Alberta Oil Sands Cover System Field Trial: Development, Construction, and Results Two Years In

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ABSTRACT

Syncrude Canada Ltd. (SCL) has developed a field scale cover system trial at the Aurora North mine operations in Fort McMurray, Alberta, Canada. O'Kane Consultants Inc. (OKC) is part of the multi-discipline team that includes university researchers and industrial partners. The overall objective of the trial is to determine appropriate soil cover system designs and capping depth(s) for reclamation using available surface soil materials, while understanding and addressing the risk and uncertainty associated with the presence of oil sand (naturally occurring hydrocarbons) in the overburden and soil reclamation materials. The field scale cover system trial consisted of 36 one hectare cells, made up of 12 treatment options constructed in triplicate. The research cells were instrumented and planted with three native boreal forest tree species in varying densities.

OKC's primary research objective of the field trial was to investigate internal overburden disposal area dynamics, and develop an understanding for the key mechanisms and processes that influence the performance of various soil cover system prescriptions. Instrumentation was installed to monitor water balance parameters and groundwater, and to collect pore-water. Of the cells examined, the treatments with peat as a surface material had the lowest net percolation, due to higher water storage capacity. Groundwater levels revealed small, dynamic hydraulic gradients across the trial, and groundwater chemistry was generally typical of mine affected groundwater elsewhere at the Aurora North mine. Results from the study will serve to identify optimal cover system configurations and will be used by SCL to guide future reclamation operations.

Keywords: cover system, net percolation, overburden

INTRODUCTION

Syncrude Canada Ltd. (Syncrude) has developed a field-scale soil capping study at their Aurora North mine operations in Fort McMurray, Alberta, Canada. The overall research objective of the Aurora soil capping study (ASCS) is to determine appropriate soil cover system designs and capping depth(s) for reclamation using readily available surface materials, while understanding the risks and uncertainties associated with overburden and soil reclamation materials containing naturally occurring oil sand (petroleum hydrocarbons).

Syncrude has undertaken the study to examine alternatives for rehabilitation of their overburden areas. Rehabilitation practices must optimize the available reclamation materials to provide the foundation for re-emergence of sustainable, productive ecosystems. It is the research team's expectation that a wide range of land capability will be required within reclaimed areas and, as a result, reclamation treatments might change from one area to the next within the final landform. Consequently, the differences in performance between different surface materials, the thickness of the surface material, and the influence of the underlying subsoil materials need to be defined.

Indicators of cover system performance include net percolation and health of vegetation. OKC's contribution to the multi-disciplinary study is to examine the hydrological performance of the treatment alternatives. As soil moisture dynamics and vegetation health are interrelated, indirect indicators of vegetation performance such as plant available water and soil temperature are also considered. Further conclusions on vegetation health are within the scope of other researchers on site and are supported by data collected by OKC.

BACKGROUND

Oil sands mining is an open-pit mine operation. It involves removal of surficial geologic materials within the mine footprint that are suitable for use later in reclamation. This primarily includes discrete salvage of upland surface topsoil and subsoil materials and peat materials from lowland bogs and fens. Following reclamation soil salvage, overburden is removed to the oil sand ore body. The overburden is transported to a designated disposal area (generally above-grade or out of pit) where it is landform graded to defined elevation and grade specifications and capped with previously salvaged soil reclamation materials.

The appropriate soil reclamation capping design and depth is dependent on the underlying overburden quality and risk. For Syncrude's Aurora North mine, there are a number of risks and uncertainties associated with their overburden reclamation. Due to the geologic processes that took place at the end of the last glaciation, naturally occurring sand material which contains petroleum hydrocarbons have been mixed in the overburden and the soil reclamation materials in the region. Naturally occurring hydrocarbons are present in the entire matrix of the overburden, while they are present as discrete bands or chunks of varying size and proportion within the soil matrix. The removal, disruption, and spreading of these materials in a new setting poses a risk to the closure landscape, and the appropriate soil cover design and thickness is also uncertain.

