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Electrokinetics - Insitu Remediation of Salt Impacted Fine-Grained Soil and Groundwater at a Former Battery Site

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Introduction

Pioneer Professional Services Group (Pioneer), Shell Canada Ltd. (Shell), Volker Stevin Contracting Ltd. (Volker) and Southern Alberta Institute of Technology (SAIT) partnered with the National Research Council – Industrial Research Assistance Program (NRC-IRAP) to determine the viability and impact of using Ground Effects Environmental Services Inc. (Ground Effects) EK3 electrokinetics and Volker's electrodialysis systems for the insitu remediation of salt impacted soil and groundwater at a former battery site. Shell contributed in providing project funding and the salt impacted site for the project. SAIT provided technical advice and researched the application of the Volker electrodialysis water treatment system. NRC-IRAP provided federal funding and industrial technology advice.

The goal of the project was to develop a sustainable remedial process for salt impacted sites with a view to reduce the need for land filling. While electrokinetic remediation has been proven, to a limited degree, to be an effective technique in removing salts from saline contaminated soils and groundwater, no process is available for determining the impacts of this technology on various parameters in the soil and/or groundwater. The purpose of the project was to determine the viability of the Electrokinetics technology for treatment of salinity impacted fine-grained soils and groundwater. The primary issues of concern are how the electrokinetic process will affect the microbial activity of the soils, the metals in the soils, and the native pH of the soils after the reduction or elimination of the target salt ions. The project involved the 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, insitu treatment of soil and treatment of salinity impacted groundwater. In addition, the treated effluent water can be potentially reused in the electrokinetics processes.

Background

Salinity Issues and Traditional Salt Remediation

Salt contamination from upstream oil and gas activities and road salting processes are a major concern throughout North America. Salinity affected soil behaves like a plant sterilant. When the salinity concentrations in the soil are higher than inside the root cells, the soil will draw water (through an osmosis process) from the root, causing the plant to die. From a commercial crop perspective, salts can cause significant financial damage to agricultural operations.

Traditionally, the most cost effective remediation of salt impacted fine grained soils has been through "digging and dumping". As the cost of the “dig and dump” approach increases; and available landfill space becomes limited, this approach is not sustainable. Groundwater can also be impacted by elevated salinity. Salt impacted groundwater is typically remediated by extracting water through recovery wells, followed by deep well injection disposal. However, in fine-grained soils, extraction by recovery wells can be ineffective. As a result, industry is looking for more innovative and cost effective ways to deal with their soil and groundwater remediation liabilities.

Bench and Pilot Scale Remediation Description

Bench and pilot scale studies of the remediation technologies were performed during this project to complete the project objectives. A laboratory or bench scale test is performed in the laboratory on a small volume of soil. For electrokinetics, the bench scale study is conducted to evaluate appropriate voltage ranges, how well ions migrate, if off gases are produced, etc. The results of the bench scale study are used to optimize the pilot scale study. The objective of the pilot study is to gain information relating to the anticipated performance of the larger, full scale system. The timeline of the pilot test for this project was 2 months. Based on the results of the bench scale test ion concentrations were expected be reduced in the 2 month period but not necessarily reduced below guidelines. Another objective of the pilot project is to gain preliminary data to design a full-scale system. The full-scale system would be designed aiming to reduce the salinity in the soil and groundwater to meet applicable guidelines.

Technology Description

One way to accomplish salt removal from fine-grained soil is through electrokinetic remediation. 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.

