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DE-ICER (NACL) SALT IMPACTED SOIL: 22X REMEDIATION FEASIBILITY STUDY

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Abstract

Three remedial (in-situ) technological simulations comprising soil flushing remediation (SFR), soil chemical amendment (SCA) and electro-kinetic remediation (EKR) that focused on a comprehensive reduction of NaCl in de-icer salt impacted soils were tested. The test soil for the simulations was sampled from the 22X salt storage and maintenance site where elevated sodium (Na^+) concentrations up to 20,700 mg/L (10373 mg/Kg) and chloride (Cl^-) concentrations up to 47,600 mg/L (23,801 mg/Kg) was evidenced at depths ranging from 0.0m to 3.0m bgs. The three technological simulations apart from the reduction of the target Na^+ cation had the potential to clean-up contaminant chlorides of other cations Ca^{2+}, K^+ and Mg^{2+} in soil. Soil pre-treatment encompassing permeability enhancement (to improve the low soil permeability ($K< 10^{-6}$ cm/s)), and anti-dispersant treatment (to prevent soil dispersion) were performed on the test soils before transfer into each of the SFR, SCA and EKR macro bench-scale units.

The SFR unit injected a de-ionized water solvent through the prepared NaCl impacted soil and the extraction fluid recovered by hydro-suction was desalinated into a brine and permeate stream each for reuse. The SCA simulation involved the irrigation of 1.0 and 2.0m columns containing salt impacted test soils mixed with a calcium soil amendment and the facilitation of drainage, collection and desalination of the ensuing leachate. The EKR unit was a low voltage DC system designed with two electrodes positioned about 30 cm apart and with five intermediate cells inserted between the electrodes in order track the movement and depletion of Cl^- and other charged species across the stationary phase. The quantity of EKR leachate was negligible and did not require desalination. Following the SFR, SCA and EKR simulations, acute and chronic toxicological testing was conducted on the remediated test soils. A plant bioassay and leachate control test was also included to explore the potential of remediated soils to either support vegetation or reuse as sub-grade material for roadways.

SFR, SCA and EKR effectively reduced NaCl concentrations in soil by (>90%) and substantially improved (>70.0%) the soil quality EC and SAR parameters. However, not all soil EC and SAR parameters met the applicable regulatory Alberta Environmental Guidelines for soil quality. The leachate waters from the SFR and SCA simulations after desalination met the applicable surface water quality Guidelines. The acute and chronic toxicity testing demonstrated that the SCA soils were non-toxic. The plant bioassay showed that the SFR soils were not phyto-toxic and the leachate control showed the potential of EKR soil for reuse with an eco soil binder as sub grade under roadways. Overall, the study established a foundation for determining the bench-scale effectiveness of three in-situ salt remediation technologies and provided the remedial feasibility of difficult to treat de-icer salt impacted clay soils with low permeability. The results of this study should enable the development of design data and operating procedures to accomplish the decontamination efforts of the de-icer salt impacted soils pilot scale at the 22X site.

Introduction

This salt remediation feasibility study documents a) the efficacy and reliability of three in-situ remedial technologies, namely soil flushing remediation, (SFR), soil calcium amendment, (SCA), and electro-kinetic remediation, (EKR), on de-icer salt impacted soils, b) the desalination of the ensuing test soil leachates and groundwater composites, and c) the tests for potential post remediation soil and water reuses. The soil and ground water composites tested in this study were obtained from the 22X Maintenance Yard and Salt Storage Site, Calgary, Alberta, (herein referred to as 22X), and this study was conducted between October 2002 and February 2003 at the Southern Alberta Institute of Technology, Calgary, Alberta and the Royal Roads University, Victoria, British Columbia.

The overall objective of this study was to find sustainable salt remediation alternatives (SRA) for the de-icer (NaCl) salt impacted clay soils at 22X having low soil permeability. As a primary objective within the SRA context, this study examines the results of the three (SFR, SCA and EKR) bench-scale, in-situ soil treatments and leachate desalination before and after salt remediation, quantifies the NaCl reduction in soil and leachate water, and applies the pertinent regulatory Alberta Environment Guidelines to assess soil and leachate water quality. As a related objective, this study also investigates the potential for re-integration of post-remediated soils and presents the results of the chronic and acute toxicological analyses, using (F. *candida.),* plant bio-assay using lettuce seed germination and leachate analysis for soil reuse. Finally, this study presents a (SFR, SCA and EKR) remedial technology assessment summary and conclusions.

