North Dakota Oil & Gas Research Program
Final Report

Recipient: Terran Corporation
Contract Number: G-045-087
Report for time period of: May 2021-November 2021

Description of Project

The objective of this project was to demonstrate the viability and cost effectiveness of using direct current (DC) power to reduce the sodium and chloride mass contamination in soil and groundwater from brine releases. Typical releases may be from leaking pipelines or storage pits. A secondary objective was to integrate electrokinetic (EK) remediation system with solar power. Since the EK process relies on DC power to induce migration of chloride and sodium ions (as well as other soluble ions) to emplaced electrode wells, solar panel arrays that generally provide 24-48 volts could prove to be the ideal power source at remote sites, or eventually any site.

Three small EK systems were installed locally to three contaminated groundwater monitoring wells, MW-3, MW-4 and MW-5 at the Schmitz well site operated by Oasis Petroleum. Each monitoring well pod consisted of 8-10 electrode wells powered by groups of solar panels with operating output of 32 volts. A cellular based data acquisition and control system was installed at the site for remote monitoring. Voltage, current, select temperatures and stilling well depth readings were recorded every 30 minutes.

Project Tasks

In mid April 2019, the solar panels were installed by Terran, Stealth Energy, OneCore and AET. Later in April, the electrical wiring was completed, as was the pump and tubing for the discharge collection system. The data system was installed and connected to allow remote monitoring. At startup in late April, a complete electrical current survey was completed. Results matched the modeled output satisfactorily. In mid May 2019, to increase available power to MW-3 pod, four additional solar panels were added to overcome a current limited condition and maintain the appropriate voltage. Additional thermocouples and a water level transducer were also added to the data system. The MW-4 and MW-5 clusters did not require extra panels.

During the summer, the system was operated continuously with no interruption in power provided by the solar arrays. There were issues early on with electrode well pump tubing being damaged by rodents along with leaking pump tubing and connectors. Those issues were resolved over time. The chloride-rich and sodium-rich electrode water extraction was first accomplished using multi-head peristaltic pumps powered by constant speed gear motors at 20-70 RPM. The fluid was withdrawn from each electrode well by way of siphon tube, through the peristaltic pump head, and into a storage tote for future disposal. The pumping was later converted to single head mini-peristaltic 12 volt DC pumps at each well.

The system was shut down every winter in early October and restarted at the end of April of the following year. The winter shut down was due to the impracticality of keeping everything from freezing during the cold North Dakota winters and the lack of solar incidence.

Deliverables

This biannual report is the <u>Final</u> deliverable for this project. The system began operation on April 25, 2019 and was shut down on October 1, 2019 for the first winter. The system was restarted for the second season April 27, 2020 and operated through September 29, 2020. For the 2021 season, the system was restarted April 28 and shut down October 29, 2021.

Remarks

The EK system was shut down each winter due to water management issues and severely reduced solar power availability. Due to the well pad being de-energized for well pump removal, the data system shut down for an extended period over the winter (November 2020 through April 2021) and then again after August 17, 2021. Therefore the data system was not collecting data during that time even though the solar panels were still energizing the soil until the end of October. Figure 1 shows the daily average voltage for the Schmitz well site MW-3 cluster. The 24-hr average voltage during the summer months was around 10 to 12 volts. The instantaneous voltage can reach as high as 40 volts. A typical sunny afternoon in July would produce about 85 amps at 32 volts DC, per cluster. In contrast, during the dead of winter, a sunny day would produce only about 55 amps at 22 volts (when not covered with snow).

