

# **ENGINEERED SOIL COVERS FOR MANAGEMENT OF SALT IMPACTED SITES**

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## **INTRODUCTION**

Salt impact to vegetation growth, surficial soils and shallow groundwater resources as a result of spills and line leaks at operating oil and gas facilities and oil field drilling activities is a significant environmental and liability concern for the operators and regulators. Current remediation practices for salt impacted sites at oil and gas facilities consist of excavation and disposal, drainage improvement combined with pump and treat, or chemical amendments including gypsum or calcium nitrate. These remediation techniques have met with limited success in fine-grained soils and can be relatively expensive; particularly excavation and disposal. Risk management approaches for salt impacted sites has generally consisted of long term monitoring, however the potential for further surficial soil impact, continued impaired vegetation growth or shallow groundwater impact is a significant likelihood. As well, the risk management option of long term monitoring can be expensive over numerous years and requires landowner acceptance.

A significant majority of oil field production leases in Western Canada are located where the near surface stratigraphy consists of fine grained soils (clay or clay till) with shallow groundwater within a few meters of ground surface. Shallow groundwater resources at the vast majority of these sites are not used for drinking or irrigation purposes. The major environmental challenges on these sites is to return the land to it's pre oil field activity equivalent land capability and minimize the long term environmental impairment or impact should complete remediation to current applicable generic guidelines be impractical.

The use of engineered soil covers systems in the mining industry to mitigate environmental impact from tailings and waste rock piles is becoming more and more an accepted practice (Price and Errington 1998). In particular, engineered soil covers systems have been used where Acid Rock Drainage (ARD) from tailings and waste rock piles are of environmental concern. A significant body of theoretical research, instrumented test covers and instrumented full-scale covers has provided an understanding of the complex interaction of near surface moisture movement, evaporation and (vegetation) transpiration in unsaturated soils. The theoretical basis for the design of these soil cover systems has been well published by many (Nicholson et. Al. 1989, Barbour 1990, Yanful 1991, Rasmuson and Erikson 1986, O'Kane et al. 1993) and is not the focus of this paper.

The use of an engineered soil cover that focuses on developing a healthy vegetative cover, minimizing or eliminating infiltration and minimizing the potential for a long term exfiltration flux which would mobilize the salt minerals at depth to within the root zone

may be an acceptable risk management approach for salt impacted sites. This paper presents the design concepts used for soil covers related to reclamation practices in the mining industry and its potential applicability for an effective risk management practice at salt impacted sites.

## **ENGINEERED SOIL COVER DESIGN APPROACH – MINING APPLICATION**

### **Acid Rock Drainage Research**

Significant research and evaluation of the performance of engineered soil covers has been conducted since the late 1980's in an effort to effectively mitigate environmental impacts associated with ARD. In the case of ARD, acidic leachate is generated when both oxygen and moisture react with sulphide bearing minerals within the mine wastes. The primary design objectives for soil cover systems used in the mitigation of ARD (Barbour et al. 1996, O'Kane Consultants Inc. 2002, O'Kane and Wels 2003) are the following:

- Minimize the flux of oxygen to the underlying waste by maintaining a high degree of saturation within a layer of the cover system thus reducing oxygen diffusion rates; and / or,
- Minimize the flux of precipitation to the underlying waste by placement of a low permeability layer or a moisture storage and release layer within the cover system.

A soil cover system to be effective in the mitigation of ARD would be required to meet either or both of the above objectives. The growing body of research and performance monitoring of test covers and constructed covers at mine sites throughout the world has provided insight and development of effective soil cover designs to meet the intended design objectives. The research and performance monitoring data have provided a thorough understanding of the complex issues controlling moisture flow and oxygen ingress through dry soil covers.

- In addition to the above performance design objectives, other important operation and maintenance design objectives for soil covers involves maintaining the long term physical (sustainability from erosion and rodent damage) and ecological (sustainability of vegetation growth) stability of the cover system.

Although continued performance monitoring is being conducted on constructed soil, performance data beyond 10 (now 15) years in length is limited (Price and Errington 1998). Nonetheless, to date soil cover systems have demonstrated long term sustainability and more monitoring data are being published each year towards providing areas of further research and investigation.