Background

De-icer salts such as sodium chloride (NaCl) are used to melt snow on road transportation systems in winter and some salts such as calcium chloride ($CaCl_2$) are used to suppress dust in summer. Under the Canadian Environmental Protection Act (CEPA), the federal government released results from a six-year scientific assessment, concluding that road salts are "Toxic" based on the CEPA definition. Key concerns relating to mainly NaCl loading on soils in storage and maintenance yards typically are degradation in soil texture, and adverse impact on microbial processes, soil invertebrates, vegetation and wildlife. NaCl impacts on groundwater or surface water result in impairment of drinking water quality, and deleterious effects on aquatic flora and fauna (Environment Canada, 2000)[1]

The province of Alberta used an estimated 121,035 tonnes of salt and the City of Calgary used an estimated 20,428 tonnes of salt (NaCl) in the winter of 1997-1998 (Environment Canada, 2000) [1]. The other sources of salt (NaCl) releases in Alberta are either from formation water encountered during upstream oil and gas operations or naturally occurring glacial drifts discharging into the subsurface environment (Alberta Environment, 2001)[2]. The provincial government, recommends specific salt contamination assessment and remediation guidelines for the protection of soil and water quality and provides soil remediation options with a range of soil amendments (Alberta Environment, 2001) [2] to remediate salt affected soils typically from brine-spills. Brine contaminated soils require restoration and this process primarily involves natural leaching of salts, application of soil amendments to improve soil structure, biodegradation of oil and re-vegetation, (Colgan III, Vavrek and Bolton, 2002) [3]. Hydrocarbon and salt contaminated groundwater may require surfactant or co-solvent treatment in conjunction with the conventional pump and treat and secondary water treatment clean-up technologies. In Alberta for saline (produced) waters, deep well containment and disposal of leachates is a common practice and regulated by the Energy and Utilities Board (Alberta Environment, 2001) [2]. For water (including salt impacted) discharge, the local government, (City of Calgary), recommends the application of the Storm Sewer (Bylaw 26M98) and Sanitary Sewer (Bylaw 24M96) both of which are based on the provincial Alberta Surface Water Quality Guidelines.

There are excellent resources for de-icer (road) salt management made available by the Transport Association of Canada and Environment Canada, (Chemicals Control Division), through the collaborative contribution of national, provincial and municipal transportation and associated professionals. However, there is limited or no information available on the sustainable salt remediation alternatives *(in-situ)* for the clean-up of existing de-icer salt impacted soils and specifically difficult soils like those presenting low soil permeability. Current remediation practices for existing de-icer salt impacted soils include *(ex-situ)* alternatives, (excavation transportation, and landfill disposal), or containment and capping. While these mitigation measures have their merits, they either transfer the problem or mandate long-term monitoring, maintenance and management costs and restrict land use without permanently solving the problem. Consequently, the Environment Management of the City of Calgary identified a pragmatic need for sustainable de-icer salt remediation alternatives and sponsored this remedial feasibility study.

