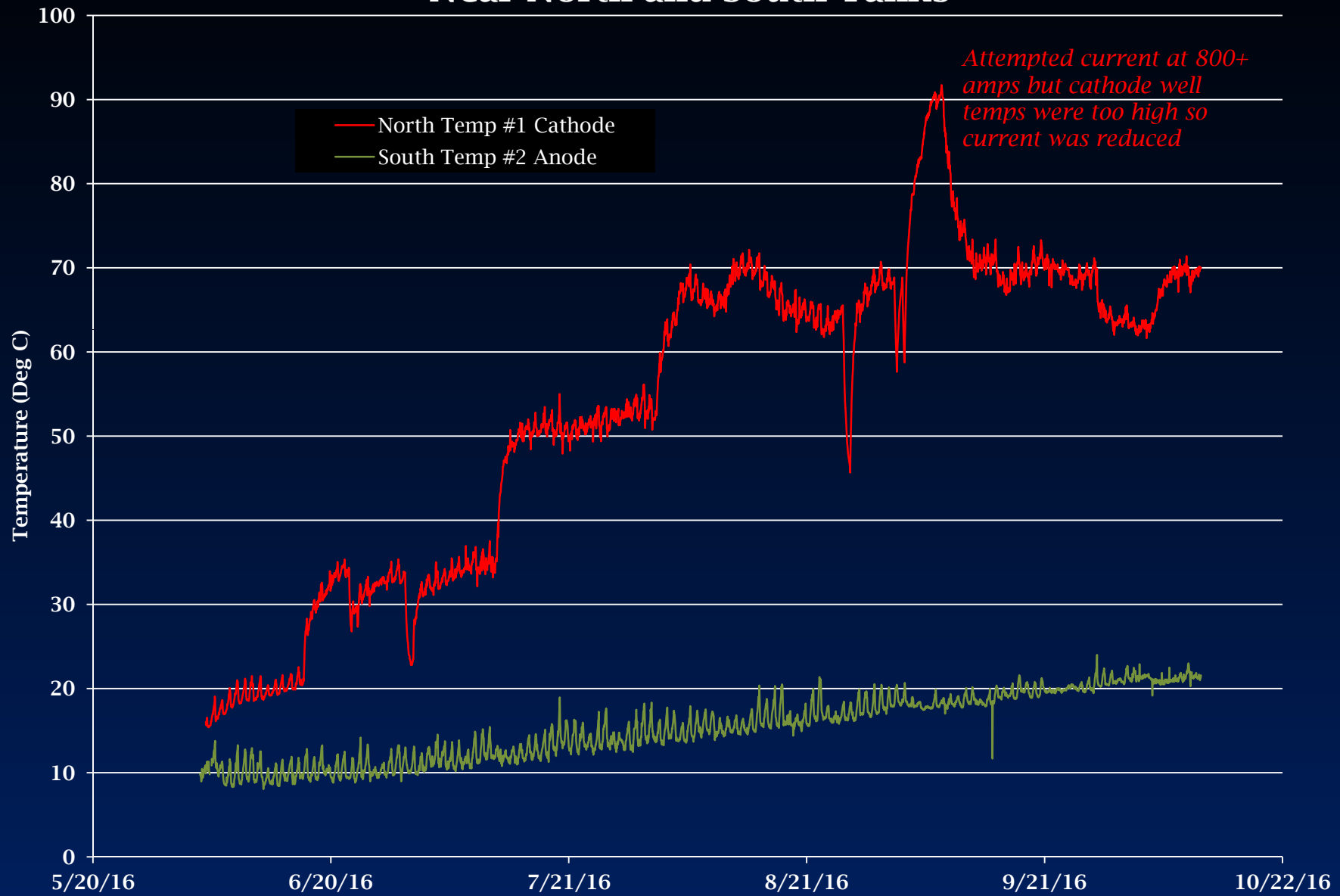


# Discharge Tanks Conductivity





# Field Temperatures Near North and South Tanks



# 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       |               |          |               | 9/20/2016       |               |          |               | Chloride<br>Reduction | Anode   |
|---------|---|-------|-----------------|---------------|----------|---------------|-----------------|---------------|----------|---------------|-----------------------|---------|
|         |   |       | Chloride<br>ppm | Sodium<br>ppm | pH<br>su | Cond<br>us/cm | Chloride<br>ppm | Sodium<br>ppm | pH<br>su | Cond<br>us/cm |                       |         |
| 15      | 1 | 3-4   | 7,310           | 3,250         | 7.5      | 17,600        | 4,400           | 1,590         | 7.77     | 12,900        | 40%                   | Cathode |
|         |   | 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%                   |         |
| 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