HYDROGEOLOGY OF SOUTH BISON HILL[1]

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Abstract. Oil sands mining in northern Alberta involve the stripping away of a saline-sodic overburden to gain access to the oil-bearing McMurray Formation. Once removed, the pyritic, saline, sodic, overburden is deposited into mined out pits or deposited as large surface fills. South Bison Hill is just one of these overburden structures. The long-term hydrogeologic system that develops within the South Bison Hill is unknown, both in terms of its final state and the time to reach this state. This newly developing groundwater flow system and its interaction with surface soils and water bodies with respect to water and salt fluxes must be defined. The primary objective of this study is to define the hydrogeologic features of South Bison Hill by documenting the hydraulic and geochemical factors controlling the evolution of the hydrogeologic system and then using these factors to develop an interpretative model of this system.

Additional Key Words: reclamation, piezometer, rising head test, groundwater flow model

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Introduction

The Athabasca Oil Sands, located in the Athabasca basin of northeastern Alberta, Canada, is one of the most extensive shallow ore deposits in the world. This deposit covers approximately 40,000 square kilometers and contains over a trillion barrels of bitumen. Surface mining is the primary method of recovering the oil sand and is used to retrieve oil sand that is located under no more than approximately 75 m of overburden. This technique can recover only approximately 7% of the deposit; the remaining 93% will have to be recovered using *in situ* methods (Industry Canada, 2005). Syncrude Canada Ltd. (SCL) is one of the world's largest producers of crude oil from oil sands and supply's 13% of Canada's total petroleum requirements. The SCL Mildred Lake Operation is located approximately 40 km north of Ft. McMurray, Alberta, Canada (Fig. 1) and produces approximately 240,000 barrels per day of a product known as Syncrude Sweet Blend.

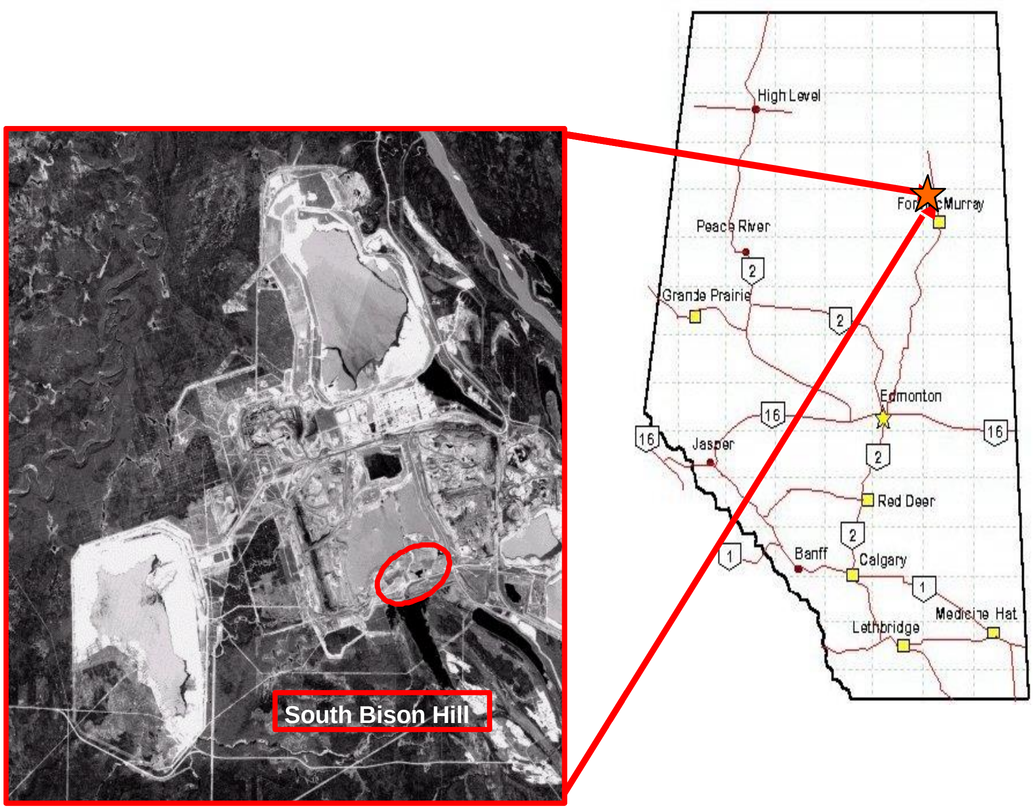

Figure 1. Location of Syncrude Canada Ltd. Mildred Lake Operation.