Challenge

The 22X site located at highway 22X and 14th Street S.W., is one of approximately ten de-icer salt storage yards providing winter maintenance for the rapidly expanding urban transportation systems of the City of Calgary. The soil media for this study were sampled at (0.0m, 1.0m, 2.0m and 3.0m) depth below ground surface and the ground water was sampled between (1.18m and 3.50m) from the delineated areas of the highest salt (NaCl) impact at the 22X site. The background soils showed no evidence of NaCl contamination with a chloride concentration of 32 mg/Kg and sodium concentration of 15 mg/Kg. In the surface soils sampled from five test pits elevated chloride concentrations ranging from 8200 mg/L (2133 mg/Kg) to 47,600 mg/L (23,801 mg/Kg) and sodium concentrations ranging from 4710 mg/L (1225 mg/Kg) to 20,700 mg/L (10,373 mg/Kg) were evidenced. In soils at 1.0 m, 2.0 and 3.0 m depths salt concentrations ranged from a high of 19,400 mg/L (8556 mg/Kg) to a low of 473 mg/L (227 mg/Kg) for chloride, and a high of 11,500 mg/L (5038 mg/Kg) to a low of 105 mg/L (50 mg/Kg) for sodium. The NaCl soil concentration at 22X gradually decreased by depth. An elevated chloride concentration of 4730 mg/L and sodium concentration of 2090 mg/L was found in the ground water composite. Sieve and hydrometer analysis conducted on select soil composites provided an estimate of the spatial variability in 22X soil physical properties and confirmed the clay and silt content with sand and gravel. Hydraulic tests conducted on the site ranging between 3.0m to 9.0m indicated that the permeability *K* ranged from 10^{-10} m/s to 10^{-8} m/s. The soil permeability *K* of the 22X soils from bench-scale measurements ranged from 10^{-8} cm/s to 10^{-4} cm/s. A synthesis of bench scale and site hydraulic conductivity confirmed that the 22X soils presented low soil permeability and poor drainage. For soil permeability of K~10 $^{-5}$ cm/s, in-situ soil remediation technologies have marginal success while soils with K <10 $^{-6}$ cm/s are normally a challenge to remediate and less likely to succeed.

Methods and Observations

The green chemistry principles (EPA-742-F-02-003, March 2002) [4] were employed in the design and operation of these three bench-scale technologies (SFR, SCA and EKR) wherever possible and some associated green chemistry techniques were extrapolated from an applied research performed on a suite of BC soils in an earlier (2001) SRADSI project, as summarized below. The soil pre-treatment commenced with a series of range tests using clear acrylic soil columns in order to determine the optimum conditions to promote soil hydraulic conductivity and prevent sodicity. The solvent used was de-ionized water. Following these iterative experiments a common soil amelioration regime was designed for the 22X test soils using natural materials (a 50% by weight blend of 1.9 cm and 7.0 mm washed gravel) and a suitable anti-dispersant (a 10:1 w/w ratio of calcium nitrate and calcium sulphate) mixture was blended. The 50% (by weight) blend of natural materials was used on all test soils uniformly but the amount of anti-dispersants differed depending on the technology simulated. For the SFR and EKR soils a 3.0% by weight soil anti-dispersant was used and for the SCA soils the TGR (Theoretical Gypsum Requirement) value was used to determine the amount of soil anti-dispersant required on the test soils.

The SFR, SCA and EKR technological simulations focused on a comprehensive reduction of the target de-icer salt contaminant NaCl at various (surface, 1.0m and 2.0m) soil depths. Further, the three technologies tested had the potential to clean-up contaminant chlorides of $Ca^{2+,}$ K^{+} and Mg^{2+} in the soil and water media. The SFR involved the flooding of each of the fifteen contaminated test pit (TP) soils (approximating 25 kg each), by a hydro-injection process. Extraction fluid recovered from the underlying base by hydro-suction amounting to a total volume of (~100L to 150L) per test sample was able to dissolve and mobilize the sodium and chloride ions in 5 days and formed the feed water for the desalination unit. The R.O. desalination unit of output capacity (~ 18.9 Lph) produced a permeate (salt free water) stream and a brine stream for reuse and storage respectively. The desalination unit was also used to treat the 22X site ground water composites collected from the area of maximum de-icer salt impact.

The SCA involved the irrigation (volume <32 L each) of the fourteen proctor compacted salt contaminated soils in (surface, 1.0m and 2.0m) soil columns (~15 Kg each) mixed with a soil amendment mixture based on their corresponding soil theoretical gypsum requirement (TGR) value. The soil amendment mixture developed from the anti-dispersant range tests comprised the 10:1 w/w calcium nitrate and sulphate blend. During the 30-day column irrigation regime the mono-valent, sodium ions were displaced by the replacement calcium ions and a major reduction in soil EC and SAR was seen. The drainage leachates from column tests were desalinated, and the permeate collected for testing and reuse.