### **Typical Engineered Soil Cover Systems**

For mining applications various performance characteristics of a soil cover system are employed at any site to achieve the design objectives described above. O'Kane and Wels (2003) have promoted the use of "impact -oriented" criteria for design and selection of soil cover systems, where short term and long term impacts on the receiving environment

at a particular site form the basis for soil cover design. Regardless of the design approach, soil cover systems used for mining waste reclamation incorporate one or a combination of the following principles into the final design (O’Kane and Wels 2003):

- A conventional low hydraulic conductivity cover;
- A capillary barrier cover; and/or,
- A store and release cover.

Design factors that are evaluated as part of selecting one or a combination of design principals for a soil cover system include consideration of the local climate, waste characteristics, geologic, hydrogeologic and hydrologic settings, and the local availability of potential cover materials.

A conventional low hydraulic conductivity cover generally involves use of a compacted clay or clay till to limit infiltration. This cover system is often selected in regions where precipitation equals or exceeds evapotranspiration losses in a typical year (O’Kane and Wels 2003). In a typical Prairie climate (semi arid), a compacted clay layer would become desiccated if left unprotected from the elements and with time become less effective in meeting the objective of limiting infiltration. If the wastes being covered are fine grained, there is also a potential of moisture from the compacted zone to flow into the dryer underlying wastes.

A capillary barrier results when a fine-grained material is placed over a coarse grained material. The capillary barrier is created when as a result of relatively low infiltration fluxes the underlying coarse material becomes unsaturated and the resulting hydraulic conductivity (with respect to water flow) is lower in the coarse layer than within the overlying fine grained material (Nicholson et. al. 1989, Barbour 1990, Yanful 1991). In essence, the coarse grained layer prevents moisture movement downward (or upward) from the fine-grained layer. The capillary barrier can significantly reduce net infiltration into underlying waste if unsaturated conditions are maintained.

In regions where the climate is such that the potential evaporation flux is generally much greater than the cumulative precipitation, a store and release cover may be a more effective soil cover design (O’Kane et al. 2000, Wels et al. 2000). In this cover, a thick generally uncompacted soil profile is constructed. The cover surface is sloped in such a manner to minimize surficial ponding and promote runoff. The performance characteristics of this cover involve allowing infiltration during precipitation events. The loose material unsaturated characteristics then permit the moisture to partially penetrate the soil profile; however, the long-term evapotranspiration flux ultimately removes the stored moisture before the wetting front reaches the base of the rooting depth. In this cover design scenario, precipitation events must rarely be excessive and of long duration.

Using these or variants of these design principles researchers have been successful in reducing and managing the generation of ARD at mine sites throughout the world. Design principles use basic unsaturated soil theory although this theory is complex it is possible to apply these design principles to any problem, which involves shallow unsaturated moisture movement.

## **Computer Program “SoilCover”**

In addition to laboratory and field scale testing of soil cover systems, a computer program “SoilCover” (MEND 1997) was developed to assist in the design performance of soil cover systems. SoilCover is a finite element software package used to predict saturated and unsaturated groundwater movement through the shallow soil profile. Unique capabilities of this program over other groundwater movement packages include SoilCover’s ability to predict the moisture flux across the soil surface-atmosphere interface. In doing so, the program calculations not only involve the conservation of mass, but also the conservation of energy through the soil profile (and atmosphere).

SoilCover can predict the evaporation from a bare soil surface or both the evaporation and transpiration components from a vegetated soil profile. Data requirements for a SoilCover simulation include definition of a soil profile, unsaturated soil properties for each profile soil type, and detailed climatic parameters for the simulated season. The climatic variables are commonly measured variables at most regional meteorology stations. For design systems, regional climatic data may be reasonable; however, once a field scale test cover is installed and instrumented site-specific climatic data is necessary.

Soil properties include the soil-water characteristic curve, which describes the relationship between the moisture content within the soil and the energy level of the water phase in the soil matrix. As the matric suction (negative pressure) of the soil increases, the pores within the soil matrix dewater from largest diameter to smallest. The air entry value of the soil is an important unsaturated soil property and is defined as the matric suction at which point initial pore drainage occurs. The air entry value for coarse-grained soils (i.e. sands) is much lower than that for fine-grained soils (i.e. clays).