A second issue Syncrude faces with overburden reclamation at the Aurora North mine is the large abundance of sandy (coarse textured) mineral reclamation materials. Although Syncrude has over 30 years of reclamation experience in the region, the Aurora North mine coarse textured surficial geological materials differs from previous mining locations. The appropriate use of available soil reclamation materials to re-establish similar vegetation that was present prior to the disturbance has not been determined.

The ASCS has been constructed to address the risks and uncertainties with overburden reclamation at the Aurora North mine. The objective is evaluate the risks present and provide an appropriate soil cover system design and depth that will mitigate these risks. It is a large-scale, replicated multi-disciplinary study that spans key disciplines such as soil physics, soil chemistry, geochemistry, hydrology, plant growth and soil microbiology.

METHODOLOGY

Twelve treatment options (Figure 1) were constructed in triplicate to facilitate scientifically rigorous comparisons, resulting in a total of 36 cells (Figure 2). Surface layer materials include peat (a material of high organic content, salvaged from bogs), LFH (forest floor material), and Centre pit Bm (sandy subsoil material). Instrumentation for measurement of groundwater and various parameters of the water balance was installed in the cells (Figure 2). The research cells were planted with three native tree species in varying densities.

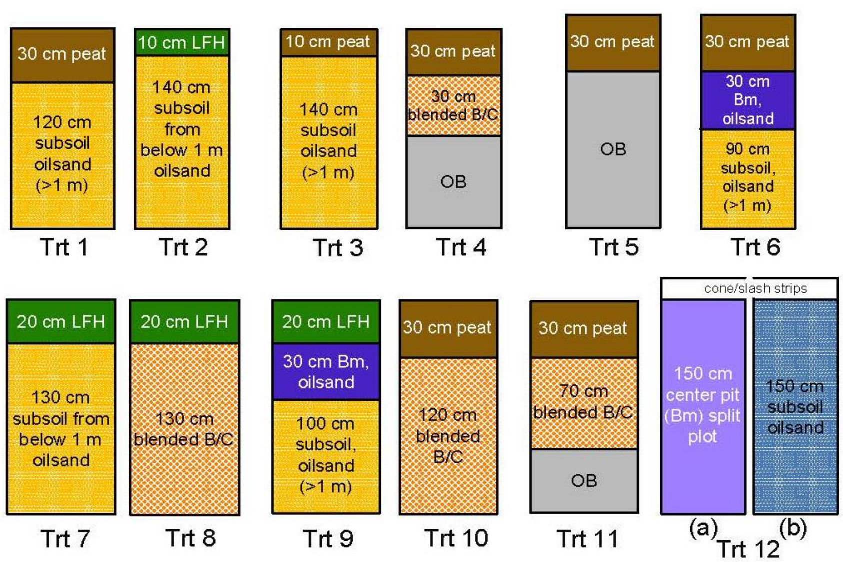


Figure ¡Error! No hay texto con el estilo especificado en el documento. Twelve treatment options applied at the ASCS. B/C = B and C soil horizons, Bm = slight colour and structural changes from the parent material (Soil Classification Working Group, 1998).