EKR was a low DC voltage demonstration system designed with two (positive and negative) electrodes positioned about 30 cm apart in two electrode wells, and five intermediate cells inserted between the electrodes in order to track the alkaline pH front and the movement and depletion of Cl^- and other charged species across the stationary phase. Each EKR test required approximately 5.0 L of deionized water for a 25 Kg test sample and produced chlorine gas at the positive electrode and sodium ions at the negative electrode. During the 18 to 30 day test period a substantial depletion of chloride from soil was confirmed.

The remediated test soils were sieved using a 2mm mesh to exclude the natural materials before the final chemical testing was performed. Post remediated surface soils form SFR, SCA and EKR simulations were subject to acute and chronic toxicological testing using *(F.Candida)*. By a process of elimination based on *(F.Candida)* toxicity results a plant bioassay using lettuce seed germination was conducted on two of the three least toxic SFR and SCA soils. A leachate control test was conducted on EKR soils after mixing it with a commercial eco-binder to explore the potential soil reuse as road sub-grade material.

Result Summary

The results of SFR for each of the fifteen 22X (TP) soil composites ranging from the (surface, 1.0m and 2.0m) depths produced a major reduction in NaCl. The average percent reduction after soil flushing remediation was (92.4%) for sodium, (96.5%) for chloride, (75.0%) for EC and (80.0%) for SAR, Tables 1 and 2 . The desalination of soil flushed aqueous composites produced a significant reduction of 83.7% and 84.3% in sodium and chloride respectively. It also reduced the EC by 86.2% and TDS by 87.5% Table-3. The desalination of groundwater composites from the 22X monitoring wells produced a substantial reduction of 90.1% and 98.2% in sodium and chloride respectively. A major decrease of 91.4% in TDS and 90.7% in EC concentration was also seen in the treated groundwater composites Table-3.

The results of SCA for each of the fourteen 22X (TP) soil composites Table-1, ranging from the (surface, 1.0m and 2.0m) depths produced a major reduction in NaCl. The average percent reduction after soil calcium amendment was (96.8%) for sodium, (97.8%) for chloride, (96.0%) for EC and (78.0%) for SAR, Table-2. The desalination of soil calcium amended leachates produced a reduction of (97.8%) for sodium, (96.8%) for chloride, (96.6%) for EC and (97.3%) for TDS, Table-3. EKR tests were conducted on TP-2 soils without soil pre-treatment (no permeability enhancement) and TP-4 soils with soil pre-treatment (with permeability enhancement) in order to test EKR efficacy and investigate their respective NaCl depletion rates in the 18 to 30 day test period.

Table-1 Comparison of Sodium and Chloride Results after SFR, SCA and EKR

		SFR	SCA	EKR
LOCATION & DEPTH	PARAMETERS	PERCENT REDUCTION IN DRY SOIL %	PERCENT REDUCTION IN DRY SOIL %	PERCENT REDUCTION IN DRY SOIL %
TP-5-SURF BKG	Chloride (Cl)	n/a	n/a	n/a
TP-5-SURF BKG	Sodium (Na)	n/a	n/a	n/a
TP-5-1.0M BKG	Chloride (Cl)	n/a	n/a	n/a
TP-5-1.0M BKG	Sodium (Na)	n/a	n/a	n/a
TP-5-2.0M BKG	Chloride (Cl)	n/a	n/a	n/a
TP-5-2.0M BKG	Sodium (Na)	n/a	n/a	n/a
TP#1 SURF	Chloride (Cl)	99.3	100.0	*
TP#1 SURF	Sodium (Na)	98.0	99.5	*
TP#1 1.0M	Chloride (Cl)	98.4	94.1	*
TP#1 1.0M	Sodium (Na)	96.3	93.9	*
TP#1 2.0M	Chloride (Cl)	95.3	*	*
TP#1 2.0M	Sodium (Na)	89.5	*	*
TP#2 SURF	Chloride (Cl)	94.1	99.8	98.9
TP#2 SURF	Sodium (Na)	89.4	99.2	89.0
TP#2 1.0M	Chloride (Cl)	81.7	99.7	*
TP#2 1.0M	Sodium (Na)	98.2	95.6	*
TP#2 2.0M	Chloride (Cl)	97.9	*	*
TP#2 2.0M	Sodium (Na)	95.6	*	*
TP#3 SURF	Chloride (Cl)	99.7	99.6	*
TP#3 SURF	Sodium (Na)	99.5	96.6	*
TP#3 1.0M	Chloride (Cl)	98.7	96.4	*
TP#3 1.0M	Sodium (Na)	55.7	69.6	*
TP#3 2.0M	Chloride (Cl)	93.6	*	*
TP#3 2.0M	Sodium (Na)	70.9	*	*
TP#4 SURF	Chloride (Cl)	99.7	98.7	99.6
TP#4 SURF	Sodium (Na)	98.5	99.5	99.4
TP#4 1.0M	Chloride (Cl)	98.8	99.7	*
TP#4 1.0M	Sodium (Na)	98.7	99.1	*
TP#4 2.0M	Chloride (Cl)	98.4	99.9	*
TP#4 2.0M	Sodium (Na)	97.9	97.9	*
TP#6 SURF	Chloride (Cl)	99.0	99.8	*
TP#6 SURF	Sodium (Na)	99.2	99.1	*
TP#6 1.0M	Chloride (Cl)	96.0	99.7	*
TP#6 1.0M	Sodium (Na)	98.2	97.9	*
TP#6 2.0M	Chloride (Cl)	97.1	99.8	*
TP#6 2.0M	Sodium (Na)	100.0	97.4	*