The SCL leases overburden is a saline sodic pyritic shale known as the Clearwater Formation (K_c) which is removed by truck and shovel or by dragline. The overburden is placed back into mined out pits or placed in piles on the surface and reclaimed by material that is stockpiled from stripping. Overburden piles will occupy approximately 30 % of SCL's final landscape and cost approximately 60 million dollars to reclaim. The long-term hydrogeologic system of these structures is unknown and the newly developing groundwater system and its interaction with surface soils and water bodies needs to be defined in terms of moisture and salt fluxes. South Bison Hill provides an opportunity to examine the development of the groundwater flow system of a structure of this time from essentially 'time zero' conditions. This landform is the result of removing the geology, hence the existing hydrogeology, from an area, highly disturbing it, and then placing it into another structure in expectation for an entirely new system to evolve. The primary objective of this study is to define the hydrogeologic features of South Bison Hill by documenting the factors controlling the evolution of the hydrogeologic system. The geology of South Bison Hill was complied from mine records and data collected of *in situ* hydraulic conductivity and water quality samples from an existing piezometer network was used to develop a conceptual model of South Bison Hill to predict current groundwater flow conditions.

Site Description

South Bison Hill (SBH) is one of six overburden piles constructed in the South Hills area at the southern edge of the Syncrude mine lease. Mining in this area commenced in 1977 and continued until 1997. South Bison Hill is the amalgamation of two overburden piles, operationally known as the S1 and the SW30 overburden hills. The S1 overburden hill was constructed on the surface and the SW30 was constructed in-pit. In total, SBH is approximately 2 km (E-W) by 1 km (N-S) and is comprised of fill materials approximately 50 m deep. A pillar of lean oil sand, an area deemed uneconomic to mine, was left in the center of the mined-out pit and is now situated the northern edge of SBH below overburden fill materials. A natural wetland known as Beaver Creek Reservoir is located to the south side of SBH and to the north a mined out pit filled with mature fine tailings known as Base Mine Lake. The final design of the top of the pile incorporated slopes and swales to create a free draining surface using a series of small watersheds. A cross section of SBH is shown in Fig. 2. This landform was constructed in roughly four sections using different methods over the years of 1980 – 1996 with final reclamation taking place in the summer of 2002.

Construction and Geology of South Bison Hill

The most important data required in predicting the hydrogeology of SBH is to create a precise geological model. Materials that make up SBH can be considered in two divisions: below 320 m elevation and above 320 m elevation. Construction commenced in 1996 in four phases. The first segment of SBH is known as the S1 overburden hill and was constructed on the surface in 1980. This segment was constructed mostly of glaciolacustrine tills with less than 10 % Clearwater Formation (K_c) clays. Construction occurred in 2 m lifts by a dozer. Lift construction in this manner creates 'layers' of differing hydraulic conductivity by compacting the top of the lift from traffic. Values of vertical hydraulic conductivity (K_v) are estimated to be an order of magnitude lower than the horizontal hydraulic conductivity (K_h) by 10:1.

The second segment consisted of a filled in pit that was end dumped overburden material from the southwest quadrant of the mine. The K_c formation becomes thicker as mining moved west and as a result, the percentage of K_c in the filled in pit is variable. The east side of the pit has less than 15 % K_c and as mining progressed, the west side of the pit has more than 25% K_c clays. The end dumped fill results in a structure that not defined but the 45^{o}-dipping depositional layers may result in differential settlement.