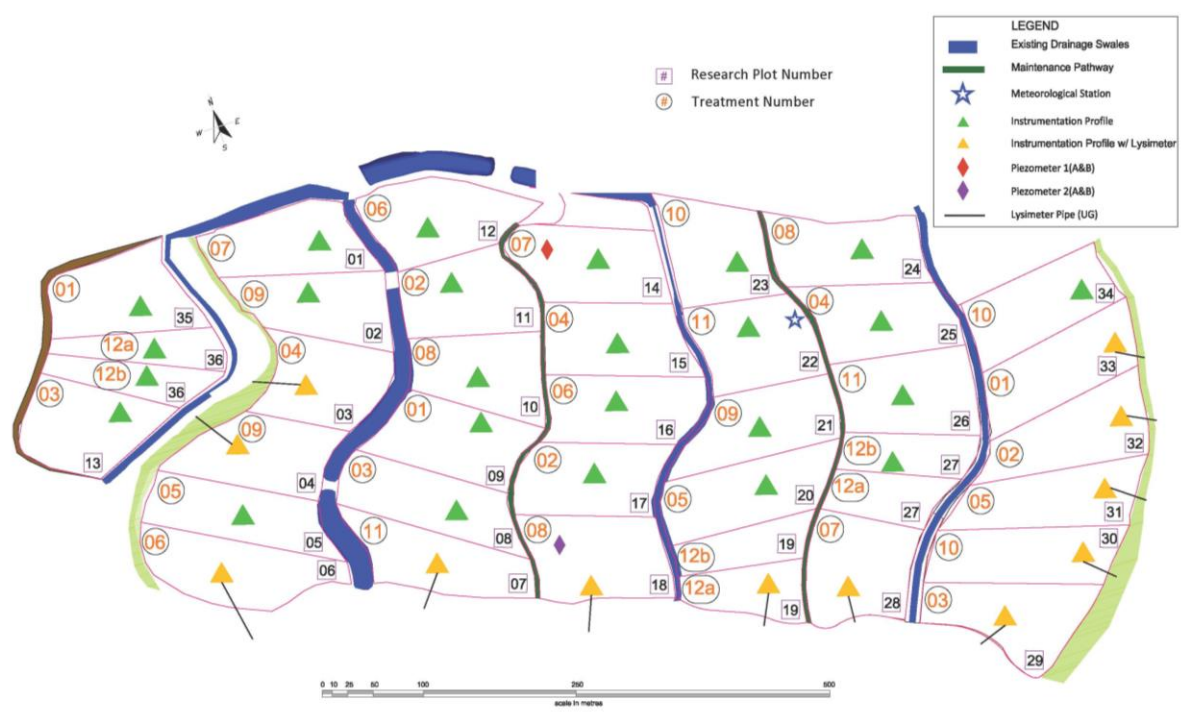


Figure 2 Study layout and instrumentation installed at the ASCS.

Water balance method

Analytical water balances were performed for cells on the perimeter of the ASCS to quantify the volume of water percolating through the cover systems in the 2012 - 2013 water year (November 1, 2012 to October 31, 2013). Water balances use calculated, estimated and field measured components as inputs to solve the water balance equation [1] on a daily basis during frost-free periods. In this way, the water dynamics of the various cover system treatments, and the hydrology of the system as a whole, can be characterized.

$$PPT = RO/S + AET + NP + dS \qquad [1]$$

PPT = precipitation (rainfall plus snow water equivalent (SWE)),

RO/S = runoff and sublimation,

AET = actual evapotranspiration,

NP = net percolation, and

dS = change in moisture storage.

A meteorological station was erected at the ASCS on Cell#22 to measure site-specific climatic parameters (Figure 2). The station included instrumentation to monitor air temperature, relative humidity, net radiation, wind speed and direction, rainfall, snow depth, and air pressure.

Potential evapotranspiration (PE) was estimated using the modified Penman-Monteith method (Vanderborght et. al, 2010) and site meteorological data collected by the meteorological station. AET was calculated based on climate data and rates of PE, while AET/PE ratios were based upon soil saturation levels, and field capacity and wilting point values, and adjusted to match the calculated storage to the measured storage in the water balance.

Vadose zone water dynamics in the cover systems and overburden at the ASCS were monitored by Campbell Scientific (CS) model 616-L volumetric water content sensors and CS229-L matric suction sensors. Data from these sensors was used to determine measured change in storage for the water balance. Pairs of soil water sensors were installed by hand in all layers of cover materials and in overburden, with focus on material interfaces.

CS229-L matric suction sensors also recorded soil temperatures. Soil temperature data was used to determine the frost-free period, and assist with the interpretation of water content data. In addition, the season when vegetation on the test cells is active is heavily influenced by soil temperatures.

Net percolation through the cover system treatments was monitored by large-scale lysimeters (Figure 2). The large-scale lysimeters were installed in the upper overburden profile of 12 of the perimeter test cells. Smaller scale Gee drain gauges were installed to assist in the characterization of water flow dynamics. Water balance net percolation was estimated using lysimeter and Gee gauge data, and the change in water storage at the base of the cover system.