BKG: Background; * Not tested

Table-2 Comparison of EC and SAR Results after SFR, SCA and EKR

	SFR		SCA		EKR	
	% EC REDUCTION	% SAR REDUCTION	% EC REDUCTION	% SAR REDUCTION	% EC REDUCTION	% SAR REDUCTION
TP-1-SURF	96.7	97.0	98.9	98.3	*	*
TP-1-1.0m	89.7	93.1	90.8	87.4	*	*
TP-1-2.0m	66.6	42.6	*	*	*	*
TP-2-SURF[1]	97.0	92.4	99.1	95.4	-4.0[2]	-564[2]
TP-2-1.0m	-8.3	33.0	95.5	75.5	*	*
TP-2-2.0m	89.1	57.9	*	*	*	*
TP-3-SURF	97.4	98.8	97.7	98.7	*	*
TP-3-1.0m	86.4	40.0	85.1	-50.0	*	*
TP-3-2.0m	-5.6	64.7	*	*	*	*
TP-4-0.0m SURF	95.7	95.7	98.7	91.5	87.7	98.4
TP-4-1.0m	90.0	97.1	98.1	94.1	*	*
TP-4-2.0m	83.8	96.4	97.4	78.8	*	*
TP-6-0.0m SURF	88.8	98.0	97.7	94.7	*	*
TP-6-1.0m	77.5	94.2	96.8	91.8	*	*
TP-6-2.0m	82.7	92.7	96.4	79.9	*	*

Note:* Not tested 1 Without permeability enhancement [2] (-ve values denote and increase).

Table-3 Comparison of Ground water, SFR and SCA results after Desalination

PARAMETERS	GW BEFORE	GW AFTER	SFR BEFORE	SFR AFTER	SCA BEFORE	SCA AFTER
Chloride (Cl) mg/L	4730	86.4	1200	196	3880	86.3
Sodium (Na) mg/L	2090	207	950	149	2770	90
Total Dissolved Solids mg/L	10200	878	6820	853	18000	481
pH	7.6	8.0	7.0	7.3	5.5	6.8
Conductivity (EC)	15.1	1.41	9.63	1.33	22	0.7
Hardness (as CaCO3) mg/L	4370	42	2730	266	6460	131
Alkalinity,T (CaCO3) mg/L	259	29	21	19	6	14

The EKR results for the TP-4 test soil produced a major reduction in concentration of (99.0%) for sodium, (99.6) for chloride, (87.7%) for EC and (98.4%) for SAR. The EKR results for the TP-2 test soil produced a major reduction in concentration of (89.0%) for sodium, (98.9%) for chloride, but showed a major increase of (4.0%) for EC and (>100%) for SAR Tables-1 and 2.

