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Effluent Treatment: Pre-treatment Train Integrated with Electrodialysis for Use in Electrokinetic Remediation

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Abstract

Salt impacted soil and groundwater generated from produced water spills, persistently plague the oil and gas industry. Traditionally remediation of salt impacted fine-grained soils has been dealt with through "digging and dumping" which essentially transfers the problem to another location. Saline impacted groundwater is conventionally remediated by extracting contaminated water through recovery wells, followed by deep well injection disposal or storage in retention ponds. While both of these conventional methods provide a solution in the short term they are not sustainable practices in the long term.

The purpose of this pilot project was to explore short and long term sustainable soil and groundwater remediation by employing a proprietary and innovative combination of geophysics (electromagnetic and resistivity imaging), in-situ electrokinetics for soils and groundwater remediation, and addressing effluent treatment by electrodialysis for reuse. In-situ soil and groundwater remediation using electrokinetics was demonstrated at the bench and pilot scales. Based on positive results an appropriate pre-treatment train for the clean up of highly contaminated effluent waters was developed in order to demonstrate potentially comprehensive sustainable remediation solutions for salt impacted sites.

Introduction

Pioneer Professional Services Group and Shell Canada Ltd collaborated with Ground Effects Environmental, Volker-Stevin Contracting Ltd (VSC) and Southern Alberta Institute of Technology (SAIT – Applied Research and Innovation Services (ARIS)) through the National Research Council's Industry Research Assistance Program (NRC-IRAP) to remediate soil and groundwater with elevated salinity at a former oil battery site in Alberta. Bench and pilot scale studies of Ground Effect's advanced electrokinetic remediation (EK3) in-situ technology were conducted on the saline impacted soils and groundwater. Pre-treatment and desalination by electrodialysis (ED) was chosen to treat the salt impacted effluent from the EK3 system. These effluent water treatment systems were provided by VSC and SAIT. The goal of the project was to develop an in-situ sustainable remedial process for salt impacted sites with a view to reduce the need for ex-situ land filling and water disposal.

The pilot project involved an innovative and unique combination of geophysics (electromagnetic and resistivity imaging), electrokinetics (soil and groundwater remediation), and electrodialysis (effluent water treatment) technologies. The anticipated advantages gained by implementing electrokinetic remediation with electrodialysis for the effluent water treatment include: minimal ground disturbance, elimination of soil excavation and landfilling, elimination of groundwater disposal, treatment of effluent for beneficial reuse and in-situ clean-up of salt impacted soil and groundwater.

The objectives of the project were to:

- Determine site contamination via geophysical (electromagnetic and resistivity imaging).
- Demonstrate the viability of electrokinetics for soil and groundwater remediation of salt impacted sites
- Examine potential impacts to the condition of soils and groundwater as a result of electrokinetics.
- Determine appropriate water treatment train for the highly contaminated effluent water and establish whether treating the EK3 effluent was a problem or opportunity.

Background

Technology Descriptions

Electrokinetic remediation is accomplished by placing electrodes in salinity impacted soil and/or groundwater and applying direct current across electrodes. The basic process of electrokinetics includes: imposing an electrical field on the volume of contaminated soils; migration of charged ions and cations under the influence of the electrical field; anions and cations migrate to the respective opposite electrodes; flushing the vadose zone (unsaturated soils in the subsurface) with clean water; and extracting contaminated groundwater (effluent) from the electrodes for potential disposal or exsitu treatment (above ground treatment of effluent water). Figure 1 illustrates a cross-section of an electrode setup beneath the ground surface.

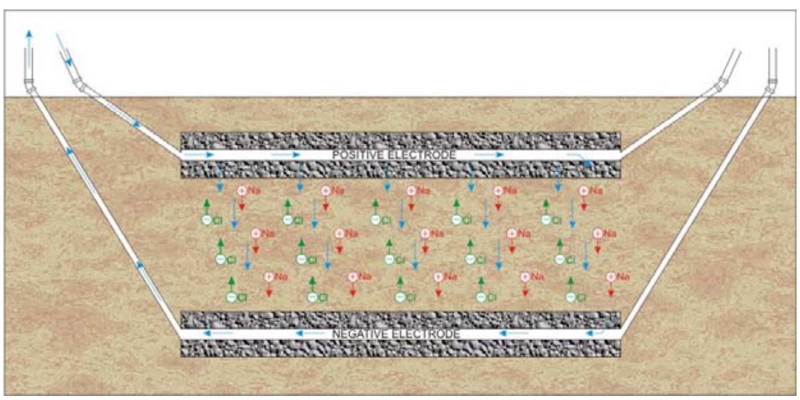


Figure 1: Electrokinetics Electrode Cross-section

Electrodialysis selectively transports positively and negatively charged dissolved ions respectively through ion selective electro membranes under the influence of an electrical potential gradient. The positively and negatively charged ions separate from the feed water to form a brine stream (waste effluent) and a de-mineralized product water stream (clean effluent). Figure 2 provides a schematic of an electrodialysis system.

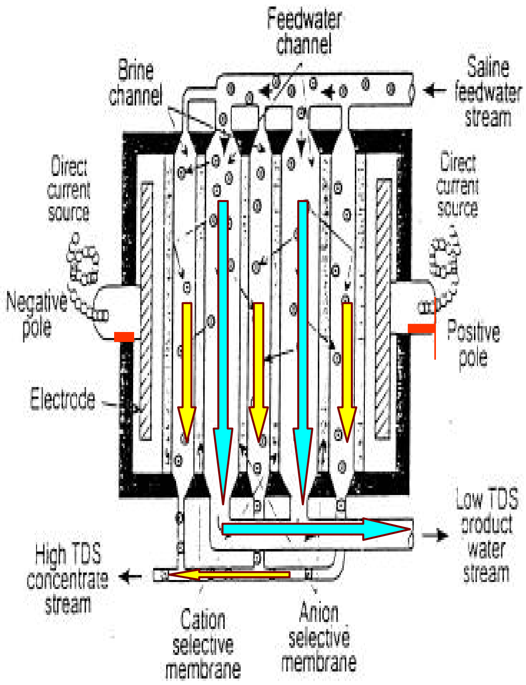


Figure 2: Electrodialysis ***Adapted*** **(Buros, 1990)**

Geophysical investigation methods used for monitoring purposes included electromagnetic (EM31) and electrical resistivity tomography (ERT). EM31 scanning provides 2-D horizontal image of the bulk surface electrical conductivity from surface to approximately 6 m below the ground surface. ERT provides 2-D vertical image of the conductance of subsurface materials. Examples of EM and ERT results are shown in Figures 3 and 4, respectively.

