MONITORING OF COVER AND WATERSHED PERFORMANCE FOR SOIL COVERS PLACED OVER SALINE-SODIC SHALE OVERBURDEN FROM OILSANDS MINING[1]

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Abstract. The mining of oilsands near Fort McMurray, Alberta involves the stripping of saline-sodic overburden to access the underlying oilsands. The overburden is placed in mined out pits or in piles on the surface and reclaimed by means of soil covers, which must provide a sufficient rooting zone for vegetation establishment while minimizing percolation into the shale to prevent the occurrence of slope instability and salinization. A multi-year study was initiated in 1999 to observe the performance of three 1-ha peat over till layered soil covers and a 5-year-old single layer (peat/mineral mix) cover. This paper will outline the extensive instrumentation program and will present a preliminary water balance for the observed areas.

Additional Key Words: reclamation, water balance, Bowen Ratio, interflow

Introduction

The Athabasca Oil sands (mined by Syncrude Canada Ltd.) in Northern Alberta provided approximately 13 percent of Canada's petroleum requirements in the year 2000. The oil sands are found beneath glacial deposits and a layer of saline-sodic cretaceous shale known as the Clearwater Formation. The oil sands are accessed by open pit mining in which the overlying shale is stripped away and placed back in the mined out pits or in large surface deposits. These overburden piles are reclaimed by placement of a soil cover consisting of a surface layer of peat over a layer of glacial deposits (secondary) composed of glacio-lacustrine clay or glacial till.

There are a number of concerns associated with the reclamation of the excavated overburden shale. Prior to mining, the shale is in a stable condition - confined, overconsolidated, and

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exposed only to saline/sodic pore fluid. Exposure of the saline/sodic clay to freshwater can lead to particle dispersion and subsequent erosion problems. Salinization, as a result of shale weathering, salt leaching, and salt transport into the cover layer is also a potential concern. Subsidence may also occur as wetting and loading takes place. As the water table rises within these deposits, saline groundwater discharge zones may develop which have the potential to affect surrounding surface water bodies. A soil cover plays an important role in the reclamation of the overburden structures by providing a barrier against freshwater infiltration into the saline/sodic shale while supplying sufficient moisture for sustainable vegetation growth.

A field research program has been developed to investigate the performance of three 1-ha peat over till soil covers as well as a 5-year-old single layer (peat/mineral mix) cover constructed at the Syncrude Canada Ltd. oil sands mine site in Northern Alberta. This paper will describe the research sites, outline the field-monitoring program and look at some preliminary results.

Site Description

The research site is located at the South Hills overburden piles at the Syncrude Canada Ltd. Mine site, 40 kilometers north of Fort Mc Murray, Alberta (Fig. 1). Three full-scale soil covers, each approximately 1-ha (50m wide by 100 m long) in size were constructed along a 5:1 north-facing slope in 1999. Each prototype cover was constructed with different layer thicknesses of peat over secondary in agreement with the soil classification system developed by Leskiw et al. (1999). An additional site known as Bill's Lake, an opportunistic wetland area adjacent to the prototype covers study area, was constructed with a peat/secondary mix in 1996. Monitoring at this location includes a wetland and its catchment. Soil cover depths at the study sites are as follows:

- D1 - 20 cm of peat overlying 30 cm of secondary,
- D2 - 15cm or peat overlying 20 cm of secondary,
- D3 – 20 cm of peat over 80 cm of secondary, and
- Bill's Lake – 100 cm of mixed peat/secondary.

The D3 cover acts as the control cover as it meets the criteria for a standard 1-m cover set by Alberta Environment. The D1 and D2 prototype covers require less material and therefore are more economical to place. The objective of this study is to determine the optimum soil cover depth/sequence over saline sodic shale that will support the target reclamation ecosites,. This information is critical to the oil sands operators as up to 1/3 of the final landscapes in this region will be constructed using the overburden material.