Figure-1 SFR, SCA and EKR Results after NaCl Remediation in TP-4 Surface Soils

Figure-2 Soil Quality after SFR, SCA and EKR in TP-4 Surface Soils

Met
SAR
Not
EC

Met
EC
Not
SAR

Met
SAR
Not
EC

The result of one set of test soils (e.g. TP-4 surface) after SFR, SCA and EKR illustrating the NaCl decontamination accomplished is shown in Figure-1. The soil quality results after each simulation, where at least one of the soil quality parameters did not meet the applicable Alberta Environment Guideline are shown in Figure-2. The post remedial acute and chronic toxicological testing was based on the mortality of F.*Candida* in TP-4 surface soils. Figure-3 illustrates the mean numbers of F. *candida* surviving in undiluted test soils after 7 days. Ten individuals were added to each test unit at the start of each test. Numbers followed by the same letter do not differ from one another (Bonferroni multiple range test, $p<0.05$).

Figure-3 Acute Toxicity Testing- TP-4

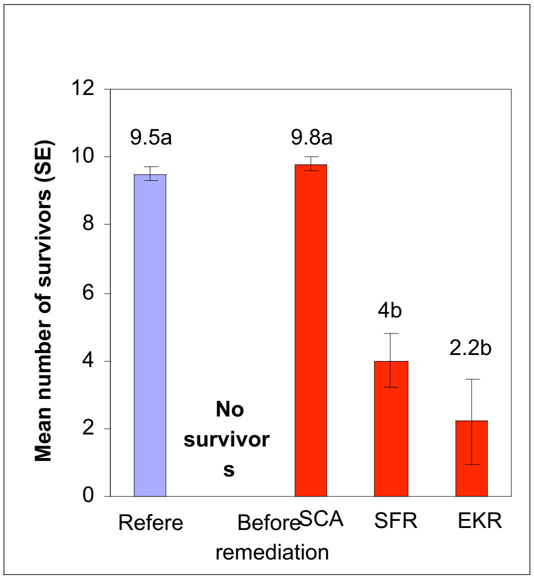

Figure-4 Chronic Toxicity Testing - TP-4

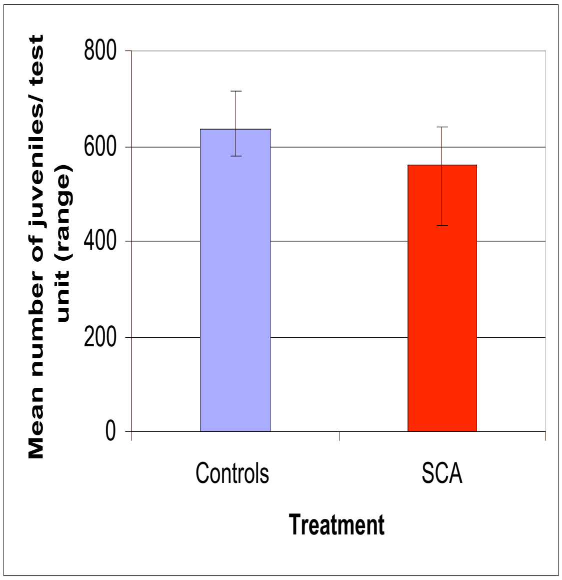

Figure-4 illustrates the mean number of juvenile *F. candida* /test unit after 6 weeks exposure to uncontaminated reference soil (controls) or to contaminated soil, that had been remediated using SCA. Error bars show the range of the individual replicate counts for each treatment. Figure-5 illustrates that nutrient composition of the SFR soil at a 100% (without soil dilutions) that evidenced no phyto-toxicity. This result was based on a germination rate of 76% against a reference soil germination rate of 82%. It also depicts the nutrient composition of SCA soil at 50% dilution (with the reference soil), which showed phyto-toxicity based on a germination rate of 44% against a reference germination rate of 88%. The leachate control results in post-remediated EKR soils before and after using a commercial eco soil binder has been depicted in Figure-6.