The unsaturated hydraulic conductivity function also needs to be defined within SoilCover. This function describes the ability of a soil to conduct liquid phase water at varying energy levels within the soil matrix. The hydraulic conductivity of the unsaturated soils decrease from the saturated value with increasing matric suction. The rate of decreasing hydraulic conductivity is directly related to the shape of the soil-water characteristic curve. The clay materials have a modest decrease in moisture content with increasing suctions and as a result the hydraulic conductivity function decreases modestly. In general, the tortuosity of the water movement increases, but a continuous water phase occurs within a clay soil at high suctions. Alternately, sand desaturates quickly at suctions greater than the air entry value, the liquid water filled pores become discontinuous and as a result the unsaturated hydraulic conductivity of the soil decreases dramatically beyond the air entry value. This basic unsaturated soils principle forms the performance characteristics of a capillary break within a soil cover system. When saturated, sand is highly permeable, however if an unsaturated state can be maintained, a sandy soil forms a hydraulic barrier to moisture movement.

## **APPLICATION OF SOIL COVER SYSTEMS TO SALT IMPACTED SITES**

### **Proposed Design Approach**

Design of an engineered soil cover on salt impacted land may be an acceptable risk management practice. The basic design philosophy does not vary significantly from that of the ARD objectives except the movement of oxygen through the cover is not important. The design objectives revert to simply the control of moisture above the impacted soils through the rooting zone.

Using a soil cover system as a risk management option, the impacted soils are not removed, rather are covered with a soil cover system. The soil cover provides a clean soil profile for the rooting zone. The soil cover would require engineering to ensure the fluxes through the base of the cover into the salt impacted native soils do not impact the new soil profile. To meet this latter objective, the engineered soil cover is designed to ensure an upward exfiltration flux does not occur. Furthermore, the design could be optimized by ensuring the infiltration flux is not excessive (near zero), mobilizing the salt plume either downwards and/or horizontally.

The above design approach for salt impacted sites would be applicable to low sensitivity receptor sites, where shallow groundwater is not used for drinking, irrigation or livestock watering and surface water bodies that support aquatic life are not within 300 m of the impacted area. The primary receptor of significance is the surface vegetation. Local topographically controlled shallow groundwater recharge or discharge areas downgradient of the impacted area would require site-specific evaluation.

### **Proposed Soil Cover System**

Considering the majority of the Prairies are located within a semi arid climate and that near surface stratigraphy is predominantly fine grained, the proposed soil cover system to meet the above objectives at a salt impacted site would consist of the following:

- A store and release cover for vegetation sustainability; and
- A capillary break to limit infiltration and minimize exfiltration of the underlying salt up into the vegetated cover.

The capillary break, provided it remains unsaturated, would also act to minimize diffusion of salts upwards based on research by Lim et al. (1999) which has shown that the diffusion coefficient for a soil decreases as the degree of saturation decreases. The capillary break would also reduce the impact of frost heave as the capillary break would limit moisture movement upwards (from the underlying water table) towards the freezing front (Henry and Holtz 2001) in the cover material above the capillary break.

## **Regulatory Setting**

Currently in Alberta, the Salt Contamination Assessment and Remediation Guidelines (AENV, May 2001) provide the regulatory framework for assessment, remediation and risk management practices of salt impacted sites.

Under Alberta's Environmental Protection and Enhancement Act (province of Alberta 1992) the following requirements must be met with respect to responsible parties in remediation of lands where substance releases have occurred:

- Contaminant concentrations must meet remediation objectives (background levels, generic guidelines or site-specific risk-based objectives) or better.
- Any residual contamination must not adversely affect ("Impairment of, or damage to, the environment, human health or safety or property") current receptors or other potential receptors possible under the existing land use.
- Capability of the affected area must not be any more limiting after remediation than before the spill – "equivalent land capability".

Current remediation objectives for salt impacted sites are based on "Soil Quality Relative to Disturbance and Reclamation" adapted from Alberta Agriculture (1987) and the Canadian Council of Ministries of the Environment (1991).

Under the current regulatory framework in Alberta, remediation to generic guideline levels is expected in order to obtain a Reclamation Certificate. Alternatively, the proponent may implement a risk management strategy that will manage the salts in place in a manner that the risk of adverse effects is minimized. There would be a requirement for ongoing monitoring and acceptance of long-term liability. In addition, regulatory acceptance of the risk management approach is contingent on Landowner acceptance.

## **Soil Cover Systems and Risk Management**

There may be some merit for regulatory acceptance of soil cover systems within the regulatory framework under risk management if the following objectives can be demonstrated:

- An Engineered Soil Cover System eliminates or minimizes infiltration and mobilization of salts to the shallow groundwater table;
- An Engineered Soil Cover System eliminates or minimizes exfiltration of the salt impacted soils upwards through the cover so that "equivalent land capability" of unimpacted surface soils is maintained; and
- An Engineered Soil Cover System demonstrates that no adverse effect to the environment or human health will occur in the long term.