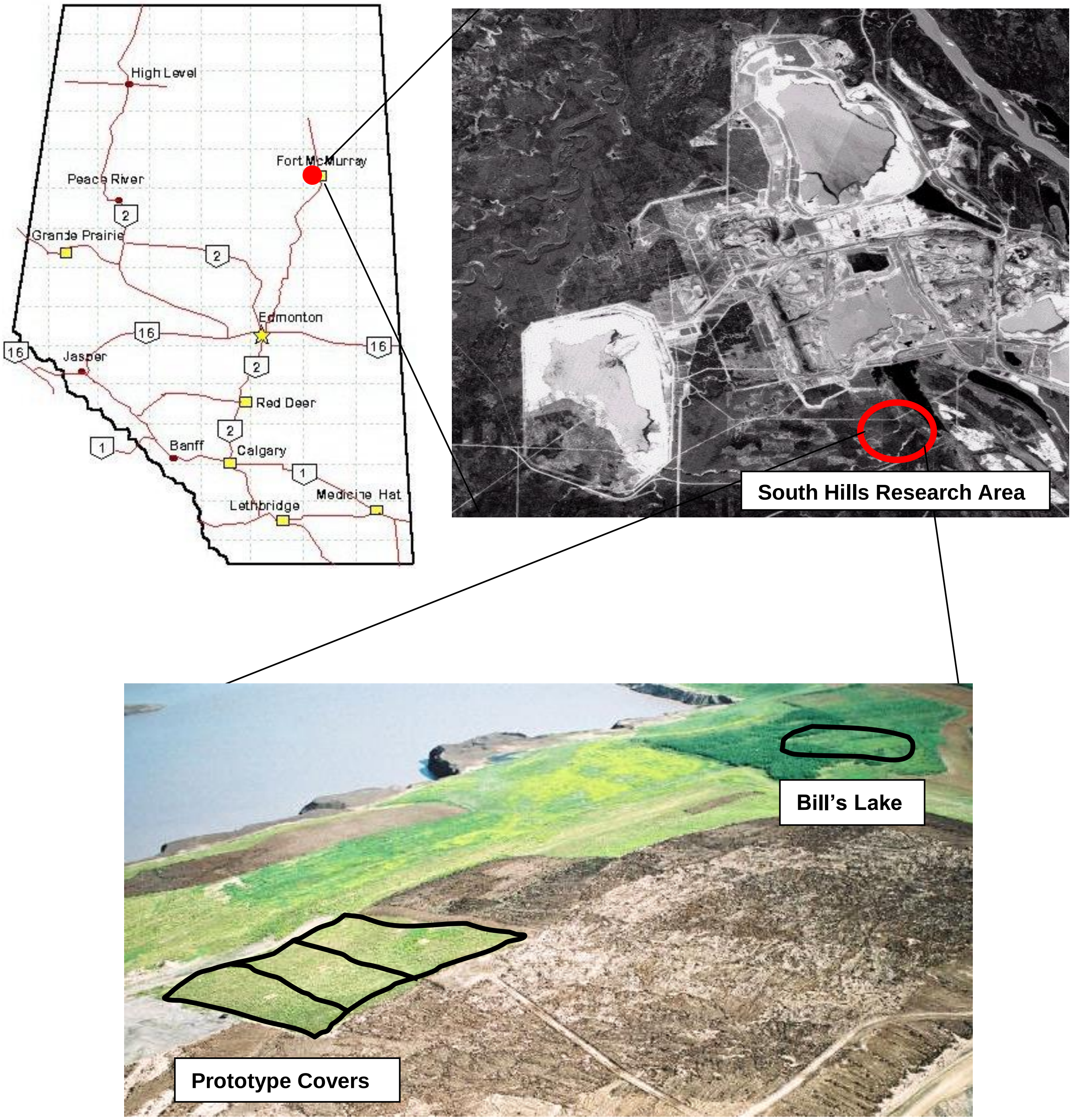

Figure 1. Location of instrumented study sites.

Monitoring Program

An on-going field research program was initiated in the summer of 1999 to measure various components of the water balance such as climatic conditions, evapotranspiration, soil moisture, interflow, and runoff.

Continuously monitored climatic conditions include wind speed and direction, ambient air temperature, relative humidity, and precipitation measured on an hourly basis. A Bowen Ratio Energy Balance (BREB) station measures parameters to calculate evapotranspiration throughout the growing season. These measured parameters include wind speed and direction, net radiation, soil temperature and moisture content, and ambient air temperature and vapour pressure at two heights above the ground surface. The Bowen station was placed on the prototype covers from May to July of 2000 and was then moved to Bill's Lake from July to October of 2000. The locations of the Bowen were reversed in 2001.