Runoff is not directly measured at the site. Runoff and sublimation from the snowpack were estimated from the water balance.

Groundwater monitoring instrumentation

Four standpipe piezometers were installed at the ASCS (Figure 2) to measure groundwater levels and facilitate groundwater sampling, using Barber Dual Rotary and Coring Rigs. SP-1A and SP-2A are deep standpipes, while SP-1B and SP-2B are shallow standpipes. Groundwater levels were manually recorded in August and September of 2013, and samples taken using an inertial pump.

RESULTS AND DISCUSSION

Two cells with the surface treatment types of 20 cm LFH (top 15 cm of soil which consists of litter layer plus a portion of the immediately underlying mineral material) (Cell#18) and 30 cm peat (surface peat salvaged from bogs and fens) (Cell#30) were selected for presentation of results, but trends for research cells with large scale lysimeters and located on the perimeter of the study area are also discussed.

Temperature

Cells with peat as a surface material had dampened freezing penetration, in that they did not freeze as deep or as quickly as cells with LFH as a surface material. Freezing penetration occurred to approximately 90 cm for Cell #30 (Figure 3), versus approximately 200 cm for Cell #18 (Figure 4). In addition, freezing was more gradual for Cell#30 than for Cell#18 which showed an immediate spike of freezing to approximately 50 cm depth.

The number of days that soil temperatures at 10 cm depth exceeded 5°C was determined for the four major surface treatment types (Figure 5). The criteria of 5°C at 10 cm depth was used as an approximate indicator for when vegetation becomes active (Novak, 2005). The cells with 20 cm LFH at the surface had a greater number of days with active vegetation than cells with 30 cm of surface peat. Peat is an excellent insulator and more easily transmits energy from the material surface to the atmosphere relative to the sandy textured LFH. If soil-water is present to meet vegetation demand, increased soil temperature (more active vegetation days) in the boreal forest will likely translate into increased tree growth.

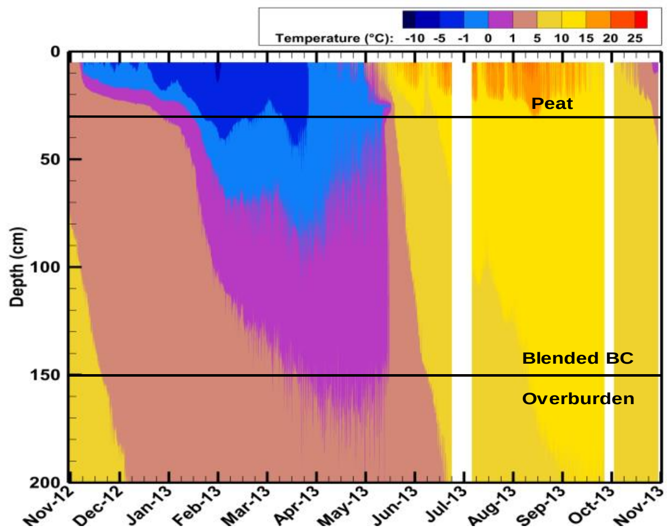


Figure 3 *In situ* soil temperature contours measured at Cell#30 (30 cm peat cover treatment) during the 2012-2013 water year.