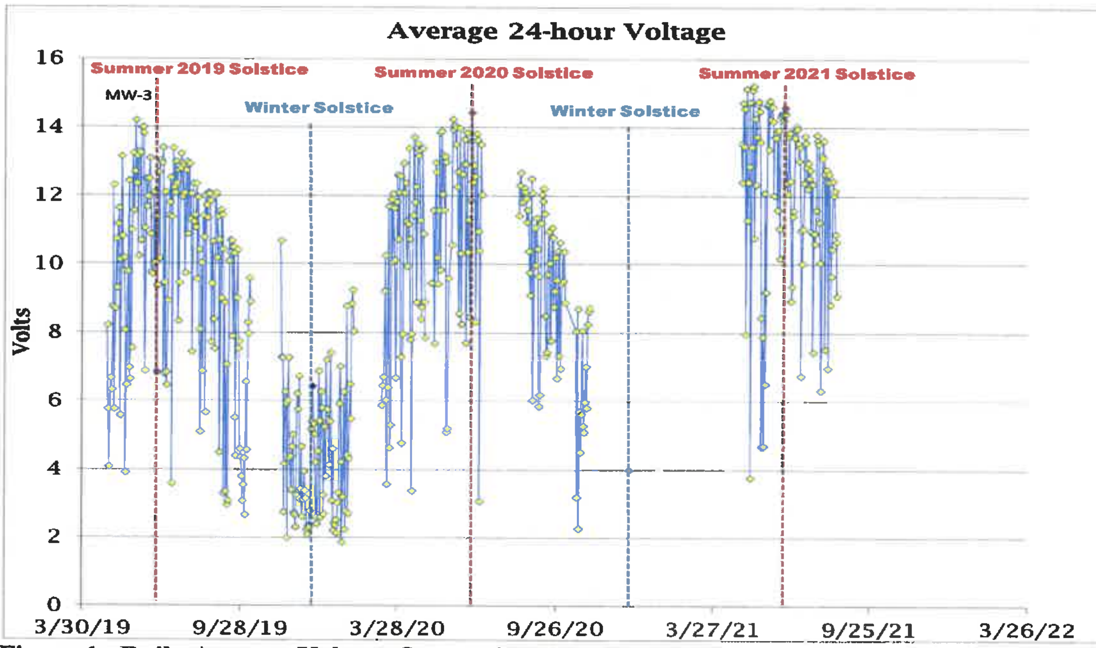

Figure 1. Daily Average Voltage Output for MW-3 Cluster.

Several times during each season, a current survey was performed to determine the electrical current load balance and health of each electrode. In each area, MW-3, MW-4 and MW-5, the total anodes current reading should balance with the total cathode current readings. Slight differences in the totals are due to varying solar penetration (clouds) during measurements and basic measurement errors with the DC clamp current probe. Table 1 shows an example current survey for September 2020.

MW3	Electrode	Current (A)	MW4	Electrode	Current (A)	MW5	Electrode	Current (A)
9/17/20		A=Anode / C=Cathode						
A	3-0	9.98	A	4-0	5.07	A	5-0	7.82
A	3-1	10.54	A	4-1	7.87	A	5-1	9.33
A	3-2	12.91	C	4-2	13.83	A	5-2	7.34
C	3-3	15.42	C	4-3	10.41	C	5-3	15.59
C	3-4	12.64	C	4-4	10.81	C	5-4	17.47
C	3-5	19.51	A	4-5	5.98	C	5-5	9.3
C	3-6	17.57	A	4-6	7.08	A	5-6	11.52
A	3-7	8.95	A	4-7	4.5	A	5-7	6.68
A	3-8	7.34	A	4-8	5.11			
A	3-9	13.08						
	Total Anodes	62.8			35.6			42.7
	Total Cathodes	65.1			35.1			42.4

Table 1. Individual Current Readings at Each Electrode.

Based on the previous year recovery rates and early spring samples showing high concentrations of chloride around the electrodes (see previous report), it was decided to increase the pumping rates by using larger peristaltic pump heads. Cole-Parmer standard L/S pump heads (laboratory standard for peristaltic pumps) were ordered and installed at the site to replace the microtubing pump head cartridges used during the first two summers. The recovery rates were increased about 10 fold. However, there were many issues with tubing and pump heads with grit and corrosion. By mid-summer, the decision was made to make new pumps that were less costly than the Cole-Parmer heads and easier to operate. Two styles of educters and three types of 12 volt pumps were evaluated. Based on lab evaluations, several inexpensive 12-volt peristaltic pumps were purchased from Amazon, fitted with Santoprene tubing (off the shelf at McMaster-Carr) and tested in the lab for three weeks pumping a bleach solution with no issues. Thirty more of the pumps were made and installed at the site. The pumps were attached at the top of each electrode well. The 110 volt AC lines and relays were converted to 12-volt DC lines from a common power supply.

Sometime in early August 2021, line power was shut down at the Schmitz well pad causing loss of power to the data system and pump power supply. This upset the pumping strategy for the rest of the summer. The electrodes were still powered by the solar panels through the late summer and fall. However, the well pumping was reduced to weekly using a car battery as the power source. The data system continued recording data through August 18th, operating on its own backup battery. There was no field recorded data after the data system went dead in August. Efforts to return power to the site were unsuccessful.

The groundwater samples from MW-3, MW-4 and MW-5 continue to show a reduced chloride concentration since the start of the project in 2018. All 3 monitoring wells chloride concentration are approximately 1/3 of the 2018 concentrations and leveling off as shown in Figure 2.