Soil conditions are measured at an instrumentation station located at the midslope of each cover. Soil conditions measured include volumetric water content measured with frequency domain response (FDR) units, soil temperature using a multi-point thermistor string, and soil suction measured with two types of thermal conductivity sensors. Three neutron access tubes were installed at the top, middle, and toe of each cover. Instruments were installed within each layer of the soil cover and the underlying shale overburden. Typically two instrumentation sets were installed in the peat layer, three in the secondary till layer, and three in the overburden shale (Fig. 2).

An interflow measurement system was installed in the prototype covers in June 2000 and consists of a geo-membrane cutoff placed at the soil cover/overburden interface. Weeping tile collects the water caught by the cutoff and directs it into a collection system. Runoff due to snowmelt and rainfall events is collected by a swale at the base of the slope at the prototype covers. Flow volumes are measured using a series of four weirs; one weir located upstream of the study site to measure water entering the system and one weir located downstream of each 1 ha plot. Staff guage readings at Bill's Lake provide an estimate of runoff from this cover area. A cross-sectional view of the instrumentation locations on the prototype covers can be seen in Figure 3.

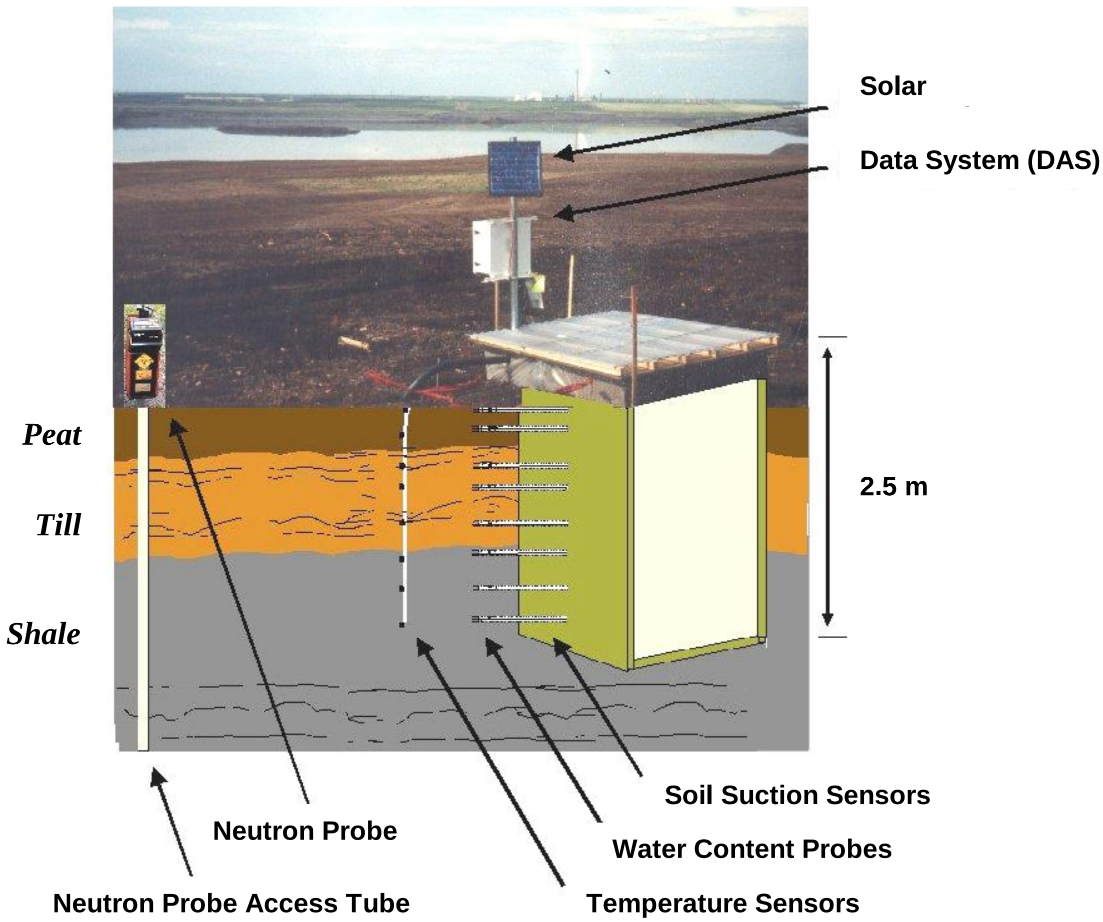

Figure 2. Profile of soil instrumentation station.