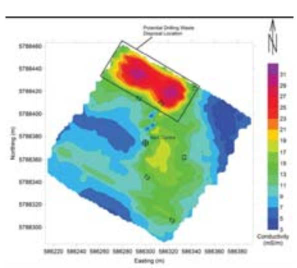


Figure 3: Example EM Scan

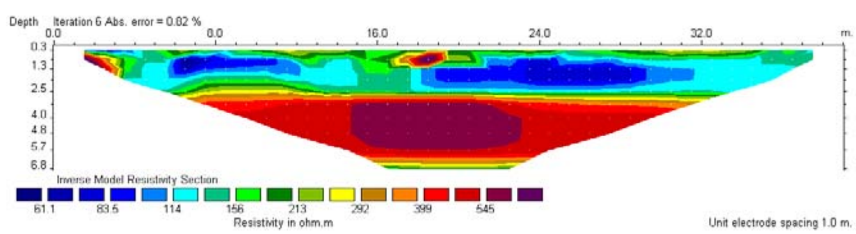


Figure 4: Example ERT Scan

Site Description

The selected site for this test is represented by a former tank farm and former pit/spill area resulted in salinity and metal impacted soils and groundwater at a former battery site near Leduc, Alberta. The site is located on agricultural land. Soils assessed in the area of the pit/spill consisted of silty clay till with sand and gravel lenses, with some cobbles, underlain by fine-grained sandstones or siltstone. Approximately 20,000 m^3 of soil, prior to the pilot, was impacted from surface down to 5 m below grade. The most concentrated impacts occurred at 0.5 to 2.5 m below grade in the spill area. Soils had electrical conductivity (EC), sodium absorption ratio (SAR), calcium, sodium, chloride and boron values/concentrations exceeding applicable guidelines.

The groundwater on the lease is encountered between 1.2 and 2.3 m below grade and has an estimated hydraulic conductivity varying between 1.6 E-8 and 1.9 E-6 m/s, which is indicative of fine-grained soils. Groundwater had elevated EC, pH, sodium, chloride, total dissolved solids (TDS), barium, cadmium, chromium, lead, sulphates, nitrite and nitrate values/concentrations.

Project Phases

Baseline Assessment Activities

Baseline assessment activities are required to establish existing conditions of soils and groundwater prior to conducting remediation activities. Assessment activities included:

- Conducting geophysical scans (EM31 and ERT);
- Testing soils and groundwater for routine water chemistry, salinity, pH, metal and/or heterotrophic microbe parameters; and
- Monitoring groundwater levels and conducting hydraulic conductivity testing.

In June 2006 Pioneer conducted an EM scan of the site to identify the terrain conductivity of the subsurface prior to conducting remediation activities. An isolated "finger" of the plume identified by the EM31 survey was chosen as the pilot study area. Figure 5 shows the baseline EM scan of the site and the area chosen for the pilot study.

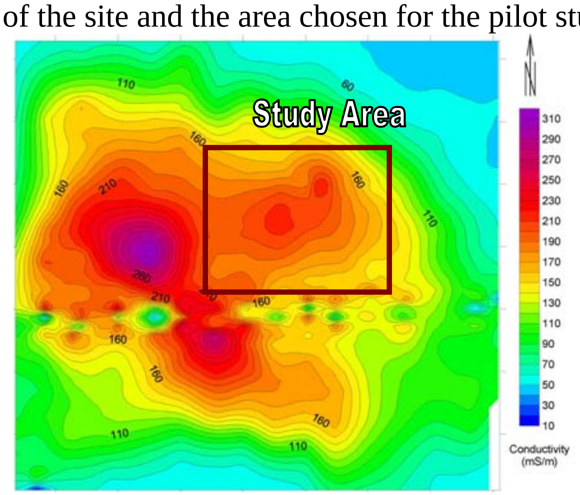


Figure 5: Baseline EM Scan

Soil samples were collected at regular 0.3 m intervals beginning with topsoil. Additional soil samples were also collected at depths that corresponded to the depth of the electrode placements within the unsaturated (0.9 m below grade) and saturated (3.0 m below grade) zones. The baseline soil analytical results were compared to the results obtained after the system was shut down.

Groundwater was monitored and sampled prior to the start-up of the system to establish baseline groundwater conditions. The baseline groundwater results were used for comparison of results obtained during and after the operation of the system. This was done to establish trends in groundwater conditions in relation to electrokinetics operation.

Bench Scale Study

On June 6, 2006 approximately 2 m^3 of soil was obtained from the pilot study area. The soil was placed in a soil tote and shipped to Regina, Saskatchewan for bench scale testing at the Ground Effects laboratory. The bench scale tests consisted of applying different voltages and amperages using a step approach to determine the rate of movement of water and ions in the soil. The processes involved in the design of the bench scale were adjusted to determine the best efficiency of contaminant migration. The soil conditions and contaminant concentrations were also examined to test the effectiveness of the electrode design. The results of the bench scale indicated that salinity in the soils can move under the influence of the electrokinetics and salinity concentrations declined to promising levels. H_2S and chlorine gas were not detected during the bench or pilot scale tests. Based on positive results of the bench scale tests, the project moved ahead to a pilot scale remediation study. Similarly the effluent water collected during the bench scale testing was tested for routine water, salinity and total hardness parameters at VSC-SAIT. The bench scale pretreatment study involved developing both standard and custom precipitation sequences. The results of the bench scale studies were used to optimize the pilot scale study.

Installation and Operation of Pilot Scale EK3 System

The pilot scale system operated for two months from August 28 to November 7, 2006. Ground Effects installed the pilot system components. The system components installed included, 2” diameter and 18.3 m long electrodes. The three sets of electrodes, each containing a positive and negative electrode, were horizontally drilled into the soils. The electrodes were placed at the top and bottom of the encountered salinity contamination and spaced 3 meters horizontally. Groundwater was extracted at the electrodes and stored in tanks onsite until it could be hauled offsite for disposal or treatment. The system was remotely monitored using a telemetric setup.