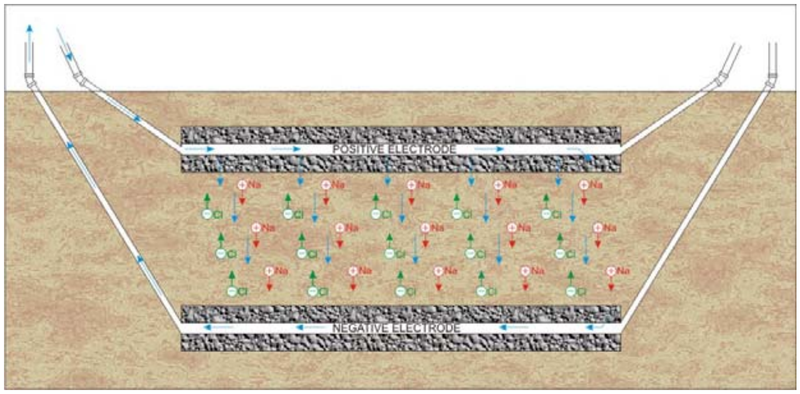


Figure 1: Electrokinetics Electrode Cross-section

Typically saline water is disposed of using deep well injection. Utilizing electrodialysis or equivalent salinity treatment technology enables the effluent waters to be reused in the treatment process or injected back into the source aquifers. By utilizing the treated waters in the remediation process, rather than hauling in fresh water from an offsite location, the remediation process described in this document becomes sustainable. Waste is treated onsite, instead of transferred to a landfill, or deep well injection site. Figure 2 shows a schematic of the steps required to treat the effluent water.

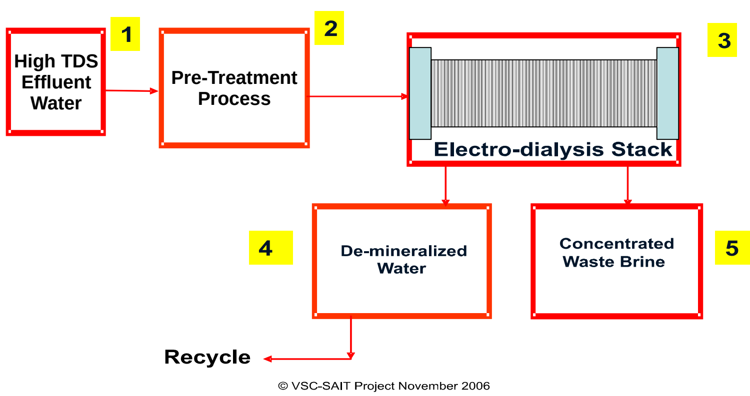
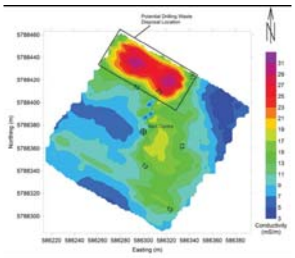


Figure 2: Effluent Water Treatment Schematic (provided by SAIT)

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.



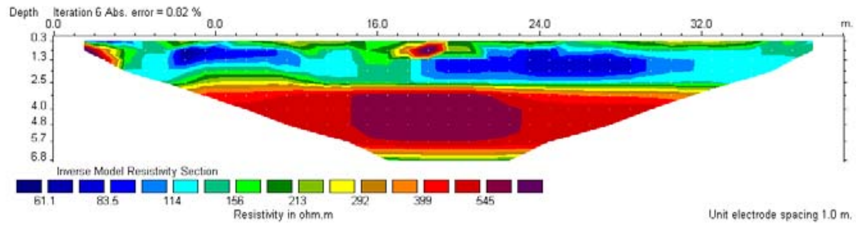


Figure 3: Example EM Scan

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 Soil and Groundwater 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.