A series of field test programs were carried out over the summers of 2000 and 2001 to measure the insitu density and water content profiles, to obtain samples for soil chemistry, and to conduct Guelph permeameter testing of the cover soils and the underlying shale. Surface water samples are collected at both sites including water collected in the drainage ditch and in the interflow catchments. Additional monitoring at Bill's Lake includes water levels, seepage rates and surface water chemistry.

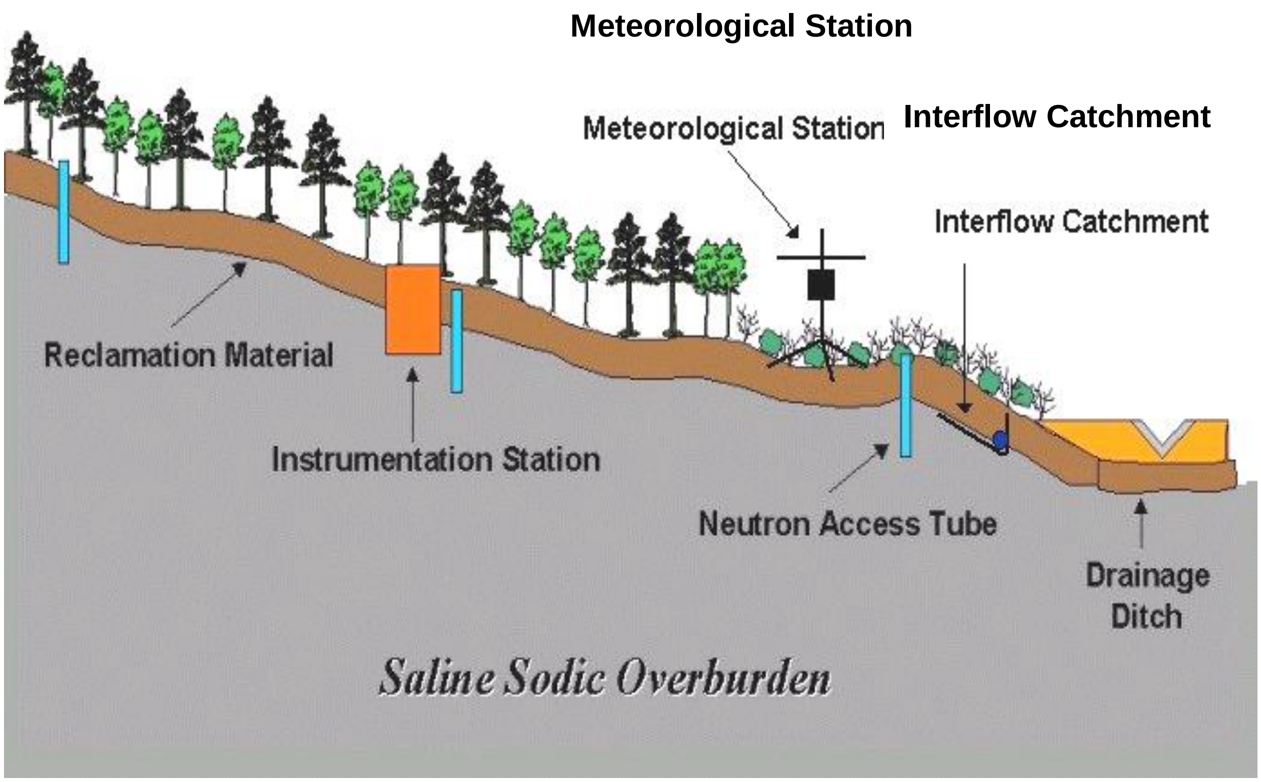

Figure 3. Cross-section of field instrumentation.

Presentation of Results

Two complete years of field monitoring took place from 1999 to 2001. An overview of instrumentation performance and a preliminary water balance will be provided in this section.

Evapotranspiration

Daily and cumulative Actual Evapotranspiration (AET) values measured by the Bowen Ratio station and cumulative precipitation values measured by the meteorological (MET) station for the months May through October (considered to be the growing season) for 2000 and 2001 are presented in Figures 4 and 5.