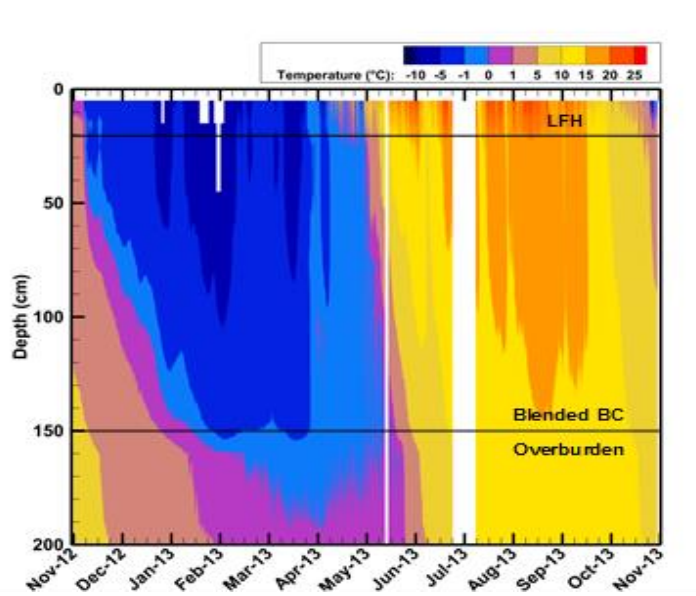
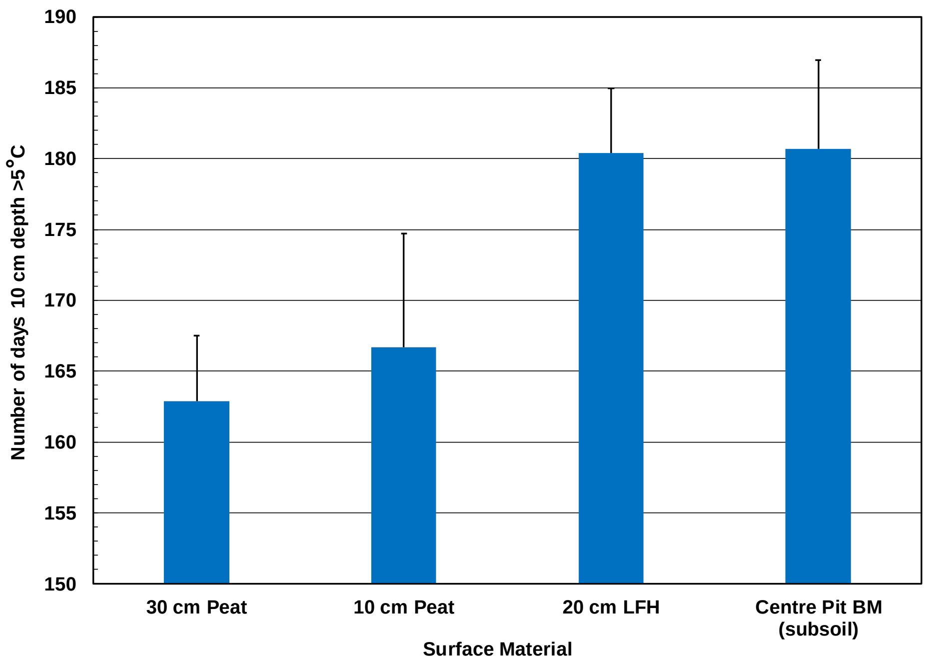


Figure 4 *In situ* soil temperature contours measured at Cell#18 (20 cm LFH cover treatment) during the 2012-



2013 water year.

Figure 5 Number of days soil temperature at 10 cm depth was greater than 5°C for surface materials during the 2012 - 2013 water year.

Water balances

Water balances were completed for all research cells with large scale lysimeters and located on the perimeter of the study area. Calculated and measured storages matched well for Cell #30 (Figure 6) and Cell#18 (Figure 7) for the 2012 – 2013 water year, and for all water balances. Runoff and sublimation were higher for Cell#30, as well as for the majority of cells with peat as a surface material. AET rates were similar for Cell#18 and Cell#30, and ranged between 61% and 76% for all water balances constructed. AET rates did not have a discernible pattern based on material type. Rainfall for the year was above average, with two major rainfall events resulting in the majority of net percolation through the cover systems.