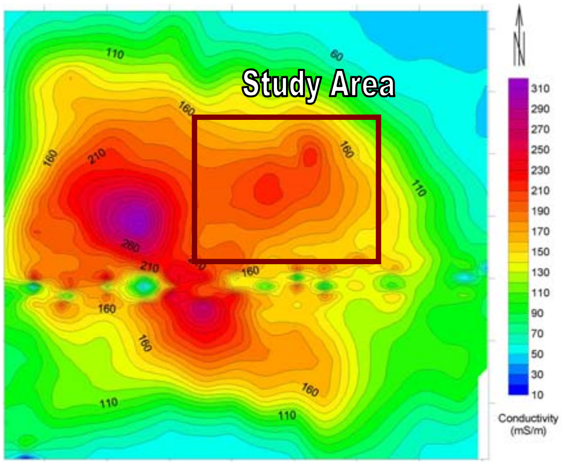


Figure 5: Baseline EM Scan

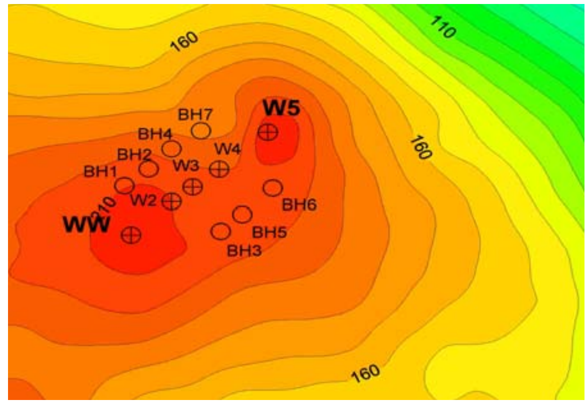


Figure 6: Placement of wells and boreholes

The EM scan results were also used to establish the locations of the some of the monitoring wells and soil testing locations, shown on Figure 6. On June 5, 2006 twelve boreholes were advanced to depths ranging from 3.6 to 8.4 m below grade within the pilot study area placed at varying distances from electrodes to monitor process influence. Five of the borehole locations were completed as monitoring wells. There were 3 additional wells previously installed on the property that were utilized in the pilot study. Monitoring wells W2, W3 and W4 were installed in close proximity to the electrode locations. Monitoring well W5 was installed at a downgradient location and W6 (located NW of the well network shown on Figure 6) was installed as a control location upgradient from the expected contamination area. Figure 7 provides the spacing arrangement of the boreholes, wells and electrode locations.

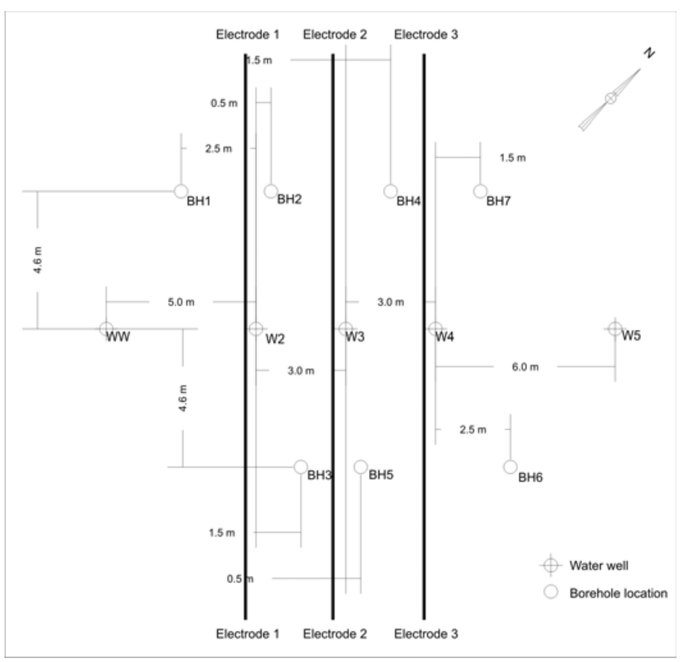


Figure 7: Electrodes and Sampling Locations

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. Selected soil samples were submitted for analyses of salinity parameters, metal and/or hydrocarbon concentrations. Soil samples were also submitted for heterotrophic microbe plate counts. The baseline soil analytical results were compared to the results obtained after the system was shut down. Baseline soil data indicated salinity parameters exceeded Alberta Environment guidelines at depths of near surface to greater than 5.0 m below grade. Metal and hydrocarbon parameters were within the guidelines in the collected soil samples. Heterotrophic microbes were present in the topsoil, 0.9 m and 3.0 m soil samples.