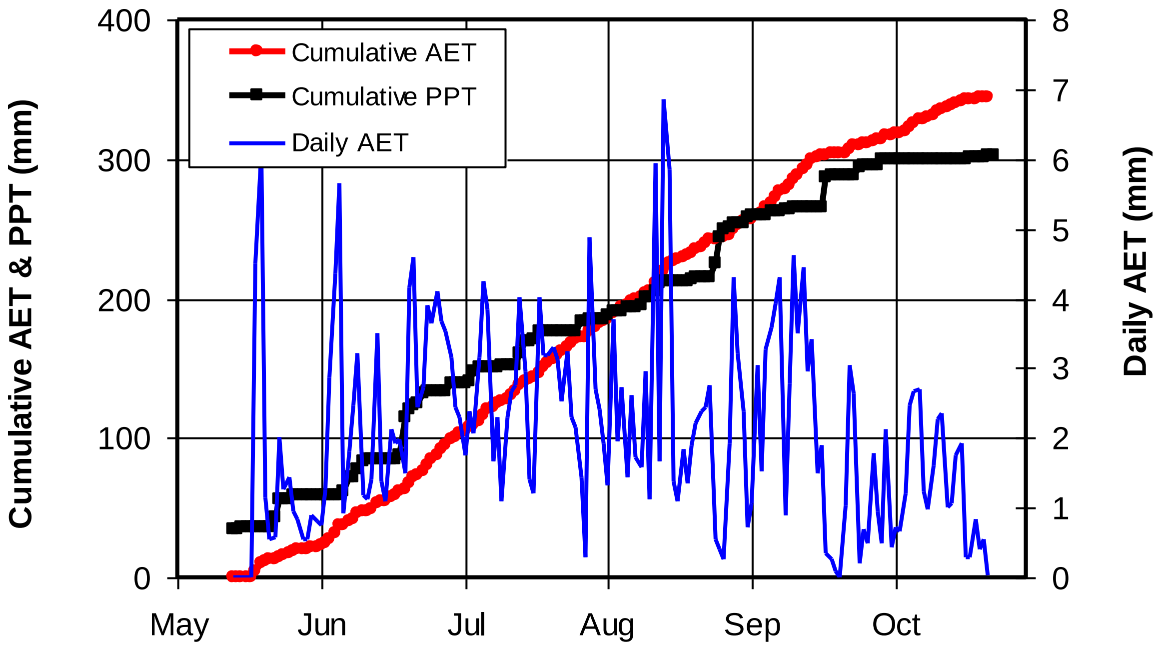

Figure 4. Daily and Cumulative AET values for 2000.

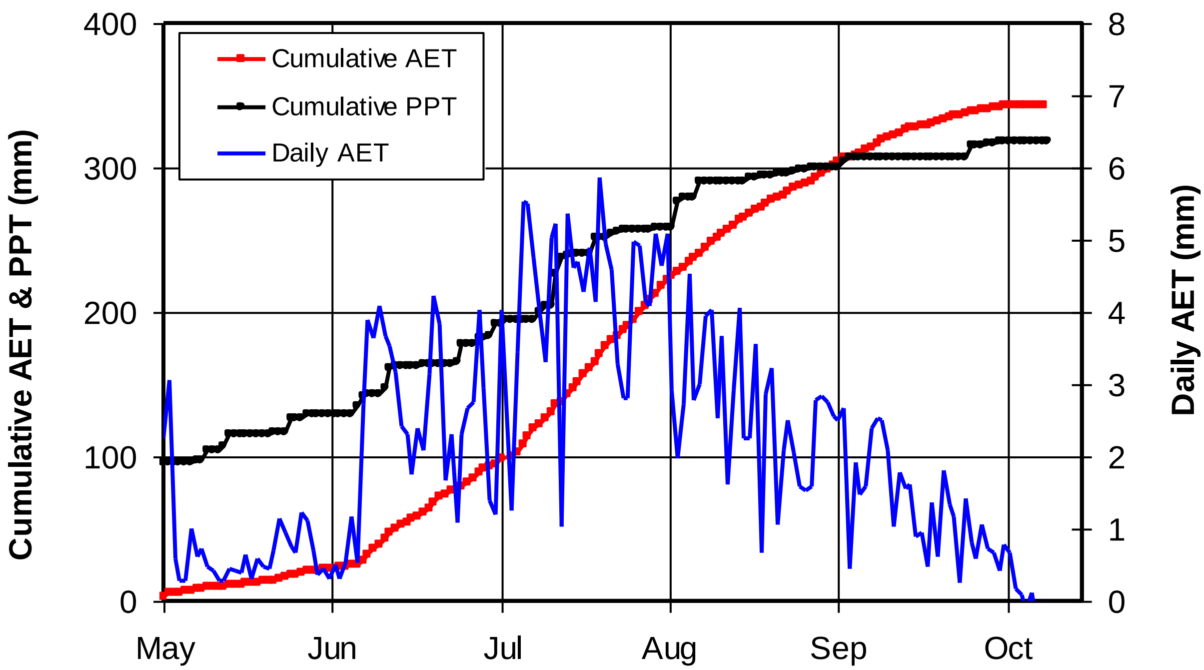

Figure 5. Daily and cumulative AET values for 2001.