Groundwater and EK3 Effluent Sampling

During the operation of the system groundwater was monitored and sampled on a regular basis to check system performance and to establish trends in pH, salinity and dissolved metal parameters. During the monitoring and sampling events, Pioneer monitored liquid levels and combustible vapour readings on all eight wells and collected samples to test for dissolved metals and routine parameters. Select samples were submitted to a laboratory for testing of vinyl chloride and trihalomethanes concentration in the groundwater samples. Water samples were also collected from the effluent water extracted from the electrodes by Ground Effects. These samples were tested for routine water parameters. The electrokinetics system was remotely monitored using a telemetric system for pH and temperature parameters.

Post Treatment Soil and Groundwater Testing / EM Scans

The pilot scale system was shut down in the winter of November 2007 and a post treatment soil and groundwater sampling occurred in December 2007. The soil samples collected were at approximately the same locations and depths as the baseline testing conducted in June, 2006. Select soil samples were analyzed for metal, pH, salinity and heterotrophic bacteria counts. Soil samples were collected above and below the encountered groundwater level. Groundwater was monitored for liquid levels and combustible vapour readings. Groundwater samples were collected for testing of dissolved metals, and routine parameters. Post treatment EM and ERT scans were also conducted in the spring of 2007 to establish conductivity changes.

Effluent Water Treatment

The characteristics of the EK3 effluent water, exhibited extreme total water hardness with elevated salt contamination as follows:

- Electrical Conductivity (EC) up to 26,000 uS/cm;
- Chloride up to 12,000 mg/L;
- Total Hardness ranging from 10,000 mg/L to 25,000 mg/L;
- Total Dissolved Solids (TDS) up to 20,000 ppm; and
- Dissolved metals and trace hydrocarbons.

A multi-stage pretreatment train was critical for the pretreatment of EK3 effluent water prior to desalination by any method namely thermal distillation (boilers), nano-filtration, reverse osmosis or electrodialysis. The pretreatment train helped reduce or eliminate a wide range of water borne multi-contaminants, including elevated water hardness. The demonstration of this patent pending multistage pre-treatment train integrated with EK3 and ED technologies provides industry with the knowledge that effluent waters can be treated (on-site) for recycle and reuse. This hybrid integration of advanced technologies is expected to reduce the requirement for hauling fresh water onsite for EK3 processes and demonstrates remediation processes that are environmentally sustainable.

The objectives of the effluent water treatment portion of the project were to:

- Determine requirements for the electrokinetic effluent pre-treatment train and conduct pre-treatment;
- Conduct desalination using electrodialysis; and
- Reuse treated water in EK3 remediation processes (flushing electrodes).

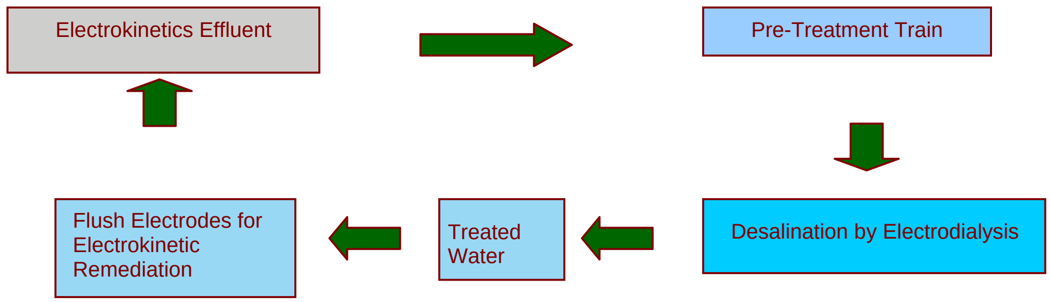


Figure 6: Effluent Water Treatment Process Flow Diagram

Figure 6 shows the process flow diagram to treat and reuse the effluent water in the EK3 processes.

The key components of the effluent pre-treatment train are illustrated in Figure 7. The initial step in pre-treatment of the effluent water consists of filtering total suspended solids (TSS). Any trace hydrocarbons present are then removed from the effluent water using activated carbon. Total Hardness is removed using a two stage softening process consisting of chemical precipitation followed by ion exchange. The chemical precipitation can reduce the hardness in the effluent water to less than 100 ppm. Softening by ion exchange, using weak acid cation resins, can reduce the hardness to less than 10 ppm as in $CaCO_3$. Thermal desalination processes require stringent total hardness reduction of less than 1 ppm as in $CaCO_3$ while nanofiltration, reverse osmosis or electrodialysis can be operated with a total hardness of less than 10 ppm as in $CaCO_3$.

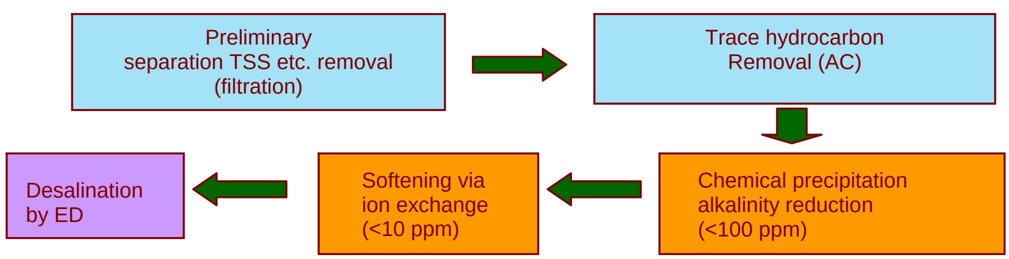


Figure 7: Pre-treatment Train Components

Following pretreatment, the effluent water can be processed by electrodialysis to remove salinity. The pre-treatment train and electrodialysis system are available as a mobile system as shown in Figure 8. The Mobile ED desalination system combines a series of pre-treatment filtration units, with a proprietary electrodialysis (ED) stack, to produce de-mineralized (NaCl salt free) water. Once this water is treated it can be used for flushing the electrodes during EK3 remediation. The effluent water can be stored on the tank provided by the mobile system on within a lined pond onsite prior to treatment.

Figure 8: Mobile Pre-treatment and ED System.