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. Baseline groundwater data indicated elevated levels of salinity and metal parameters that exceeded applicable guidelines (Canadian Environmental Quality Guidelines for Human Drinking Water and Livestock Criteria). Salinity parameters that exceeded guidelines included chlorine, sodium and calcium. Metal parameters that exceeded guidelines in groundwater samples collected included arsenic, barium, cadmium, Lithium, manganese, selenium, sulphur, thallium and vanadium.

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. Prior to beginning the study, soils in the tote were tested for H_2S and chloride gas using detectors.

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. Soil samples were taken prior to bench scale initiation and then every 7 days (1 from the positive electrode, 1 from the middle, and 1 from the negative electrode) during the operation of the bench scale tests. At the end of the bench scale testing, soil samples were also collected. Soils were tested for salinity and microbial activity. Water extracted at the cathode and the water flushed through the anode was also tested for routine water parameters (salinity, total dissolved solids, etc.) and dissolved metals.

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.

Remedial System Installation and Operation

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 were installed in a northwest to southwest orientation 0.5 m southwest of the monitoring wells W2, W3, and W4. Electrodes were horizontally drilled and were installed greater than 10 m from all pipelines or electrical lines. The electrodes were placed at the top and bottom of the encountered salinity contamination and spaced 3 meters horizontally. The layout of electrodes is provided in Figure 7. Phase I power and a phase converter (to obtain 3-phase power) were installed to provide the required power to remediation equipment. 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.

Pilot scale remediation systems are operated to determine system adjustments that will be required during the full-scale operation of the system based on site conditions. Electrical connection failure occurred at the electrode ends due to corrosion. Ground Effects rectified this issue by exposing the electrodes to air. The electrodes ends have been brought to the ground surface in the full-scale design of the electrokinetics system to avoid corrosion. Winter weather conditions caused the injection lines to freeze. As a result, water lines had to be heat traced to continue operation of the system. The effluent water extracted from the electrodes had unanticipated water hardness. As a result, the effluent water required pre-treatment prior to treatment with the electrodialysis system.

Groundwater and System Monitoring

During the operation of the system groundwater was monitored and sampled on a regular basis (every two weeks after system operation commenced) 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. 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

The pilot scale system was shut down early 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.

Project Results

Hydrogeology

Groundwater elevation changes in the remediation area (top trend lines) had similar trends to groundwater elevations changes in the background well (bottom trend line) as shown on Figure 8. Therefore, the remediation system is anticipated to have little or no effect on local groundwater levels. Groundwater flow direction was also not affected during the operation of the system as water was added and extracted during the remediation processes.

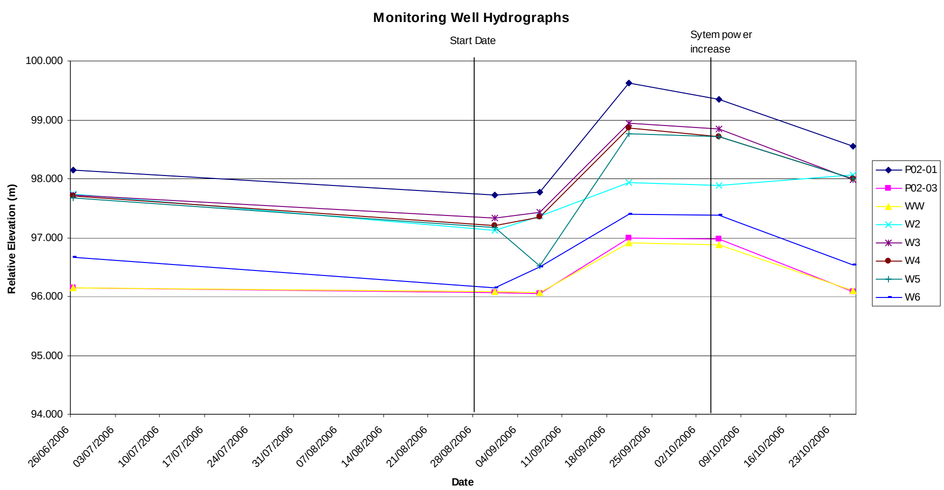


Figure 8: Groundwater Monitoring Well Hydrograph

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. 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 9.