The measured AET values may be suspect during May since the covers remain frozen at depth for more than half of the month. Daily values vary significantly and a noticeable increase in AET values occurs throughout June and July in conjunction with vegetation maturation. Peak AET values occur in late July and early August as vegetation reaches maximum growth. Values taper off in late August through October as available moisture is depleted in late summer and then falls off rapidly as vegetation undergoes killing frosts. The fall of 2000 received enough precipitation to cause a slight increase in AET values later in the season compared to the continual decrease in AET values of the drier fall of 2001. The annual precipitation totals for both 2000 and 2001 reached near normal levels for the Ft. McMurray region of approximately 430 mm.

A 'One-dimensional Footprint' analysis based on the theory in Scheupp et al. (1990) was conducted on Bowen ratio station data to attain what effective upwind sources are contributing to flux measurements. Calculations based on this method take into account wind speed, height of vegetation and the height of the wind sensor. The wind sensor was located at a height of 2.2 m and the average height of the vegetation was estimated to be 0.6 m. The 'footprint' analysis can be seen in Figure 6. Bowen station flux measurements were being influenced minimally by an area greater than 250 m away from the station and the primary upwind contribution was coming from an area located approximately 14 m away. This area of influence may come into effect during the period when the Bowen station is set up at Bill's Lake. The presence of the wetland may cause a slight overestimation in AET values with the instrumentation obtaining measurements from the open water surface. The overestimation of AET must be considered when looking at an overall water balance for the area.

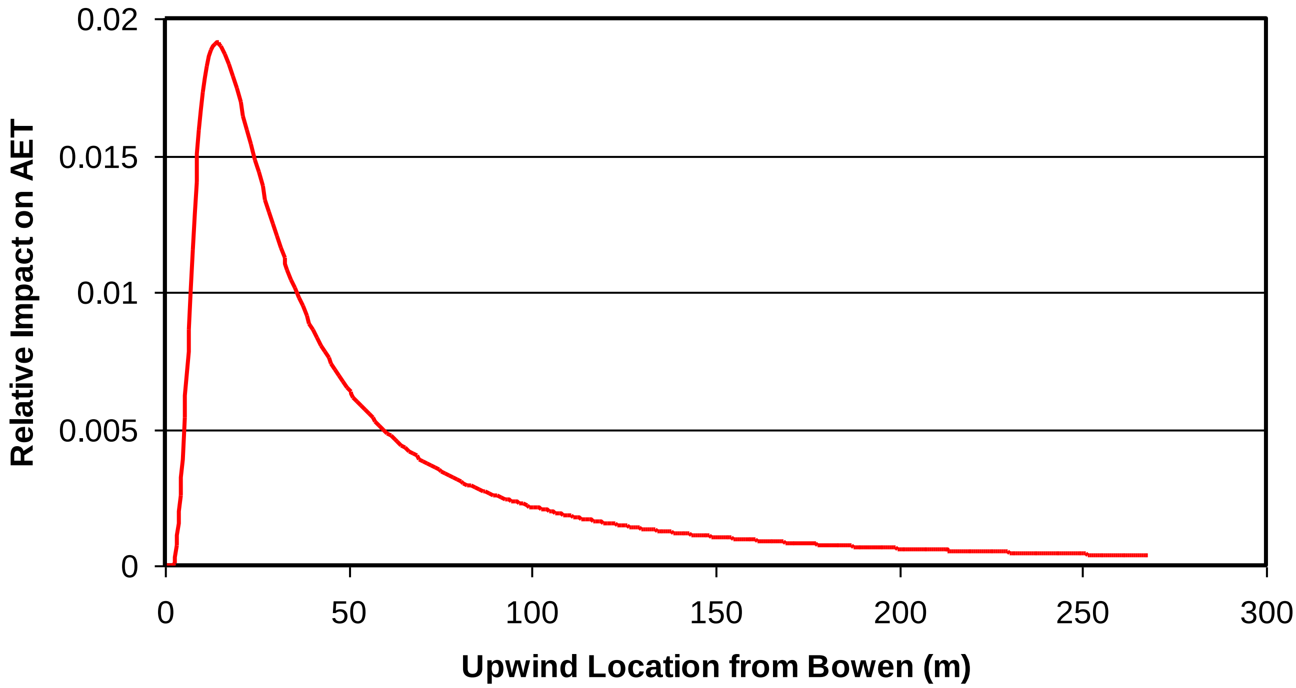

Figure 6. One dimensional footprint analysis on Bowen ratio station data.