Landowner acceptance may be more likely if "equivalent land capability" could be established and demonstrated that no long-term environmental impact will occur. This approach would likely reduce the post cover construction monitoring costs and with long-term sustainability of the cover demonstrated, regulatory acceptance of the cover without

long term monitoring may be a possibility. However, a research process similar to the approach the mining industry has undergone would be required before regulatory acceptance is likely.

## **ENGINEERED SOIL COVER SYSTEM ANALYSIS**

### **Site Setting**

A hypothetical salt impacted site was used to demonstrate the potential effectiveness of an engineered soil cover to meet design objectives and regulatory requirements for risk management. An agricultural based site near Edmonton, Alberta was selected for the hypothetical analysis. The hypothetical site conditions consisted of clay matrix till with the water table located 3 m below ground surface. The site shallow groundwater has no defined use (i.e. drinking, irrigation or livestock watering) and surface water bodies that may support aquatic life are not located within 300 m of the site. Average annual climate data provided by Environment Canada for the Edmonton Area was used for the analysis.

### **Objectives and Method of Analysis**

The objectives for selecting the optimum soil cover design are to:

- Establish sustainable “equivalent land capability” of surface soils, and
- Demonstrate no adverse effect to the environment or human health will occur in the long term.

The first objective would be obtained immediately with the construction of a soil profile using clean clay rich soils and appropriate organic topsoil. Ensuring long-term sustainability of the agricultural productivity is accomplished by maintenance of a net infiltration flux (or zero) beneath the rooting zone so salts occurring at depth do not re-impact the shallow soils with upwards-unsaturated groundwater movement. In addition, a soil cover that will retain sufficient moisture for vegetation sustainability over the long term would be required. Establishing no adverse effect to the environment or human health would be accomplished with a soil cover that would eliminate or limit infiltration to the underlying salt impacted soils.

The computer program SoilCover was used to predict the moisture flux across the soil-atmosphere interface for a normal climatic season for the Edmonton region. Material properties required by SoilCover include the soil-water characteristic curve and unsaturated hydraulic conductivity function for each soil. The soil properties for the clay till were based on the Indian Head Till: 10% gravel 30% sand, 30% silt and 30% clay, data presented by Khanzode et al. (2002) which is representative of a typical till in the Prairies. The soil properties for the sand were obtained from the API (2004) database for well-graded sand: 97% sand, 3% silt, Sample ID 108. The unsaturated hydraulic conductivity functions were based on the theories presented by van Genuchten (1980). Properties for the materials used in this analysis are shown in Figures 1 and 2, respectively.