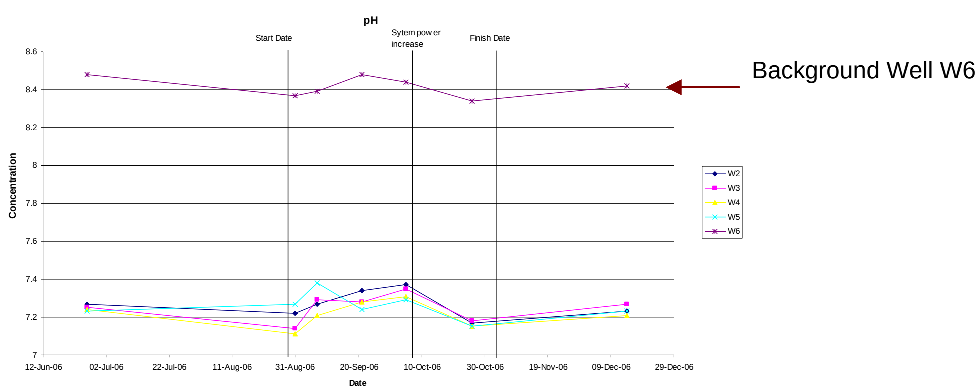


Figure 9: pH Groundwater Samples

Groundwater at monitoring wells was tested for dissolved metal parameters. Some of the dissolved metals trends are provided in Figures 9 through 13. 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.