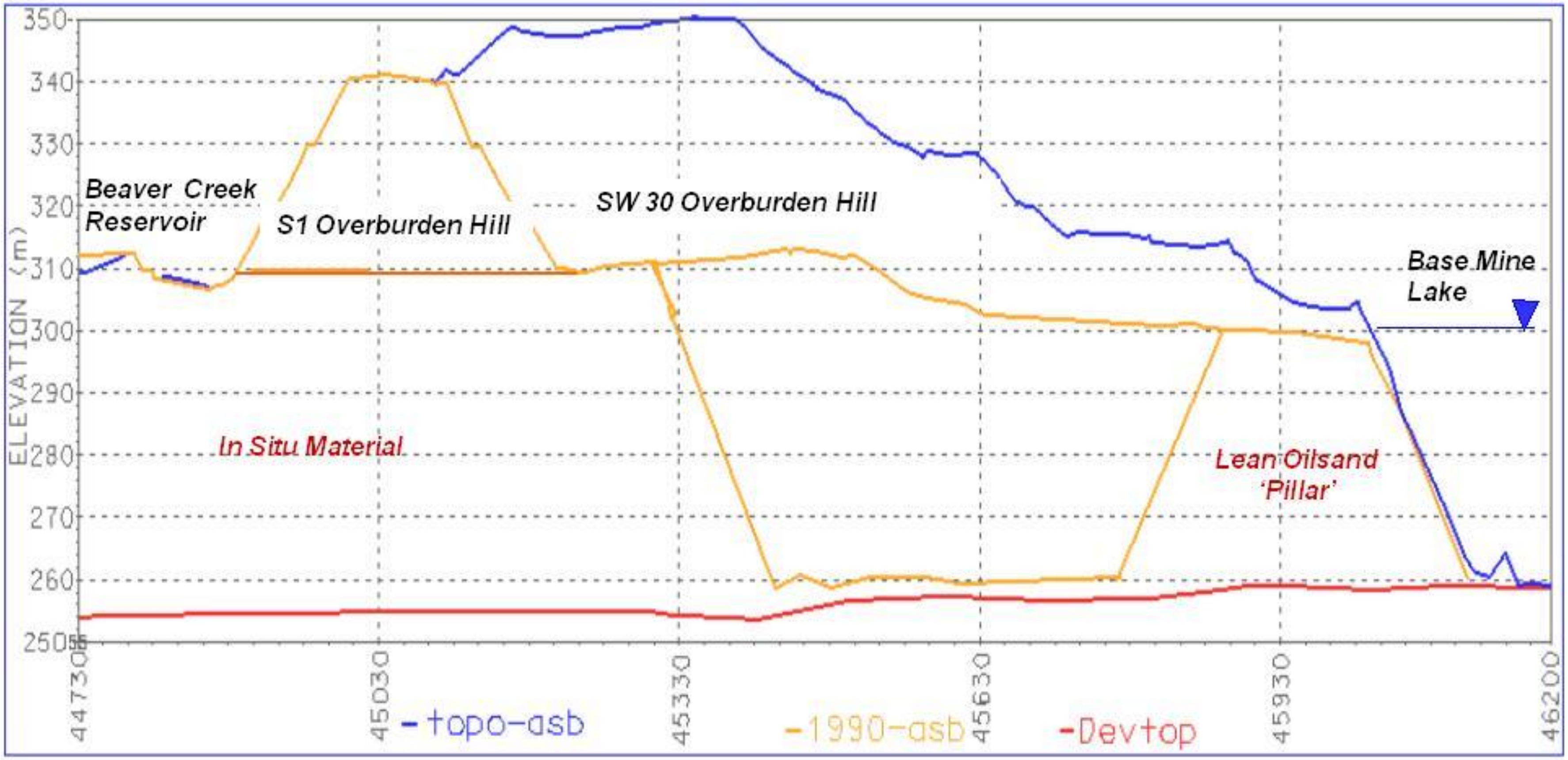

Figure 2. Cross-section through South Bison Hill.

The third segment was built from 1992 to 1994. Materials in this section contain less than 40% K_c clays in 10 to 20 m lifts that were pushed and allowed to fall into the pit. Structure of this section is similar to the section described above.