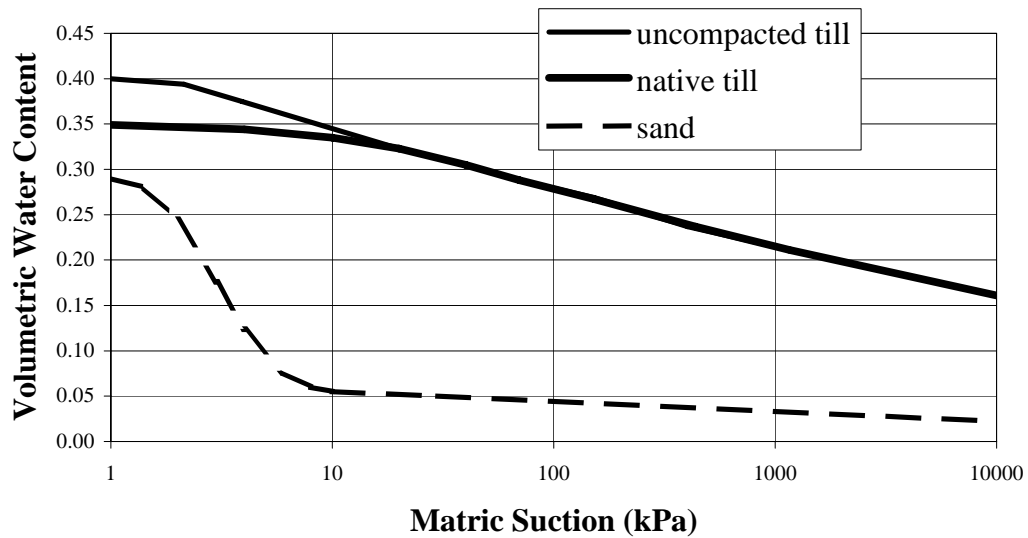


Figure 1: Soil-Water Characteristic Curves Used in the Hypothetical Analysis

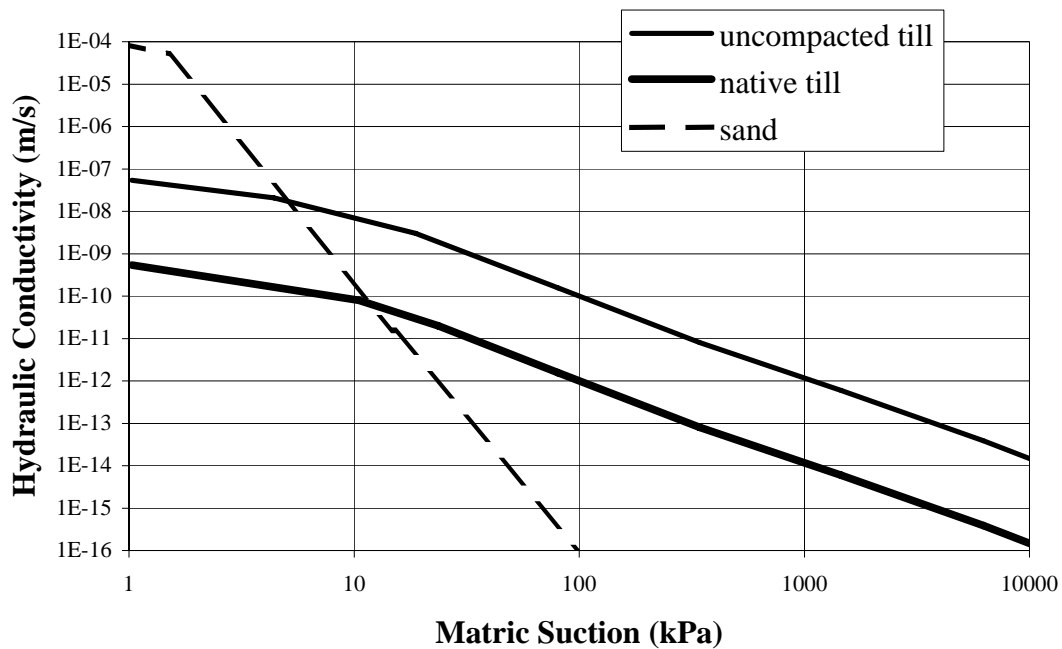


Figure 2: Unsaturated Hydraulic Conductivities Used in the Hypothetical Analysis

The climatic conditions identified in Edmonton through 2001 were used to simulate a typical season for the hypothetical site. The total precipitation occurring in 2001 (376 mm) is equivalent to the 30-year normal precipitation for the Edmonton region. The calculated potential evaporation for the season is 696 mm for the 2001 year. Initial conditions were established for the model using the 30-year normal precipitation event until steady state conditions were achieved. Once steady state conditions were achieved the 30-year normal precipitation event was simulated to generate a seasonal matric suction profile and a degree of saturation profile.