Moisture Storage

The volume of water stored in each cover was calculated for 1999 to 2001 (Fig. 7 through 10). The data shown by 'lighter lines' represent periods when the soil is frozen and data should be viewed with caution as to its accuracy.

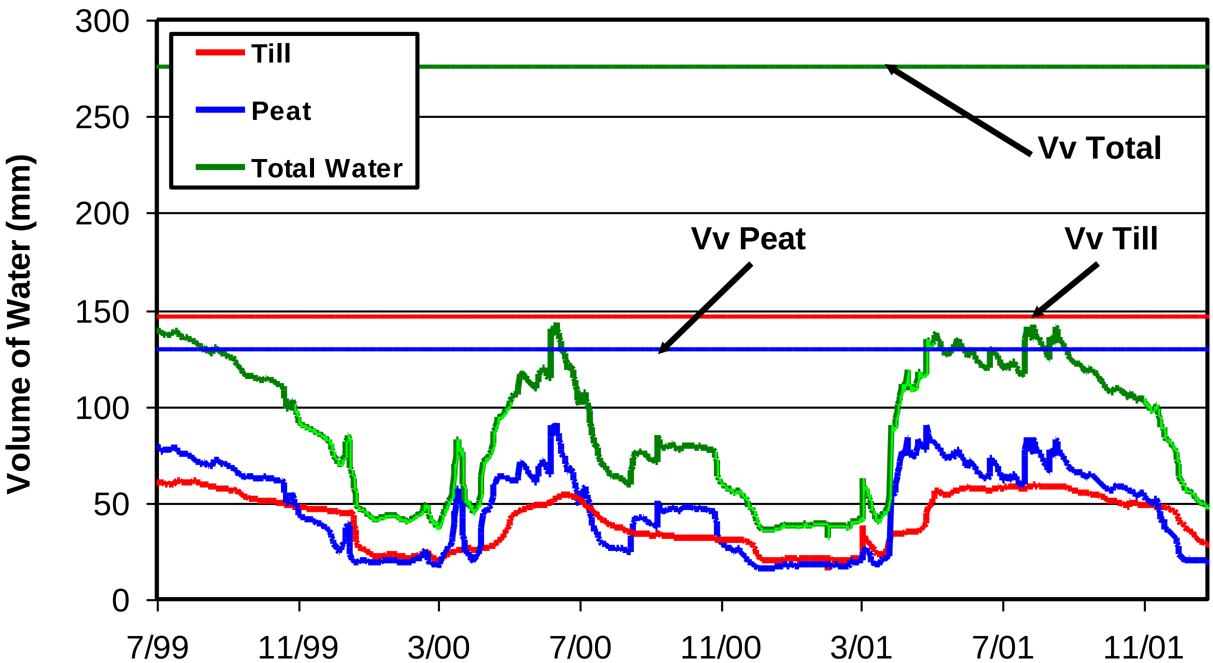

Figure 7. Calculated water volumes for D1 (50 cm) cover.