Figure-5 Phyto-Toxicity Testing- TP-4

Germination 76% with no soil dilution

***Germination 44% with 50% dilution**

Figure-6 Leachate Control - TP-4

Assessment Summary

The SFR, SCA and EKR technological simulations tested in this study met the primary objective in accomplishing a (>90.0%) decontamination of NaCl de-icer salt from a total of twenty nine, 22X test soils and a (>80.0%), desalination of NaCl from a total of six leachate and ground water composites. Further, a substantial reduction in the soil quality parameters EC (>75%) and SAR (> 78%) was achieved in the test soils excluding the TP-2 EKR test soil. TP-2 test soil produced a major increase of (4.0%) in EC and (>100%) in SAR Tables-1 and 2. This increase in soil EC and SAR was not expected as literature studies indicate that EKR is particularly applicable to soils presenting low soil permeability. However, based on the experimental results, using the TP-2 soil without any pre-treatment (permeability enhancement) likely inhibited the hydraulic conductivity and promoted soil dispersion contributing to the high EC and SAR results. All other remediated test soils that were subject to soil pre-treatment, showed a major decrease in EC and SAR, but had at least one of the two soil quality parameters that occasionally did not meet the applicable Guideline likely because of inherent soil heterogeneities in the test soils Table-4. The SFR soils presented a SAR that met the soil quality Guidelines but had one *Unsuitable* EC result out of fifteen composites. The SCA soils presented an EC that met the soil quality Guidelines but had one *Unsuitable* SAR result out of twelve composites. The EKR soils presented one SAR value that met the soil quality Guidelines and one SAR value that did not and showed two *Unsuitable* EC results out of the two composites tested Table-4.

Table-4 : Comparison of Regulatory Soil Quality (EC and SAR) Parameters

DEPTH AND LOCATION	EC			SAR		
	SFR	SCA	EKR	SFR	SCA	EKR
	GSQG [1] FOR ULU	GSQG [1] FOR ULU	GSQG [1] FOR ULU	GSQG [1] FOR ULU	GSQG [1] FOR ULU	GSQG [1] FOR ULU
TP-5-0.0m BKG	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
TP--5-1.0 m BKG	GOOD	GOOD	*	GOOD	GOOD	*
TP-5-2.0m BKG	GOOD	GOOD	*	FAIR	FAIR	*
TP-1-0.0m Top Soil	GOOD	GOOD	*	GOOD	GOOD	*
TP-1-1.0m Sub Soil	GOOD	GOOD	*	GOOD	FAIR	*
TP-1-2.0m Sub Soil	GOOD		*	GOOD		*
TP-2-0m Top Soil	GOOD	GOOD	UNSUITABLE	POOR	FAIR	UNSUITABLE
TP-2-1.0m Sub Soil	UNSUITABLE	GOOD	*	FAIR	GOOD	*
TP-2-2.0m Sub Soil	GOOD		*	GOOD		*
TP-3-0.0m Top Soil	GOOD	GOOD	*	GOOD	GOOD	*
TP-3-1.0m Sub Soil	GOOD	GOOD	*	GOOD	GOOD	*
TP-3-2.0m Sub Soil	GOOD		*	GOOD		*
TP-4-0.0m Top Soil	POOR	GOOD	UNSUITABLE	GOOD	POOR	GOOD
TP-4-1.0m Sub Soil	FAIR	GOOD	*	GOOD	FAIR	*
TP-4-2.0m Sub Soil	FAIR	GOOD	*	GOOD	UNSUITABLE	*
TP-6-0.0m Top Soil	POOR	GOOD	*	GOOD	FAIR	*
TP-6-1.0m Sub Soil	POOR	GOOD	*	GOOD	FAIR	*
TP-6-2.0m Sub Soil	GOOD	GOOD	*	GOOD	POOR	*

1 GSQC for ULU: Generic Soil Quality Guidelines for Unrestricted Land Use, Salt Contamination Assessment & Remediation Guidelines, Alberta Environment, May 2002. * Not Tested