Project Results

Geophysics

Electromagnetic (EM31) surveys were applied to outline conductivity changes in the soil. EM scans were conducted both prior to and following electrokinetic remediation. The results are shown in Figure 9. The image to the left in Figure 9 shows the results of the EM scan of the pilot area prior to electrokinetic remediation. The image to the right in Figure 9 is the result of an EM scan after the electrokinetic remediation. This post scan illustrates the presence of a chain link fence which was installed around the pilot scale infrastructure. This fence was not present during the baseline EM scan. The post EM scan shows that the conductivity of the contaminated area has decreased after the electrokinetics system was applied.

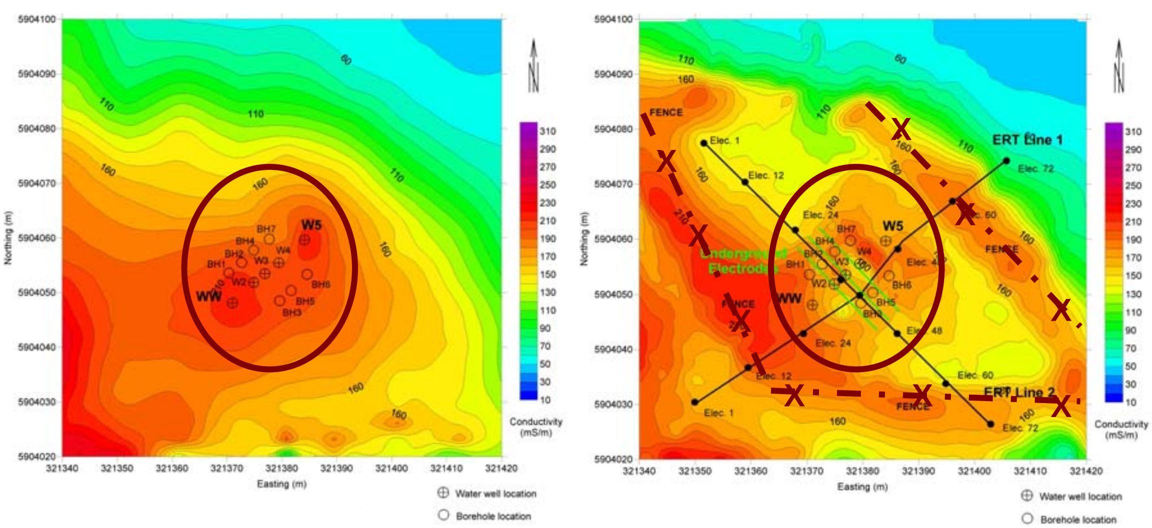


Figure 9: Baseline and Post EM Scans.

ERT investigations were conducted following the remediation only. An ERT survey was conducted to delineate the distribution of conductivity at depth within the pilot area following the pilot scale study. The resulting survey is shown in Figure 10. The ERT model indicates lower conductivity is present in the vicinity of electrodes. ERT model data also showed the zone of influence to extend deeper than expected.

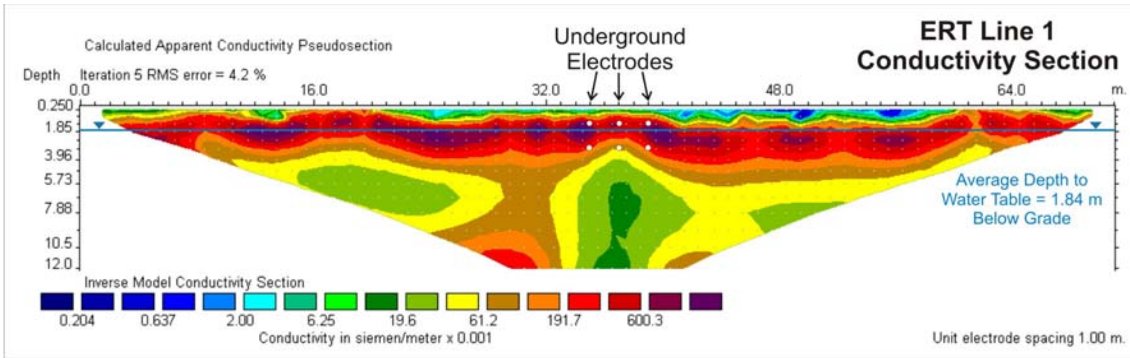


Figure 10: Post ERT Scan

Soil Testing

One of the primary reasons for conducting the study was to determine if electrokinetics processes affected heterotrophic microbe populations in the soils. The results of the study indicated there was no apparent affect of electrokinetics on microbe populations with distance from electrodes, and at depths of 0.9 m (unsaturated zone) and 3.0 m (saturated zone).

Soil assessment results indicated that metals concentrations and pH in soils had negligible changes when comparing pre-remediation and post-remediation soil samples. One soil sample had an exceedence of barium concentrations, but otherwise metals in soils did not exceed applicable guidelines in baseline and post testing. Although changes in metal concentrations in soils samples were negligible overall, there were minor increases in barium concentrations and minor decreases in chromium, vanadium and zinc.

Positive ions, EC, SAR and sodium, regardless of distance of soils from electrodes, generally decreased at a depth of 0.9 m (unsaturated zone and depth of positive electrode) and increased at a depth of 3.0 m (saturated zone and depth of negative electrode). These changes in concentrations are due to the migration of the positive ions towards the negative electrode.

At the depth of the positive electrode (0.9 m), the chloride concentrations increased approaching positive electrodes. These increases in chloride concentrations were greater the closer the soil samples were collected from the electrodes. At a depth of 3.0 m (negative electrode depth) the chloride concentration generally increased regardless of soil sample collection distances from the electrodes. As chloride is a negative ion, concentrations of the chlorides are expected to decrease at the positive electrode. Decreases in chloride concentrations are expected to occur at the positive electrode when the system operational time is increased and with reduced electrode flushing rates. For the pilot testing the system was run for approximately 2 months.

Groundwater Testing

The post groundwater analytical results when compared to baseline study results indicated pH in groundwater was not affected by electrokinetics operation. pH trends in groundwater samples collected from the pilot area wells were consistent with background well trends as shown in Figure 11.