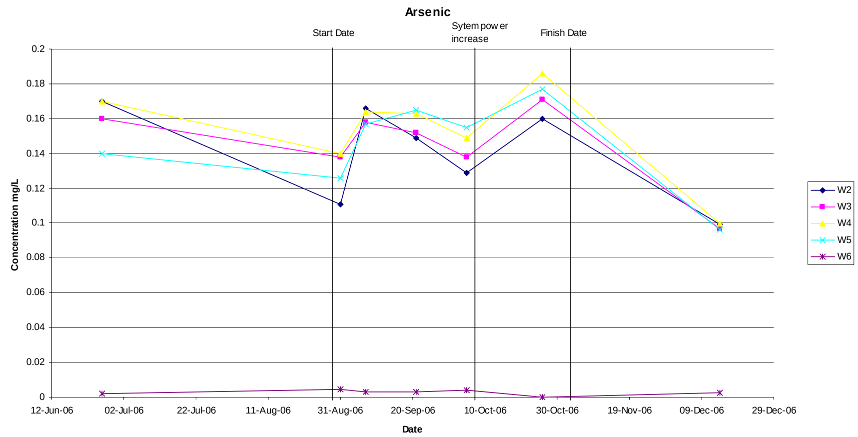


Figure 10: Arsenic Groundwater Samples

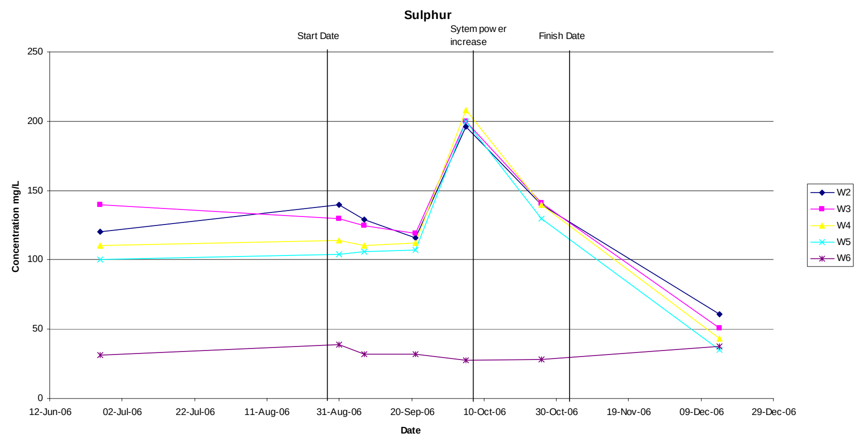


Figure 11: Sulphur Groundwater Samples

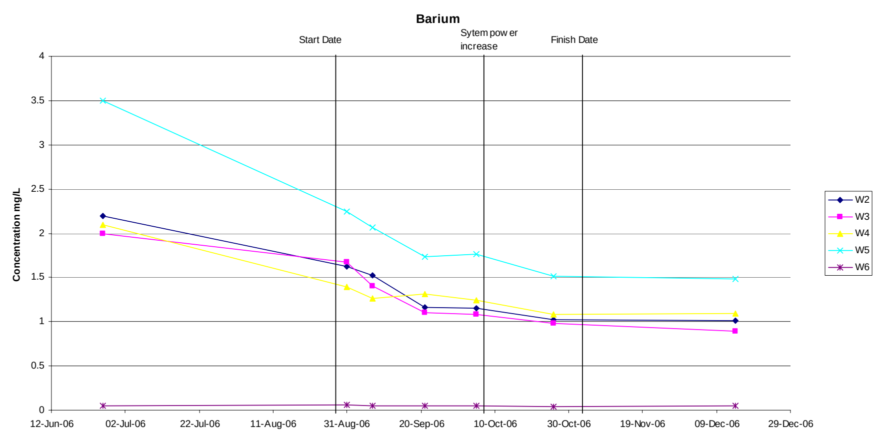


Figure 12: Barium Groundwater Samples

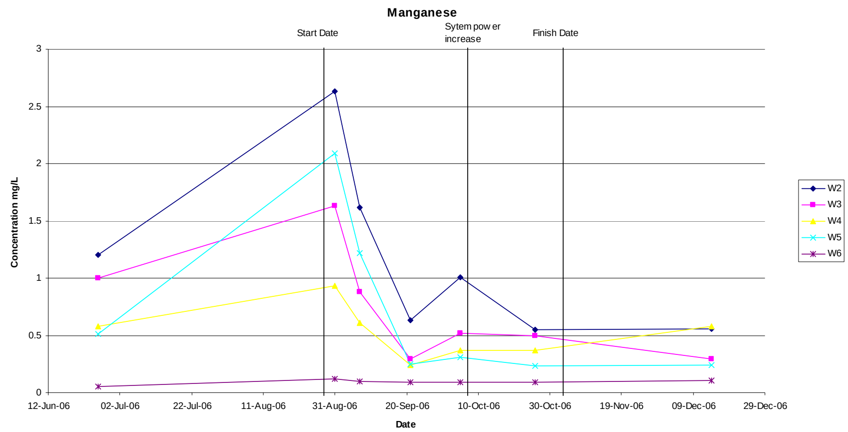


Figure 13: Manganese Groundwater Samples

EC, sodium and chloride parameters in groundwater had similar trends. Trends of EC and chlorides are provided in Figures 14 and 15, respectively. Figure 14 shows decreasing trends of EC in the groundwater during the operation of the electrokinetics system. Both figures 14 (EC) and 15 (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.