The final phase of SBH commenced in 1995 and was completed in 1996. Materials in this section consist of less than 75 % K_c clays with the remaining being low grade oil sands and small amounts of glacial tills. This section, being above the 320 m bench, was constructed during a time when materials considered to be of better quality were salvaged for dam construction. Cobblestones and boulders, locally known as siltstones, ranging sizes were observed to be mixed randomly in the pile and are approximated to account for 1 to 5 % of the total volume. This section of the pile was constructed in 5 m lifts resulting in an even greater difference in K_v to K_h of approximately 100:1. Several meters of subsidence is expected to occur due to the nature of the materials and the construction methods used. The pile is noted to be moderately jointed as a result of gaps between large lumps and cracks caused by cracks and subsidence.

Materials and Methods

Data collected at this site was collected from seven existing nests of piezometers with the installation of three more. Water level monitoring, rising head tests and water quality sampling was completed on the existing network.

Piezometer Network

Two piezometer nests were installed in the fall of 1999 near two shallow wetlands to investigate initial conditions after pile construction and to determine the cost and challenge of drilling at a site of this nature. Drilling was successful and water levels were found to be unexpectedly high. Twenty-five additional piezometers were installed in the spring of 2000 in an approximate north-south grid across SBH. Piezometers installed consisted of 5.08 cm (OD) schedule 80 PVC pipe with threaded fittings. The intake consisted of 2 mm slotted PVC screen that varied in length from 150 to 300 mm. Standard frac sand surrounded the intake and the pipes were sealed with bentonite pellets or a grout / cement mixture. Depths of piezometers were chosen based on the anticipated lithology of the pile based on pile construction. The existing network was proposed to be supplemented in 2003 with the addition of five additional nests in key locations. Due to some difficulty during installation, only three nests were completed with a maximum depth reaching 30 m below the surface of the pile. Full details of piezometer installations can be found in Chapman (2005).

During the summer of 2002 and 2003 rising head tests were completed to determine the *in situ* field hydraulic conductivity (K_f) at each site. Samples for water quality monitoring were completed simultaneously with each rising head test. Rising head testing procedures followed ASTM standard D 4044-96 (ASTM 1996a) and water sampling procedure followed ASTM standards D 5903 – 96 (ASTM 1996b) and D 4448 – 85a (92) (ASTM 1996c). Values of K_f and the geochemical ‘fingerprint’ of the collected samples were used to verify the geological and construction make up of the hill and then used to set up a conceptual groundwater flow model.

Data Presentation and Analysis

Rising Head Tests

Rising head tests were completed on 19 of the 25 piezometers on SBH. Generally, it was observed that there was at least one piezometer at each location (depths varied) that did not contain any water, which may be a result of the tight nature of the fill material or because of lift construction. Value measured hydraulic conductivity values can be found in Fig. 4.