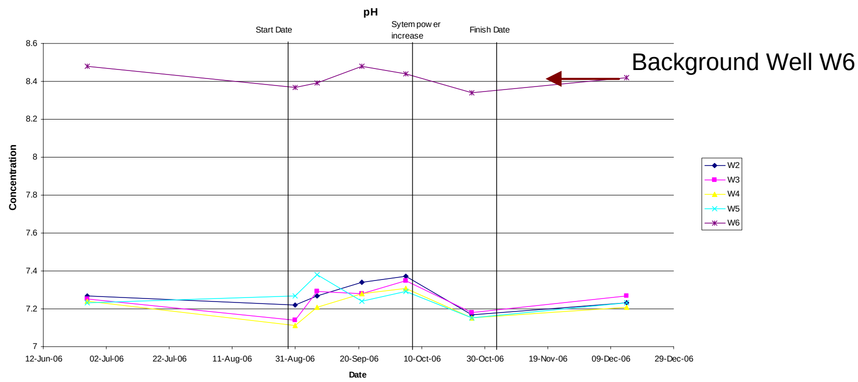


Figure 11: pH Groundwater Samples

Groundwater at monitoring wells was tested for dissolved metal parameters. Some of the dissolved metals trends are provided in Figures 12 through 15. The majority of the dissolved metals parameters (of those exceeding guidelines) indicated that the electrokinetics system operation influenced the dissolved metal concentrations as follows:

- Arsenic, lithium, and selenium increased (dissolution from soils);
- Barium, manganese, and sulphur (spike on Oct 5-06) decreased; and
- Cadmium, and chromium were not affected.