Longer treatment or a reapplication regime may have improved these soil quality parameters further but it is not certain that these improvements would be effective in meeting the recommended soil quality Guidelines. The leachate and ground water composites after desalination Table-3 met the applicable Alberta Environment Surface Water Quality Guidelines and demonstrated the potential for water reuse. Also, there was the potential to explore waste brine recycling for future de-icing. The post remediation SFR, SCA and EKR soils when tested for acute and chronic toxicity Figures-3 and 4, demonstrated that the SCA soil at a 100%, (with no dilutions), was not toxic to collembolans *F. Candida.* From the plant bioassay results, it was evident that the post remediation soils after SFR at a 100%, (with no dilutions) were not toxic to the test crop (lettuce seed germination) Figure-5. The leachate analysis confirmed that the post remediation EKR, soils after mixing with an eco-soil binder at a 100%, (with no dilutions) could be re-used for road bedding, Figure-6. These tests apart from meeting the related objective, provided valuable information in determining the re-integration potential of post-remediated soil into the environment. Following the soil and water quality assessments the advantages and limitations of the three remedial technological simulations have been compared and summarized in Table-5.

Table-5 Comparison of the Advantages and Limitations of SFR, SCA and EKR

Advantages	Limitations
SFR: Executes a rapid mass reduction averaging (>90%) of cation and anion contaminants in soil and (>80.0%) in water via desalination; quick clean-up time (< 1 week); Post remediated SFR soils (without any soil dilution) was not *Phyto-toxic.* SFR soil with a 20.0% reference soil dilution was not *Toxic* to F. *Candida.* Potential for treated water recycling and brine reuse; Water quality met Guidelines	SFR: It is inhibited by low soil permeability; Dependent on large volumes of water and efficient hydro-extraction and water treatment. Post remediated soil quality presented a high EC trend; EC parameter did not meet pertinent soil quality Guidelines
SCA: Improves soil quality. Accomplishes major chloride and sodium contaminant reduction in soil averaging (>90%) and via desalination in water (>80.0%); Post remediated SCA soil (without soil dilutions) was not *Toxic* to F. *Candida* based on acute and chronic toxicity testing. Potential for treated water recycling and brine reuse; Water quality met Guidelines	SCA: It requires a lengthy clean-uptime (>30 days)and is dependent on efficient drainage and leachate recovery. Post remediated soil quality presented a high SAR Trend. The SAR parameter did not meet pertinent soil quality Guidelines. SCA with 50% soil dilution was *Phyto-toxic* (seed germination)
EKR: Demonstrates significantly large chlorine depletion averaging (>98.0%) and sodium removal rates (>89%) from soil. Post remediated EKR soil with a 20.0% reference soil dilution was not *Toxic.* Leachate analysis of EKR soil revealed excellent leachate control and met pertinent Guidelines.	EKR: It is inhibited by high pH imbalances, secondary precipitates, and off-gas emissions, (>30 day) clean-up duration. Post remediated soil quality presented a high EC trend. The EC parameter did not meet pertinent soil quality Guidelines.

Conclusion and Next Steps

This study confirmed that all three technological simulations were able to substantially (>90.0%) reduce NaCl contamination in difficult to treat clay soil. The desalinated leachate and ground water composites demonstrated the potential for water reuse after meeting the applicable water quality Guidelines. Further, the post remedial toxicity, phyto-toxicity and leachate control testing confirmed the potential for soil re-integration or reuse.

This study also confirmed that accomplishing a large reduction of EC and SAR in soil does not necessarily guarantee compliance to the applicable soil quality Guideline Table-4. In a potential field application the success of achieving a significant NaCl decontamination in clay soil is viable but when the scale and occurrence of soil heterogeneity is high, it is likely that there will be less certainty about the uniformity of soil quality treatments and their ability to meet soil quality compliances. It is therefore imperative that pilot tests be performed at the 22X site before any future field scale-up on site remediation is considered. Some key aspects of future work at 22X should include

a) designing and operating a site specific, hydraulically isolated pilot scale demonstration with proper engineering and process controls (to reduce the downstream impacts to the soil, water and air media, reduce waste generation and prevent pollution) for the three technological simulations tested in this study,
b) focusing on the uniformity of soil quality treatment to meet compliances (e.g. scheduling longer treatment or reapplication regimes)
c) conducting a sustainability focussed technology cost and benefit analyses.

These next steps should assist decision makers in providing actual cost data and sufficient real-time technology performance information to determine the most suitable technology/treatment process demonstrating remedial reliability and cost competency for a full field scale 22X site remediation.

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