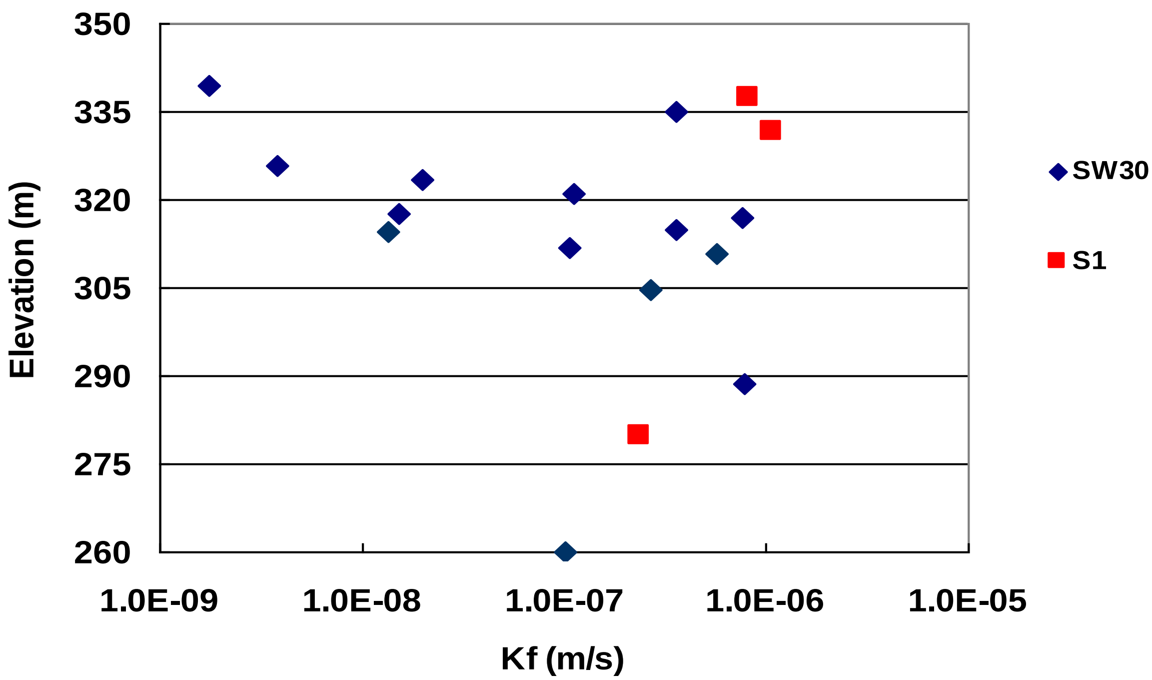

Figure 4. Distribution of values of K_f versus elevation as measured by rising head tests.

Values of K_f measured on the S1 are approximately one to two orders of magnitude greater than those measured on the SW30 portion of SBH consistent with K_f values for glacial tills. The majority of K_f values measured at tips below the 320 m elevation into the unstructured fill that contains less than 25 % K_c falls into the range of 1.0E-06 to 1.0E-07 m/s range. The two exceptions measure K_f values at approximately 1.0E-08 m/s at tip elevations right around 320 m. These particular piezometers are shallow, with the tips located near the 320 m surface and therefore may have had influence of construction traffic. Above 320 m elevation, measured values are variable and may be a result of lift construction as well as the heterogeneity of the materials.

<u>Water Quality Monitoring</u>

Samples for water quality were collected concurrently with the rising head tests in August 2002 and June 2003. Samples were analyzed for major groundwater ions. Because of the pyretic nature of the overburden, SO_4^{-2} is used as an indicator of material type. Further chemical analysis is shown in Chapman (2005). Sulfate distribution versus elevation is shown in Fig. 4.

Noticeably, the concentrations from the piezometers located on the S1 show low concentrations of SO_4^{-2}, again consistent with the till materials. Samples collected from the deepest tips also show low concentrations. Sulfate concentrations below the 320 m elevation are generally low with some exceptions. It is likely that oxidation occurred during construction. Sodium sulfate distribution is a key issue with the reclamation of overburden piles and is being further examined to determine how salt loading will influence the success of the wetlands of this structure.