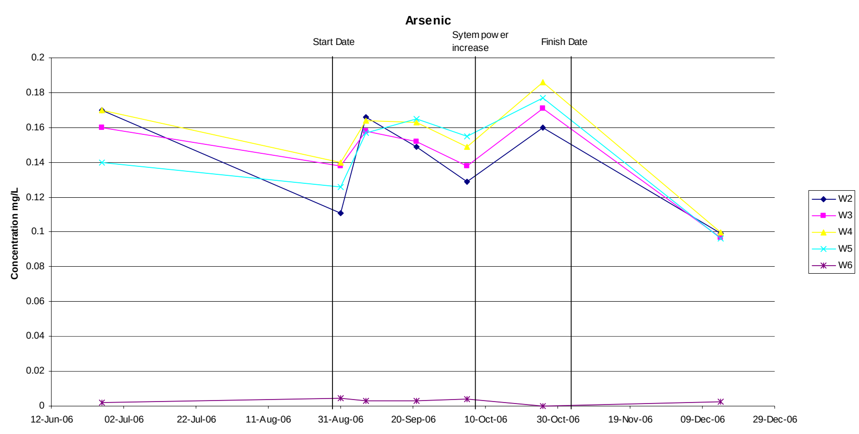


Figure 12: Arsenic Groundwater Samples

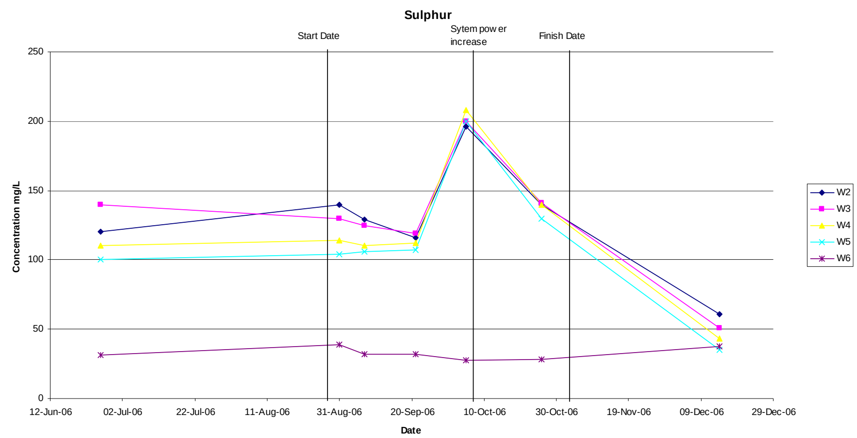


Figure 13: Sulphur Groundwater Samples

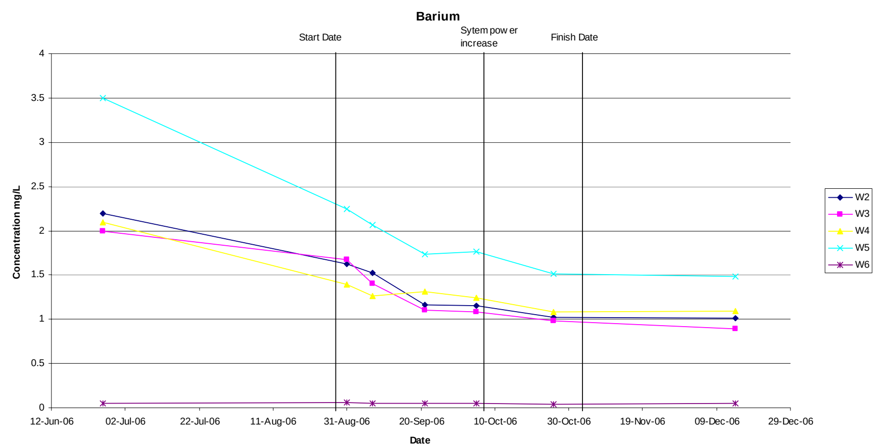


Figure 14: Barium Groundwater Samples

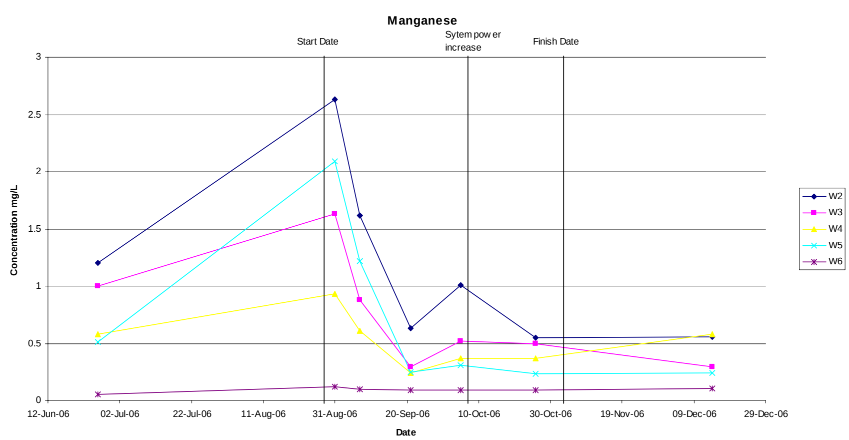


Figure 15: Manganese Groundwater Samples

EC, sodium and chloride parameters in groundwater had similar trends. Trends of EC and chlorides are provided in Figures 16 and 17, respectively. Figure 16 shows decreasing trends of EC in the groundwater during the operation of the electrokinetics system. Both figures 16 (EC) and 17 (Chlorides) show dissolution of EC and chlorides from soils to groundwater after the electrokinetics system started up and following an increase of the system voltage. Both EC and chlorides also moved toward equilibrium during cold weather, mechanical malfunctions, and after system shut down. Other site-specific parameters/concentrations were measured as appropriate (i.e. vinyl chloride and tri-halo methane). These parameters were not detected in groundwater samples collected from the remediation area during the operation of the electrokinetics system.

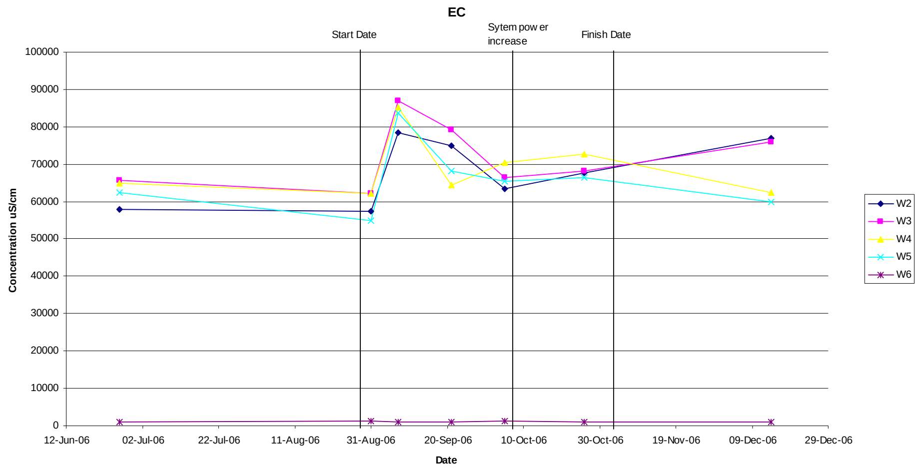


Figure 16: EC Groundwater Samples

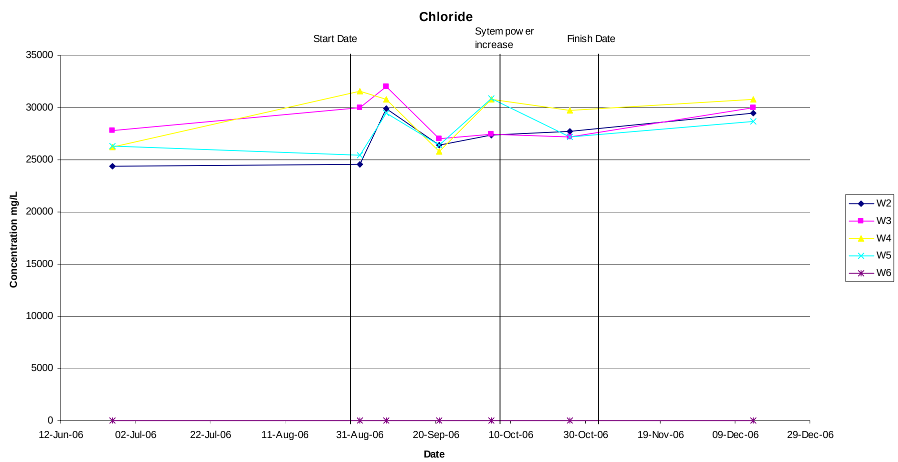


Figure 17: Chloride Groundwater Samples

Effluent Water

During both the bench and pilot scale tests, effluent water was collected at the positive and negative electrodes by Ground Effects to determine the effectiveness of ion migration towards the appropriate opposite electrical poles. The results indicated that positive ions such as sodium and potassium occurred in greater concentrations in effluent water collected at the negative electrode as expected. Chlorides were also more concentrated at the positive electrode as expected. Calcium ions appeared to move with the chlorides, as they were more concentrated at the positive electrode. Table 1 shows the results of the effluent testing during the bench scale study.

	pH	EC	SAR	Ca	Na	K	Cl
		dS/m		mg/L	mg/L	mg/L	mg/L
Positive electrode	2	12.6	1.2	193	75	8	3370
Negative electrode	12.6	14.2	160	10	2050	29	25.9
Tap water	7.4			92	54	7	<1