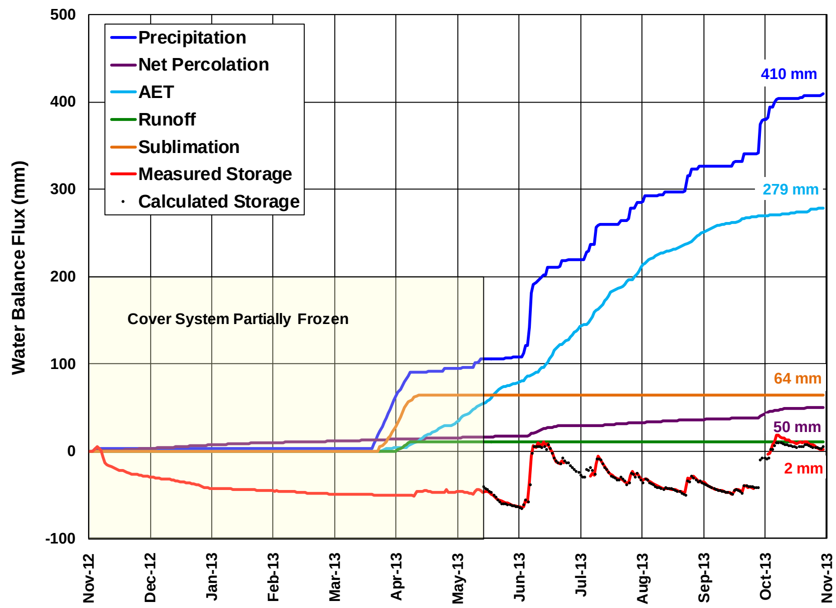


Figure 6 Cumulative water balance fluxes for the Cell#30 (30 cm peat cover treatment) for the 2012 - 2013 water year.

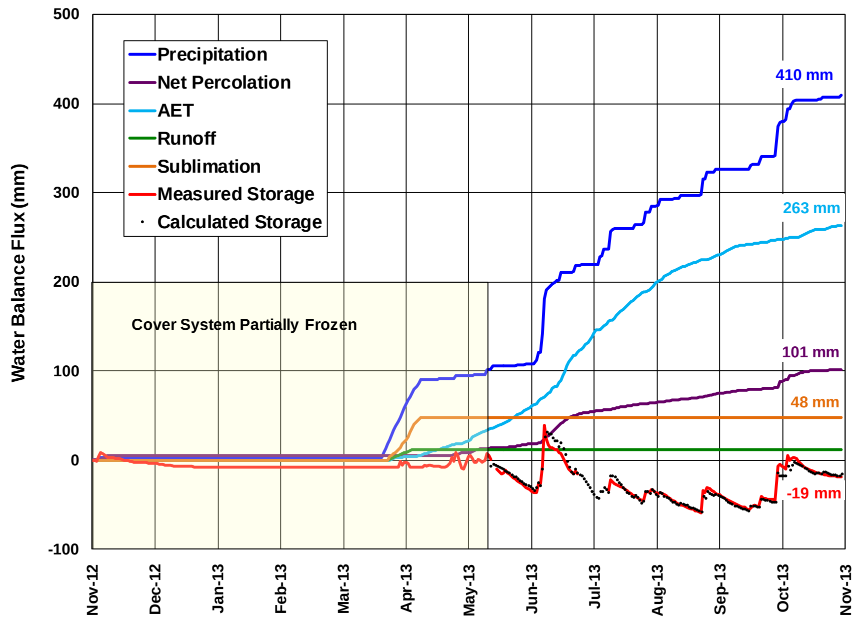


Figure 7 Cumulative water balance fluxes for the Cell#18 (20 cm LFH cover treatment) for the 2012 - 2013 water year.

Net percolation is an indicator of storage water potential of the cover system treatments,which can have implications on soil-water availability for vegetation growth and groundwater recharge rates. The net percolation rate for Cell#30 for the 2012 – 2013 water year, at 12% of annual precipitation was lower than the rate for Cell#18, at 25%. Following this trend, on average, cells with 30 cm of peat as a surface material had lower net percolation rates, at 14%, than cells with LFH as a surface material, at 23% (Figure 8). This is attributed to the higher storage capacity of peat, which improves the water store and release mechanism of the cover systems. In addition, it is possible that textural discontinuity between peat and subsurface materials inhibits drainage from peat to subsurface materials.