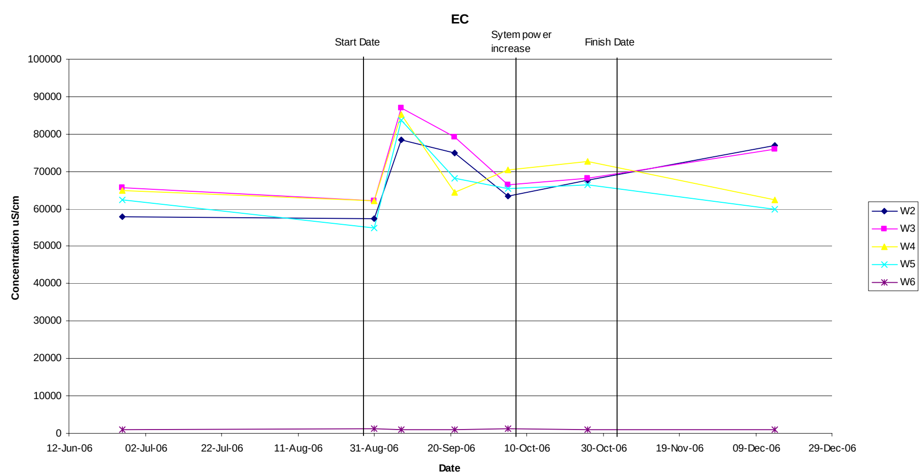


Figure 14: EC Groundwater Samples

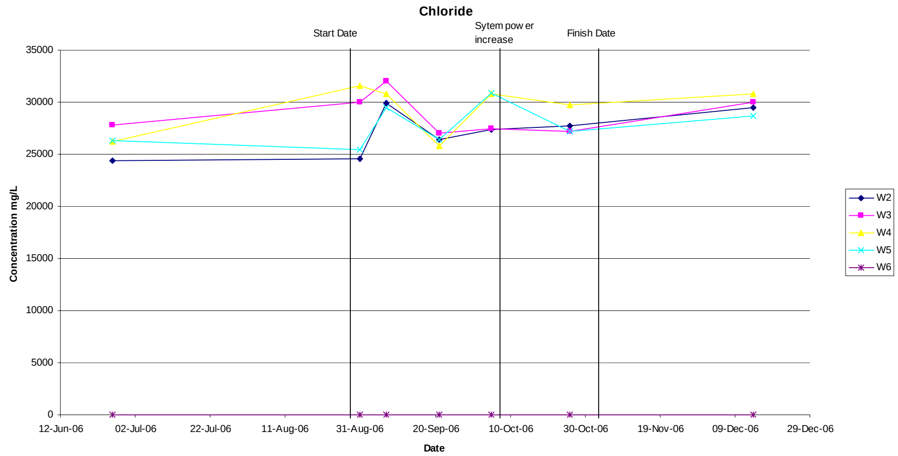


Figure 15: Chloride Groundwater Samples

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 15. The image to the left in Figure 16 shows the results of the EM scan of the pilot area prior to electrokinetic remediation. The image to the right in Figure 16 is the result of an EM scan after the electro-kinetic 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.

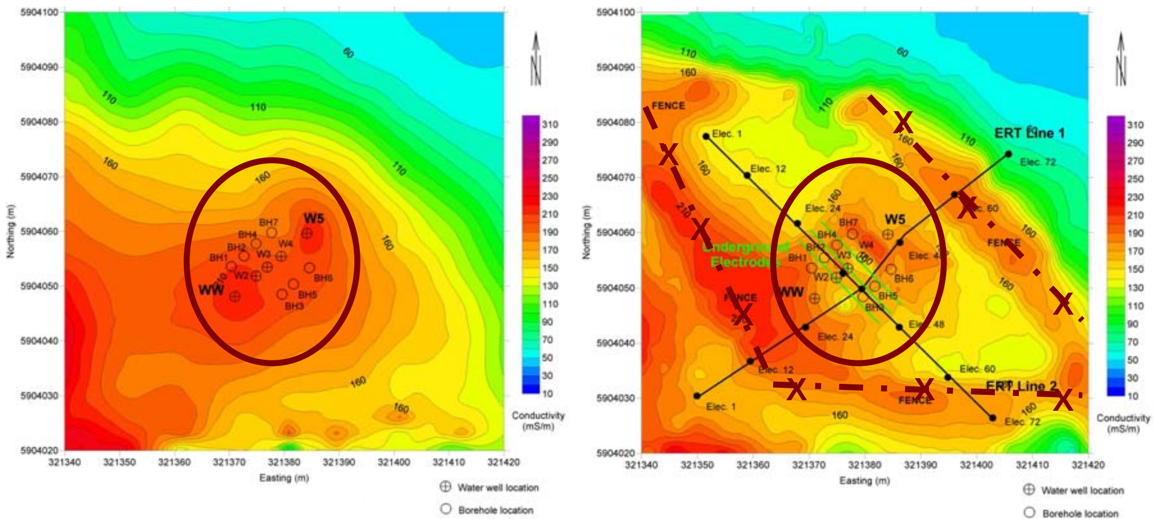


Figure 16: Baseline and Post EM Scans. ERT Lines (illustrated on figure to the right)

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 16. 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.