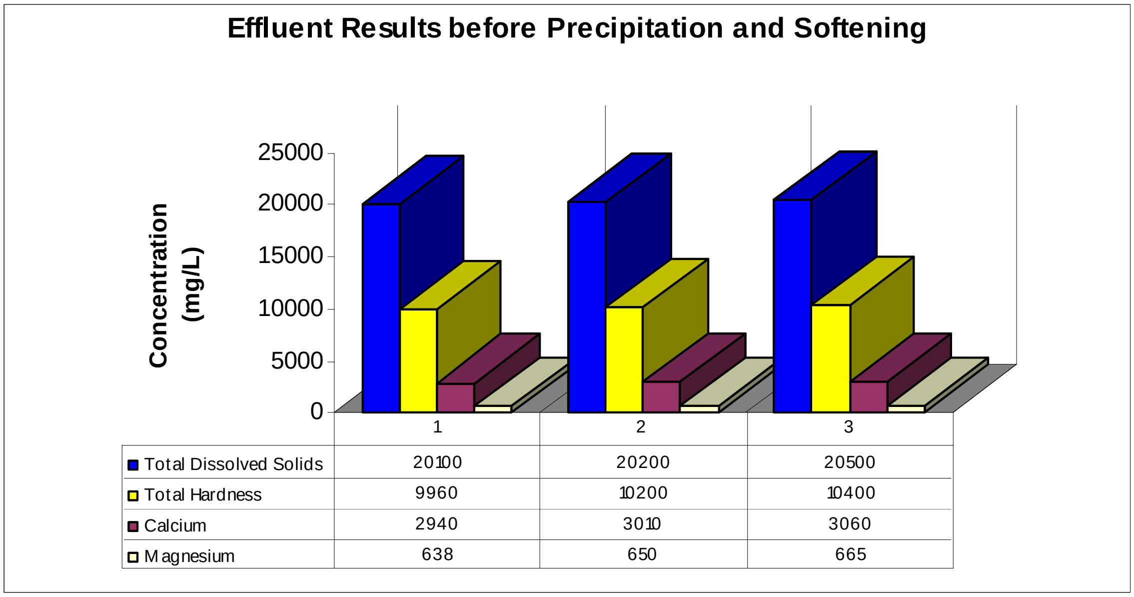
Table 1: Bench Scale Effluent Results

Table 2 provides the effluent chemistry at the positive and negative electrodes after approximately 30 days of the EK3 operation. The results showed that all salinity ions regardless of charge were more highly concentrated at the negative electrode, which was expected for the positive ions but not for the chlorides. Some chloride ions did migrate towards the positive electrode. The migration of some of the chloride ions towards the negative electrode during the pilot study is thought to be a result of the chlorides migrating with the water added to the positive electrode (for electrode flushing purposes) down towards the negative electrode. As a result the full-scale operation utilizes lower quantities of flushing water to allow the chlorides to migrate under the influence of the electrical field.

	pH	EC	SAR	Ca	Na	K	Cl
		dS/m		Mg/L	mg/L	mg/L	mg/L
Positive electrode	2.8	1840	nd	180	35	1.1	504
Negative electrode	10.6	7530	nd	720	1340	25.6	3590

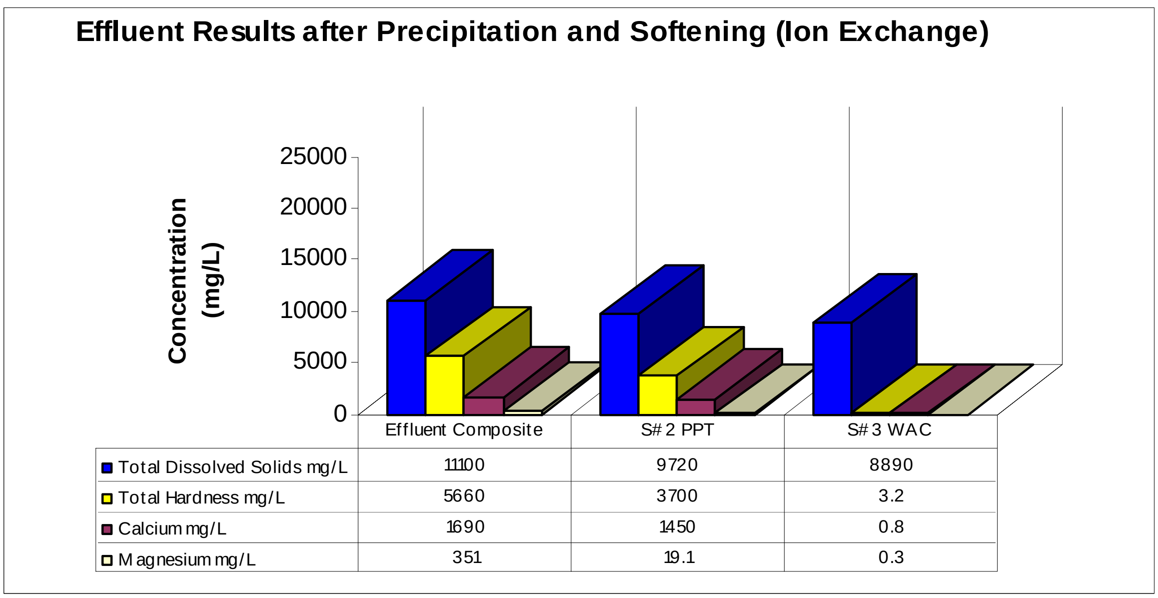
Table 2: EK3 Pilot: Effluent Results (< 30 days)

Figure 18 illustrates the TDS, hardness, calcium and magnesium in three effluent samples obtained within the first 30 days of EK3 operation, prior to pre-treatment. Figure 19 shows the chemistry of a composite sample of the effluent (post 30 days of operation) prior to pre-treatment, the water characteristics of key parameters following chemical precipitation and the water characteristics following ion exchange. Figure 19 illustrates the greater than 99% reduction in total hardness as a result of the pre-treatment processes.



	1	2	3
Total Dissolved Solids	20100	20200	20500
Total Hardness	9960	10200	10400
Calcium	2940	3010	3060
Magnesium	638	650	665

Figure 18: Effluent Characteristics Prior to Pre-treatment



	Effluent Composite	S# 2 PPT	S# 3 WAC
Total Dissolved Solids mg/L	11100	9720	8890
Total Hardness mg/L	5660	3700	3.2
Calcium mg/L	1690	1450	0.8
Magnesium mg/L	351	19.1	0.3

Figure 19: Effluent Results Prior to Treatment and After Pre-treatment

The objective at the start of the project was to treat the effluent water and reuse it in the EK3 processes to flush the electrodes. This was not possible because the EK3 effluent water composite presented unprecedented total hardness (ranging from 10,000 ppm to 25000 ppm as in $CaCO_3$) with elevated salinity.

Water with the above hardness concentrations or greater are typically disposed off as the pre-treatment costs are prohibitive. This is because the presence of hardness (>1ppm as in $CaCO_3$) in water typically leads to precipitation of scale which is detrimental to many process equipment components as well as to the water treatment system itself. Systems affected negatively by scale deposits include boilers (thermal desalination systems) multi-stage evaporators, cooling water, heat exchangers, cooling towers, hot water heaters continuous casters, heat recovery steam generators, pipe surfaces, pressure membranes (nano-filtration or reverse osmosis) and electro-membranes (electrodialysis).

Due to the extreme hardness encountered in the effluent water, the pre-treatment processes required proven compatible materials and equipment to withstand the hardness concentration. The shortage and timely availability of materially compatible, non-defective materials, including process test instrumentation and equipment, the shortage of technical skilled labour in Alberta, and high capital equipment costs were some of the key challenges encountered during the short seasonal window of time last summer when the EK3 pilot demonstration was completed.