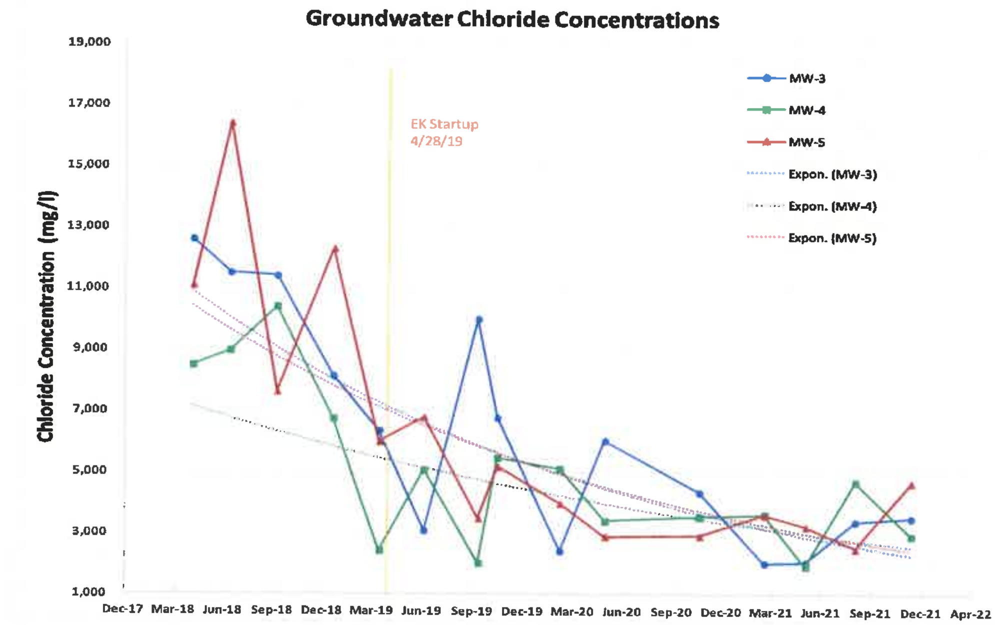

Figure 2. Groundwater Chloride Trends for MW-3, MW-4 and MW-5.

The primary issue for this last season was the line power cut to the site. This resulted in the inability to pump more water from the electrode wells to remove the chloride (at anode) and sodium (from cathode) from the saturated zone. The goal for last summer was to pump 10 times the water volume out of the electrodes compared to previous seasons.

During the summer of 2020, 1135 gallons were pumped from the electrode wells. In 2021, 2965 gallons were removed; or 2.6 times more than the previous year. Based on the results presented below, it is obvious more pumping was needed.

In November 2021, soon after shut-down, select EK wells were sampled. Table 2 shows the ionic concentrations from those select electrodes in samples from November 2020 and November 2021. There was little change in the chloride and sodium concentrations except for the chloride in the MW-3 area well #1 anode where the chloride concentration was half the concentration of the previous year. Note that the MW-4 samples were quite high. This was due to the low water levels in that area precluded effective pumping. Less water was pumped from that area this summer compared to MW-3 and MW-5 areas.

SampleID	Sampled	pH	Total Alkalinity (as CaCO3)	Silica as SiO2	Bicarbonate as HCO3	Carbonate as CO3	Chloride	Nitrate-Nitrite Nitrogen (as N)	Sulfate	Calcium	Magnesium	Potassium	Sodium	Cation Sum	Anion Sum	Cation-Anion Balance	Disolved Al	Dissolved Phosphorus
		s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	meq/L	%	mg/L	mg/L
Area 3-Well 4 (Cathode)	11/16/20	12.0	52,100	91.5	<5	700	111.0	<0.1	404	20	2	1,670	25,900	1,170	1,055	5.2	7.0	1.3
	11/22/21	11.3	92,900	122.0	<5	1,940	8.7	<0.1	<9.9	<1	<1	2,880	37,700	1,713	1,860	4.1		2.3
Area 4-Well 3 (Cathode)	11/16/20	11.4	149,000	401.0	<5	4,660	2.0	<0.1	39	80	13	5,490	70,900	3,229	2,988	3.9	18.5	5.6
	11/22/21	10.9	150,000	466.0	<5	4,700	<8.69	<0.1	<9.9	<1	<1	5,330	72,700	3,299	3,003	4.7		10.3
Area 5-Well 4 (Cathode)	11/16/20	12.0	38,400	289.0	<5	1,160	720.0	2.0	1,030	42	3	364	12,500	556	815	18.9	3.4	3.5
	11/22/21	11.2	80,000	349.0	<5	2,060	130.0	<0.1	<9.9	5	1	997	33,400	1,480	1,610	4.2		4.2
							194.3						42,183.3					
Area 3-Well 1 (Anode)	11/16/20	1.4	<5	140.0	<5	<5	13,600.0	29.1	5,570	643	573	43	1,220	134	503	58	169.0	19.5
	11/22/21	1.3	<5	77.7	<5	<5	6,260.0	14.9	5,190	367	316	30	1,400	106	314	50		4.8
Area 4-Well 1 (Anode)	11/16/20	0.9	<5	159.0	<5	<5	35,500.0	1,060.0	5,360	3,350	2,060	46	828	374	1,192	52	259.0	44.0
	11/22/21	0.7	<5	125.0	<5	<5	34,200.0	515.0	2,660	6,180	3,210	33	825	610	1,058	27		47.3
Area 5-Well 6 (Anode)	11/16/20	1.4	<5	82.0	<5	<5	19,600.0	52.4	4,660	1,250	572	163	2,130	206	655	52	85.9	12.9
	11/22/21	1.2	<5	90.6	<5	<5	14,500.0	12.3	3,800	1,190	666	61	1,620	186	490	45		19.9
Milligrams per liter = mg/L							20,610.0						1,337.2					
Milliequivalent per liter = meq/L																		
All samples are groundwater																		