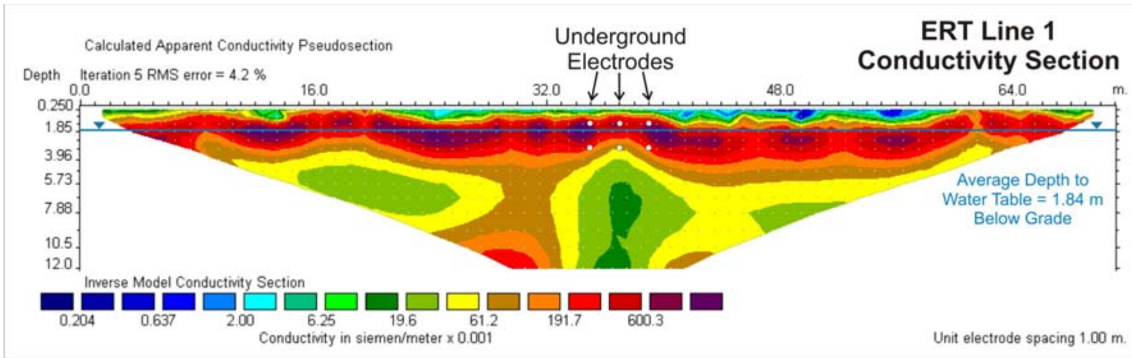


Figure 17: Post ERT Scan

Effluent Water Treatment

Effluent water was collected from the electrodes and stored in tanks. One of the objectives of the project was to collect the effluent water and conduct eco-responsible treatment of the effluent waters onsite using electrodialysis to promote a sustainable system. The success of the treatment application would be evaluated following treatment. Application of the treated effluent included using the water for irrigation or reusing it in the electrokinetic process. Reuse of the water in the process would minimize the requirement of hauling fresh water onsite.

A multi-stage pretreatment process was required for the effluent water, as the water had exceedingly high and unexpected hardness that could not be treated by electrodialysis without pretreatment. The general chemistry of the effluent waters was as follows:

- pH: 2.95 (effluent) versus 7.1 to 8.5 (groundwater in pilot areas)
- EC up to 15,000 uS/cm
- Hardness up to 25,000 mg/L
- Chloride up to 5,000 mg/L
- TDS up to 35,000 ppm (comparable to sea water)

A portion of the effluent water will be treated by the electrodialysis system following removal of certain components. SAIT and Volker Stevin are currently working on suitable applicable processes to remove these impurities.

Project Outcome

This discussion outlines the findings of the project based on the project objectives. One of the project objectives was to determine how well electrokinetics works under unsaturated and saturated conditions. Pioneer found that under unsaturated conditions, salinity ions (except Chlorides) decreased at the positive electrode located in the unsaturated zone. Under saturated conditions, salinity ions increased at the negative electrode. The project results also determined that heterotrophic microbes and pH in the soils were not affected by electrokinetics processes. In addition there were insignificant metal changes in soils overall. pH in the groundwater was also not affected. Dissolved metals in the groundwater were affected by electrokinetics with varying metal concentrations increasing and decreasing.

Moving forward, it will be beneficial to determine the required operational runtime of the electrokinetics system to reduce the ions in the soil and groundwater to levels below applicable guidelines. Additionally, it will be interesting to monitor the long term trend in dissolved metal concentrations when the system is operational for a longer time period then the pilot scale study permitted.

The present pilot study produced design objectives and approximate costs of full-scale remediation. The insitu remediation cost is comparable to "digging and dumping". The EK3 electrokinetic process indicated positive and promising results, especially in fine-grained soils, for the removal of ions associated with produced water spills. As a result Shell has agreed to move ahead with a full-scale remediation of the site using electrokinetics. The treatment of the effluent waters continues to be researched and initial results are promising.

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