In the interim VSC-SAIT developed a bench scale pretreatment prototype to test the extremely hard effluent water with elevated salinity. The test results of the bench scale pre-treatment standard and custom sequences were promising. Reproducible iterations of the precipitation and ion exchange combination on composites were able to reduce total hardness up to 0.3 mg/L as in $CaCO_3$. Following the above results a pilot pre-treatment train scale-up was commissioned. This pilot pre-treatment train will be integrated up-stream to the electrodialysis system to provide seamless effluent water pretreatment with ED water desalination this summer. Table 3 provides an example of the proven ED water desalination performance the Volker-SAIT system has achieved on elevated saline waters from a salt retention pond.

Parameters	Units	Before Start-up Feed-water Time @ 0 hrs	During Close to End of Process Time @ 48 hrs	After End of Process Time @ 55 hrs	Drinking Water Regulatory Criteria	Percent Removal Time @ 55 hrs
Chloride	mg/L	21067	175	71.2	250*	100
Sodium	mg/L	12733	145	84	200*	99.0
Potassium	mg/L	481	1.2	0.9	NG	100
Sulphate	mg/L	547	90.5	80.3	500*	85.0
TDS	mg/L	28533	482	273	500*	99.0

Table 3: ED Desalination Performance Summary

The batch water treated was about 25000 litres and the reduction in total dissolved solids from 28,533 ppm to 273 ppm was about 99.0%. Since this was a test project with multiple objectives the ED system was run longer than required. The regulatory drinking water quality criteria were met approximately 15 hours before the end of the process.

Conclusion and Next Steps

The site contamination via geophysical (electromagnetic and resistivity imaging) showed that there was elevated bulk conductivity before EK3 remediation. During the pilot program a substantial bulk conductivity of the subsurface was observed which reduced by approximately 30%. Based on the EM results and the evidence of ion migration, substantial salt remediation could be achieved through EK3 in fine grained soils.

It was found that salinity ions have the ability to migrate under the influence of an electrical field due to their polar opposite electrodes as expected. It was observed that the chlorides migrated with the flushing water toward the negative electrode. As a result the flushing water added during the EK3 processes needed to be minimized in order to allow the chlorides to migrate towards the positive electrode. Overall, the viability of electrokinetics for soil and groundwater remediation of salt impacted sites was successfully demonstrated.

The potential impact to the condition of soils as a result of electrokinetics was tested. Based on the results it was concluded that heterotrophic microbes and pH in the soils were not affected adversely by electrokinetics processes. In addition there were insignificant dissolved metal concentration changes in the soils. The potential impact to the condition of groundwater was tested. Based on the results there was no change in the pH in the groundwater. Some dissolved metals in the groundwater were affected by electrokinetics with varying (increasing and decreasing) metal concentrations. This is being explored further during the full-scale operation of the electrokinetics system as the pilot results for dissolved metals in ground water are inconclusive.

The initial EK3 effluent water composite presented unprecedented total hardness (ranging from 10,000 ppm to 25000 ppm as in $CaCO_3$) with elevated salinity. Water with hardness concentrations as seen in the EK3 effluent is typically disposed of as the pre-treatment costs are prohibitive. Since a key objective of this project was to reuse the treated EK3 effluent on-site it was found that given the elevated EK3 effluent concentrations suitable pre-treatment water systems were not available to purchase or rent at the time for a field demonstration with the EK3 pilot. The Bench scale pre-treatment tests conducted on the EK3 effluent were able to demonstrate a significant reduction in total hardness up to 0.3 ppm as in $CaCO_3$. Following these results a water pre-treatment train for the highly contaminated effluent water was determined. Based on these results and relevant process assessments it was concluded that treating the EK3 effluent was not a problem but a viable opportunity.

The findings from the bench and pilot scale demonstration have been summarized below:

- Isolate the first electrode flush waters and treat separately from subsequent flushes
- Limit the usage of electrode flush water to facilitate the complete migration of chloride ions
- Effluent water with unprecedented water hardness and elevated salinity can be treated. Treating the EK3 effluent is not a problem but a viable opportunity

- Standard engineered water systems and pre-treatment equipment are not suitable to withstand elevated concentration of hardness, salinity and other water contaminants
- Pre-treatment equipment, materials and process sequences needs to be customized for site specific water contaminants in order to obtain successful results
- Water pre-treatment train materials and equipment costs are capital intensive; Effluent treatment costs are approximately > 400% than municipal water treatment
- Un-anticipated material shortages, long supplier lead times, lack of skilled technical labour and escalating labour costs in Alberta can cause long delays in pilot projects

In conclusion the combination of the pilot EM and EK3 electrokinetic and bench scale EK3 effluent water pre-treatment process presented successful results, especially in fine-grained soils, for the removal of salinity ions associated with produced water spills.

The key next step is to commence a full-scale field demonstration of salt remediation of the site using the integrated EM, KK3, Pre-treatment and ED. The concurrent next step involves the testing of a pilot pre-treatment train coupled with ED desalination to demonstrate 10,000 gallons of EK3 effluent water clean up this summer. Future work will involve the determination of the optimal operational runtime of the electrokinetics system to reduce the ions in the soil and groundwater to levels below applicable guidelines. Additionally, it would be interesting to monitor the long term trend in dissolved metal concentrations and determine the variance in concentration when the system is operational for a longer time period than the pilot scale study permitted.

Acknowledgements:

- Mr. Dennis Twerdoff, Mr. Bryce Peterson, Dr. Janan Sallomy, and Mr. Burton Cosgrove - Pioneer Professional Services Group, Calgary
- Ms. Carol Elliot, and Mr. Randall Warren - Shell Canada Ltd. Alberta
- Dr. Rolf Stokhuyzen - National Research Council Canada, Calgary
- Mr. Sean Frisky, and Mr. Joel Wolensky - Ground Effects Environmental Services Inc. Saskatchewan.
- Mr. Fred Desjarlais, Mr. Jack Brown, and Mr. Cliff D‘Amour - Volker Stevin Contracting Ltd. (VSC), Calgary
- Dr. Alex Zahavich, Dr. Larry Rosia, Ms. Mary MacDonald, Ms. Emily Lees, Mr. Peter Leliveld, Mr. Bob Hammond, Ms. Wendy Wade and ARIS Staff, - Southern Alberta Institute of Technology, Calgary.