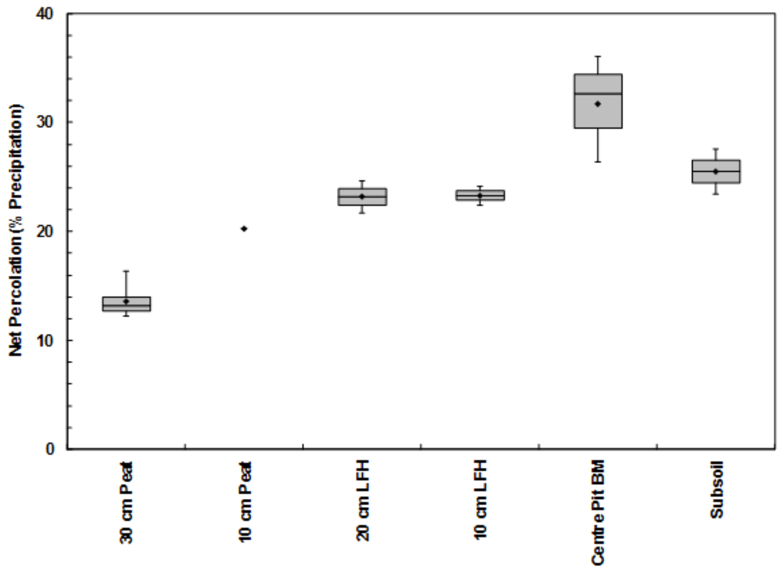


Figure 8 Net percolation box and whisker plot for all surface treatment options.

Groundwater levels and chemistry

Deep and shallow water tables were identified by manual water level measurements at SP-1A and SP-2A, and SP1-B and SP-2B, respectively. The average hydraulic gradient between SP-1A and SP-2A (the deep seated piezometers) in the 2012 - 2013 water year was -0.0098 m/m, translating into a north to south flow. The average hydraulic gradient between SP-1B and SP- 2B (the shallow seated piezometers) for the 2012 - 2013 water year was 0.0027 m/m, which translates to a south to north water flow.

Select results from chemical analyses of groundwater samples taken in standpipes (Table 1) were typical of mine-affected groundwater sampled elsewhere at the Aurora North mine.

Table 1 Select results of groundwater chemistry analyses.

Parameter	SP-2B	SP-1B	SP-1A
pH	7.35	7.89	7.88
EC (uS/cm)	2,760	3,860	2,680
TDS (mg/L)	2,340	3,060	2,240
Organic C (mg/L)	83.6	92.7	21.7
Dissolved Ca (mg/L)	429	205	436
Dissolved Mg (mg/L)	96.1	62.3	93.4
Dissolved Na (mg/L)	276	824	225
Dissolved S04 (mg/L)	955	1,360	1,060
Dissolved V (mg/L)	<0.0002	0.0024	0.0036
Dissolved As (mg/L)	<0.0004	0.001	0.0022
Dissolved Chloride (mg/L)	74.7	241	204

CONCLUSION

The influence of cover system treatments on soil temperature and water content were measured at an oil sands reclamation research study referred to as the Aurora soil capping study. Net percolation rates for the 2012 - 2013 monitoring year for treatments with 30 cm of peat at the surface were 14% of annual precipitation, which was lower than treatments with LFH (23% of annual precipitation) at the surface. The greater soil-water content of the treatments with peat at the surface is attributed to peat having a higher water storage capacity. In addition, textural discontinuity between peat and underlying sandy subsurface materials potentially inhibits drainage. Peat as a surface material also had an influence on soil temperature. Due to its ability to insulate the soil from the atmosphere, the number of active growing days was significantly lower in the peat cover treatments relative to the LFH cover treatment. Although peat may improve vegetation production in terms of water storage, it has the potential to reduce a soils effective growing season. These relative advantages and disadvantages over a range of wet-dry conditions and whether they persist as the site soil and vegetation mature may shape the preferred reclamation soil cover design strategy.

The first full year of monitoring the dynamics of the overburden disposal area at the ASCS have shown the interactions of the vegetation, cover materials, and climate are complex and further study is required to determine the preferred cover system treatment(s) for closure of the area. Data collected so far was sufficient to provide a comparison of cover system performance and identify key trends that will affect long-term performance such as net percolation, and the length of the vegetation growing season.

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