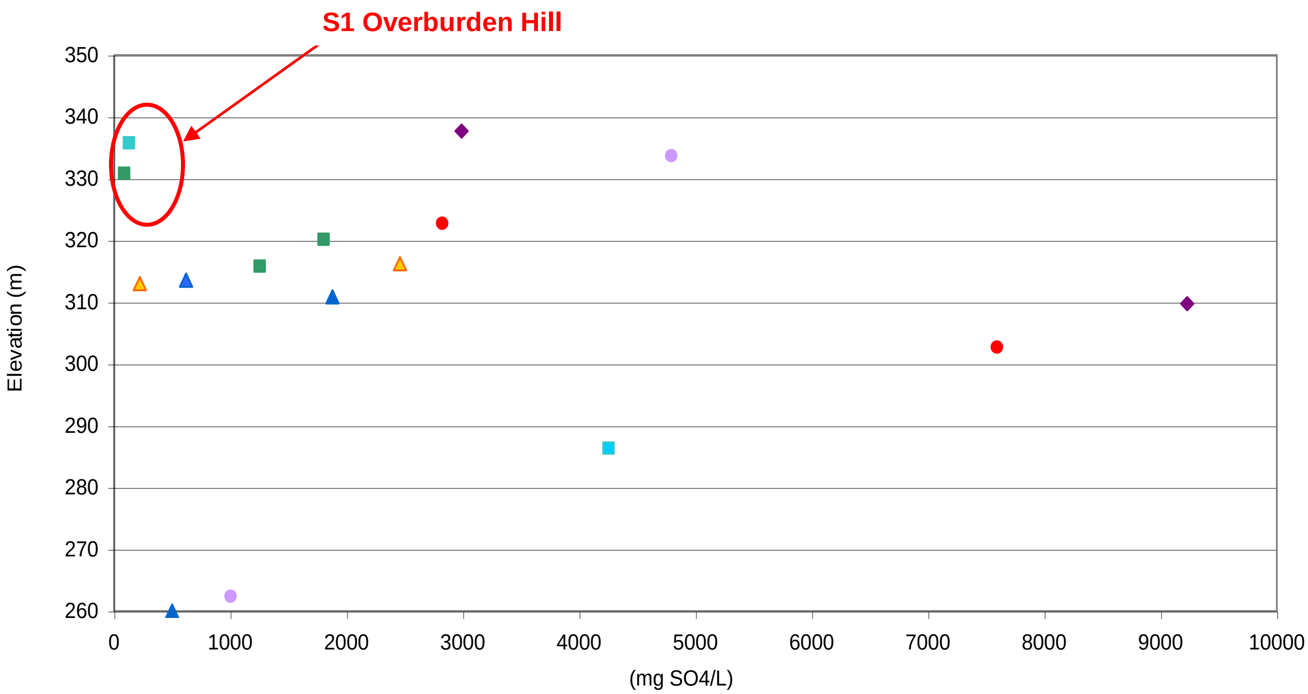

Figure 4. Distribution of Sulfate concentrations collected from piezometers on South Bison Hill.

Conceptual Model

Data collected from the piezometers as well as topographical and geological information was used to create a cross-section of South Bison Hill to run a finite element model SEEP/W (GeoSlope, 2002). Boundary values include a constant head as Beaver Creek Reservoir on the south and Base Mine Lake on the north. The base of South Bison Hill consists of a Devonian limestone and is considered to be a zero flux boundary based on tests from SCL. A flux was distributed evenly across the surface of the pile and was estimated to be approximately 1.5 % of the total yearly precipitation. Average precipitation measured from a meteorological station on SBH was approximately 400 mm, yielding a flux value of 6 mm which infiltrates through the reclamation covers into the overburden. Simplistically, the pile was divided into four main sections: S1 overburden hill, fill below 320 m, fill above 320 m, and the lean oil sand pillar. Input values for the flow model are found in Table 1.

The model showed that a permanent water table exists approximately 30 m below the top surface of the pile. This 'unconfined' flow system is controlled by two lateral drains on both the north and south sides of the pile. The south side of the pile, constructed of glacial tills, has *in situ* hydraulic conductivity values that are approximately one order of magnitude greater than the Kc fill within the pile. The lean oil sand pillar on the north side appears to also have some influence. Shallow piezometer measurements indicate that there may be a series of perched conditions within the top 20 m of the overburden pile and that these may be the result of pile construction methods.

Table 1. Input values for groundwater flow model of SBH.

Material Type	K_f Value (m/s)
S1 Pile	5.0E-08
Fill above 320 m	2.1E-09
Fill below 320 m	9.5E-08
Lean oil sand pillar*	2.1E-10

*No piezometer value available; based on value from SCL database

Summary

A preliminary groundwater flow model has been constructed for a newly constructed overburden structure in the oil sands region. The geological interpretation was verified based on *in situ* hydraulic conductivity and groundwater quality samples using data collected from an existing piezometer network. The flow model showed that perched conditions exist in the top 20 m of the pile and that a permanent water table may exist deep within the pile. Preliminary groundwater chemistry data suggests that sulphate is mobile within the upper 30 m of the pile. The mechanism for the generation and transport of the sulphate is not fully understood.

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