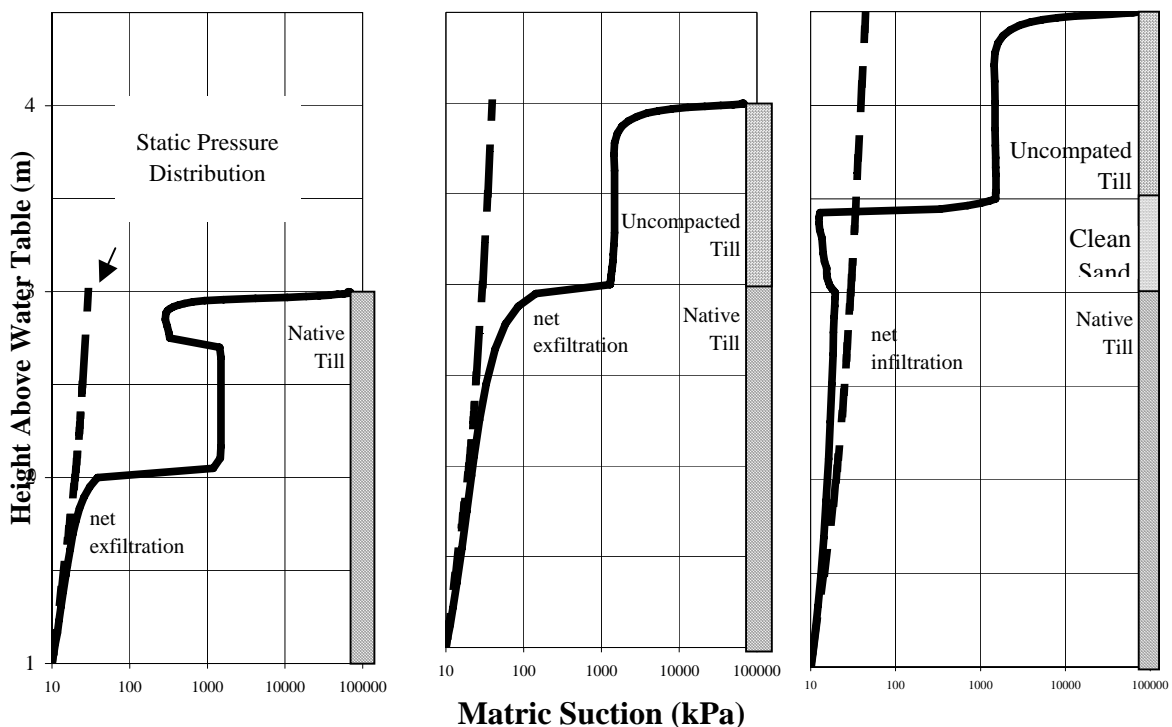
The proposed method of mitigating the salinity impact involves construction of an engineered soil cover over the area. Two soil cover designs were evaluated as part of the analysis: a 1 m uncompacted till cover (store and release cover), and a 1 m uncompacted till cover over a 0.5 m sand layer (capillary break layer). The uncovered native soil profile was also evaluated for comparative purposes.

### Analysis Results

The matric suction profile that develops across each of the three soil profiles at the end of a normal climatic season is shown in Figure 3. The static (no flow) matric suction profile is shown on each profile for common reference. If the resulting suction profile is right of the static profile, an upwards flux occurs (i.e. matric suctions are greater than static conditions), alternately if the resulting matric suction profile is left of the static profile (matric suction are less than static conditions) then an infiltrative flux occurs. The first two profiles (base case and store and release cover only) clearly demonstrate an upwards flux from the water table. The multiple layered soil cover with a capillary break (third profile) demonstrates a net downwards flux. In all three scenarios, the shallow (upper 1 m) matric suction profile ranges dramatically reflecting of short-term evaporation and vegetation transpiration.

Figure 3: End of season matric suction profiles for three soil profiles; from left to right; a 3 m native uncovered profile, a 3 m native profile covered by a 1 m uncompacted till cover, and a 3 m native profile covered by a layered soil cover with a capillary break (clean sand).

Simulation of the native soil profile confirmed that if left uncovered, a long term net upwards flux would develop through the soil profile. If salt impact is not on surface, the upwards movement of salt would eventually impact the rooting zone and thus limit the agricultural viability of the site. Salts would continuously mobilize upwards and the soil



profile would not improve in neither the short nor long term.

Similarly, a simple 1 m uncompacted till cover over the impacted site results in a net upwards flux. Initially, the clean 1 m soil cover would promote vegetative growth, however in the intermediate and long term the upwards mobilization of salts from depth would impede the agricultural productivity of the site.

Alternatively, the soil cover, which incorporates a capillary break layer, results in a profile with a net infiltration flux. However, the net infiltration is less than 4 mm/yr or 1% of average annual precipitation. With additional engineering, it is possible to optimize the soil cover design to obtain a near zero flux soil cover system. This cover allows for the establishment of a 1 m rooting zone, which is hydro dynamically separated from the underlying salt impacted soils at depth. This would protect the rooting zone soil profile and minimize infiltration to the shallow groundwater system.

Figure 4 presents the matric suction and saturation profiles for a normal climatic year at three-week intervals. Figure 4 shows that the upper 0.5 m of the store and release clay till cover experiences changes in matric suction and saturation as a response to precipitation events and vegetation transpiration. Figure 4 also shows that the capillary break remains unsaturated throughout the year.