Table 2. Select Anode and Cathode Year-end Well Analysis.

Looking Forward

The system was effectively shut down October 25 by the removal of the 12-volt pumps and data system for the winter. The solar panels remain in place for possible continued operations next year. We anticipate moving some of the wells to known higher concentration chloride areas adjacent to the presently treated areas. Based on the knowledge gained at the site thus far, the new wells will be 2-inch diameter instead of 1-inch for better electrode well maintenance. The data system and pump power will be provided by solar panels during peak sunshine times when extra power is available. Depending on the size and conductivity of the new treatment areas, additional solar panels may be needed to supply the date system and pumps.

Conclusions

The solar powered pilot was a moderate success. Based on the chloride concentrations at the anode wells and the chloride removed in the purge water shows the potential of this process. The solar panels worked well and were nearly maintenance free. The primary issues at this site was the loss of line power for the pumps and data system as well as finding a reliable micro pump for field applications and corrosive fluids. Increased water pumping from the electrode wells is needed to better remove the chloride attracted to the anode wells. There were also minor issues with rodents damaging the instrument lines periodically. Operating the system totally solar powered and 12 volt individual peristaltic pumps will make the system more reliable and require much less maintenance.

Expenditures
Below is a breakdown of expenditures. Supporting documentation is included as a separate attachment.

EXPENDITURES FOR THIS REPORTING PERIOD ONLY				
Project Expense	**NDIC**	**REP Recipient**	**Other Sponsor**	**Total**
Terran Labor	$10,191.00			
Terran Equipment	$4,759.77			
Overhead (14.65%)	$697.31			
Oasis Labor				
Oasis Direct Expense		$27,134.45		
Total	$15,648.08	$27,134.45		$42,129.22

CUMULATIVE EXPENDITURES				
Project Expense	**NDIC**	**REP Recipient**	**Other Sponsor**	**Total**
Terran Labor	$69,427.00			
Terran Equipment	$70,244.79			
Overhead (14.65%)	$10,290.86 *			
Oasis Labor				
Oasis Direct Expense		$204,543.98		
Total	$149,962.65	$204,543.98		$354,506.63

*Includes previously unbilled overhead $9593.55 (approved budget modification).

Terran labor costs for this period (Thru November 2021)

Employee	Rate	Hours	Cost	Task
C.J. Athmer	$129.00	12.0	$ 1,548.00	Project Management
C.J. Athmer	$129.00	43.0	$ 5,547.00	Project Management
C.J. Athmer	$129.00	24.0	$ 3,096.00	Project Management
			$10,191.00	

Terran equipment, materials and supplies for this period (Thru November 2021)

Item	**Cost**
Home Depot (machine screws, threaded rods)	$ 12.47
McMaster-Carr (couplings, AC gearmotor)	$ 452.09
Cole-Parmer (pump head, tubing)	$ 3,121.09
McMaster-Carr (AC gearmotors, fittings)	$ 310.27
US Plastic Corp (tubing)	$ 138.68
McMaster-Carr (tube fitting)	$ 43.73
Verizon Wireless (cellular communications) – May 2021	$ 20.53
UPS	$ 54.20
McMaster-Carr (water aspirator pump)	$ 78.72
Verizon Wireless (cellular communications) – June 2021	$ 20.53
Fox Valve Development (mini eductor)	$ 270.00
Amazon (relay switch, plastic connectors, wood screws)	$ 120.93
Lowe's	$ 66.44
UPS	$ 29.56
Verizon Wireless (cellular communications) – July 2021	$ 20.53
	$4,759.77

Oasis Costs for this Period (Thru November 2021)

Contractor	Cost	Task
Habitat Management	$11,700.00	Soil/water modeling
Pace Analytical	$303.00	Water analysis
Pace Analytical	$108.00	Water analysis
Pace Analytical	$288.00	Water analysis
Pace Analytical	$216.00	Water analysis
Pace Analytical	$288.00	Water analysis
OneCor Services	$1,084.09	Water sampling at site
Terran Corporation	$5,198.32	Parts & labor for new pumps
AET	$7,949.04	Installation of new wells
	$27,134.45	