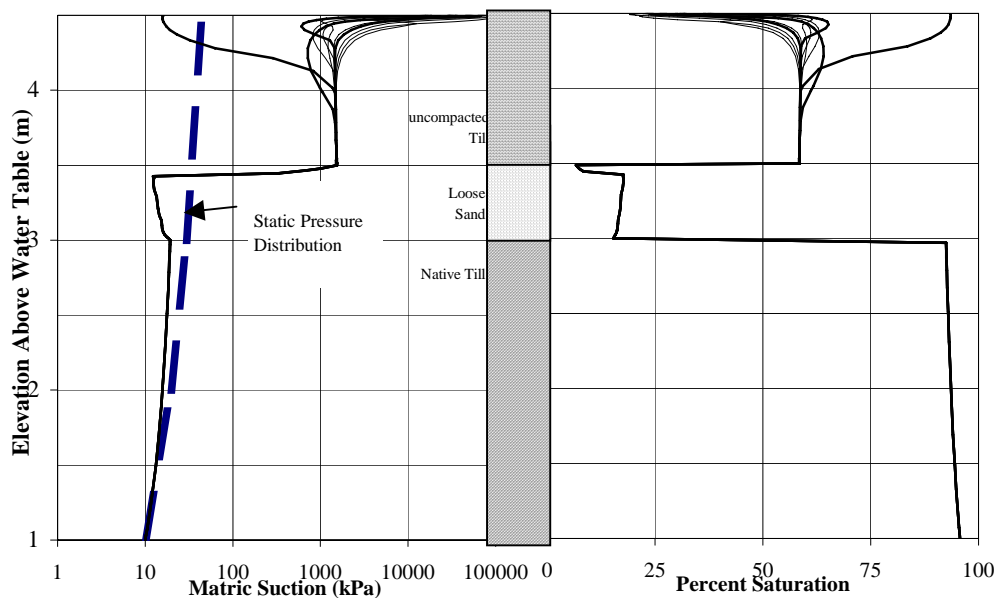


Figure 4: Matric Suction and Percent Saturation Profiles Through an Engineered SoilCover Through a Normal Climatic Season (3 week intervals).

## **WHERE TO FROM HERE**

The preceding analysis supports the body of evidence growing from the ARD research that suggests that a soil cover system can be engineered to attain design objectives related to unsaturated moisture movement. This approach can be translated to other industrial or environmental projects where a soil mass needs to be covered and moisture movement through the shallow profile needs to be managed.

It is unlikely that ultimate release of liability for the salt impacted lands would occur given Alberta Environment currently does not provide this release regardless of remediation effort employed. Regulatory acceptance of an engineered soil cover as an acceptable practice to obtain a Reclamation Certificate is the real uncertainty. Although this is a far-reaching goal, it may be possible if all stakeholders (industry, landowner and regulatory representation) are involved in any future research and field programs.

Before operators will accept this approach, landowners and regulators, a proper research and development approach needs to be identified and followed. Involvement of all stakeholders early in the process will increase the potential for development of a list of objectives that will satisfy all interests. Figure 4 identifies a conceptual methodology to achieve a soil cover system over salt impacted wastes as an acceptable method for long term risk management.

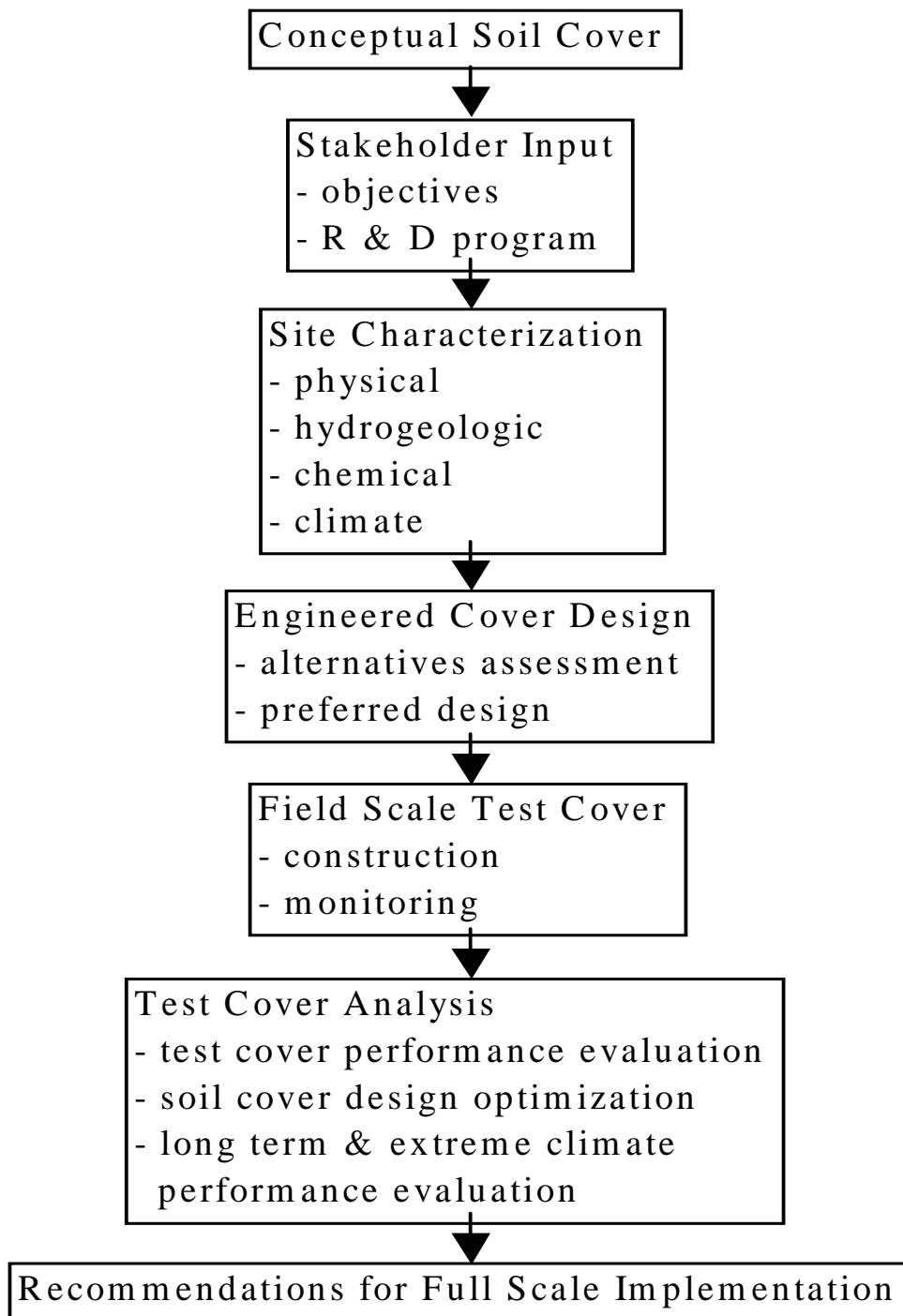


Figure 5: Suggested Methodology for Salt-Impacted Soil Soil-Cover Research & Development Process.

The mining industry has been successful in working through a multi stakeholder process to establish soil cover design objectives meeting all interested stakeholder requirements. This process continues as new research and performance data from constructed covers are presented or published.

Strong and continued development of the oil sands in northwest Alberta has provided an opportunity to obtain additional understanding of soil cover systems and salt impact. Currently the University of Alberta and the University of Saskatchewan are conducting soil cover research on oil sands tailing sites. The tailings piles contain elevated salt concentrations as a result of natural and oil extraction processes. Research is ongoing to establish appropriate reclamation objectives and soil cover design criteria. Use of these ongoing research programs would assist in the further development of soil cover systems for salt impacted lease sites in the Prairie Provinces.

## **CONCLUSIONS**

The use of engineered soil covers systems in the mining industry to mitigate environmental impact from tailings and waste rock piles is becoming more and more an accepted practice. A significant body of theoretical research, instrumented test covers and instrumented full-scale covers has provided an understanding of the complex interaction of near surface moisture movement, evaporation and (vegetation) transpiration in unsaturated soils. Design principles use basic unsaturated soil theory; although this theory is complex, it is possible to apply these design principles to any problem, which involves shallow unsaturated moisture movement.

Design of an engineered soil cover on salt impacted land may be an acceptable risk management practice. The basic design philosophy does not vary significantly from that of the ARD objectives except the movement of oxygen through the cover into the wastes is not important. The design objectives revert to simply the control of moisture above the impacted soils through the rooting zone. This paper presented a hypothetical analysis of a typical prairie lease site scenario where the use of an engineered soil cover and capillary break could be designed to maintain a healthy vegetative cover, minimizing or eliminating infiltration and minimizing the potential for a long term exfiltration flux.

Before operators will accept this approach, landowners and regulators, a proper multi stake holder research and development approach would be required.

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