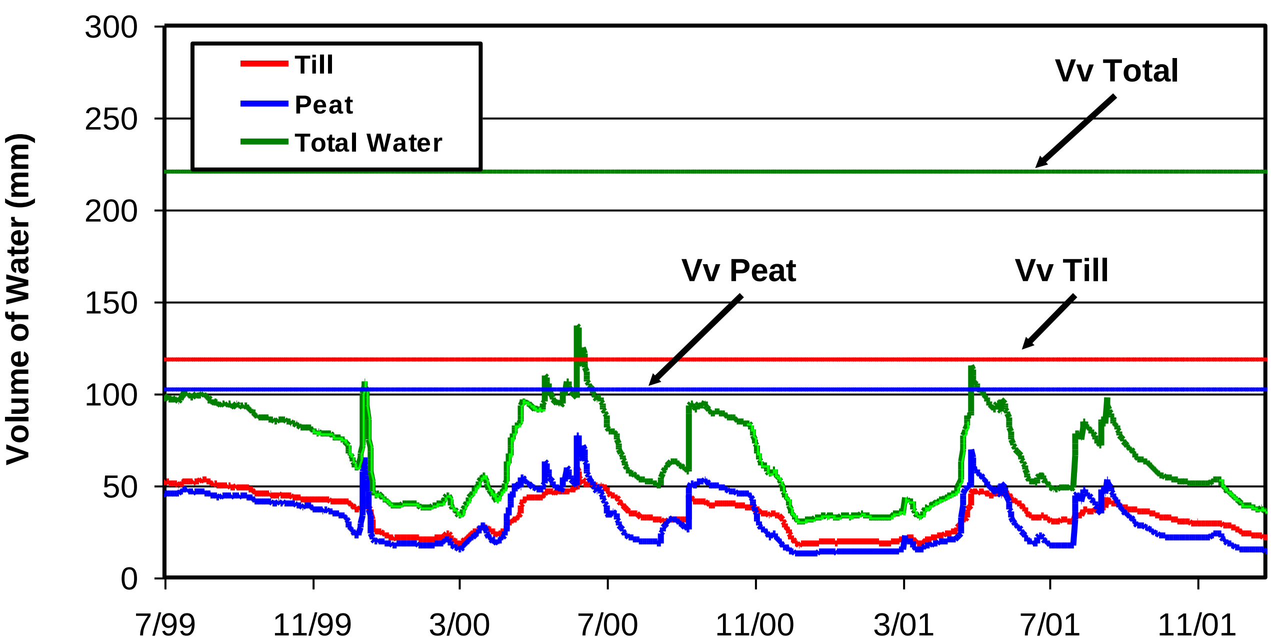

Figure 8. Calculated water volumes for D2 (35 cm) cover.

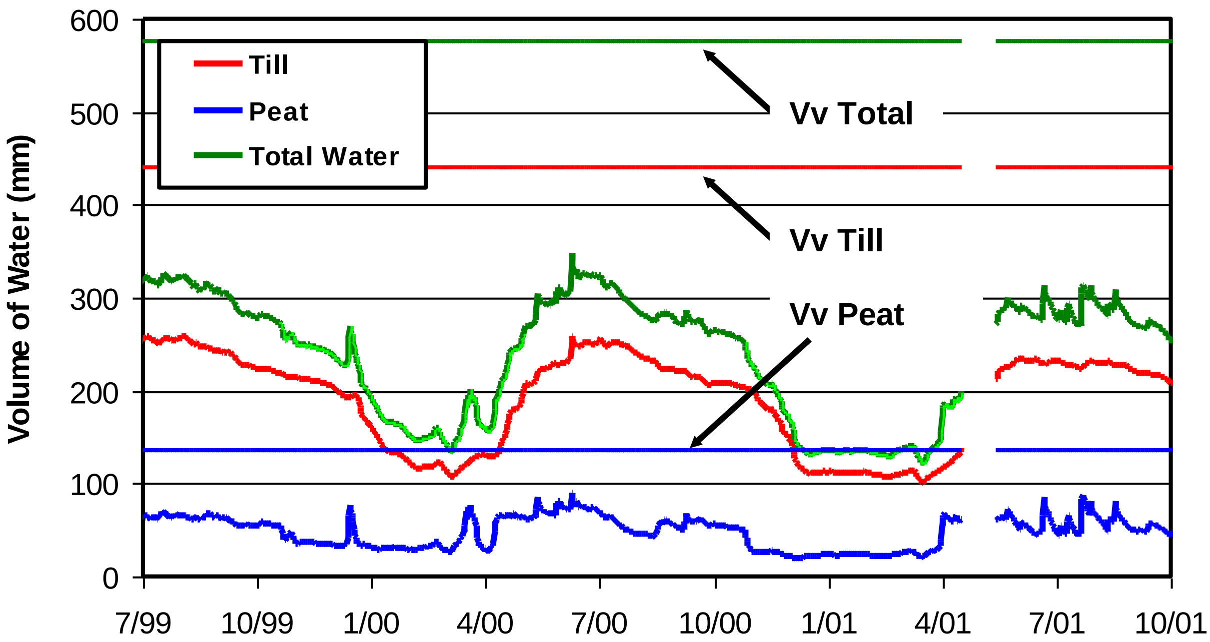

Figure 9. Calculated water volumes for D3 (100 cm) cover.

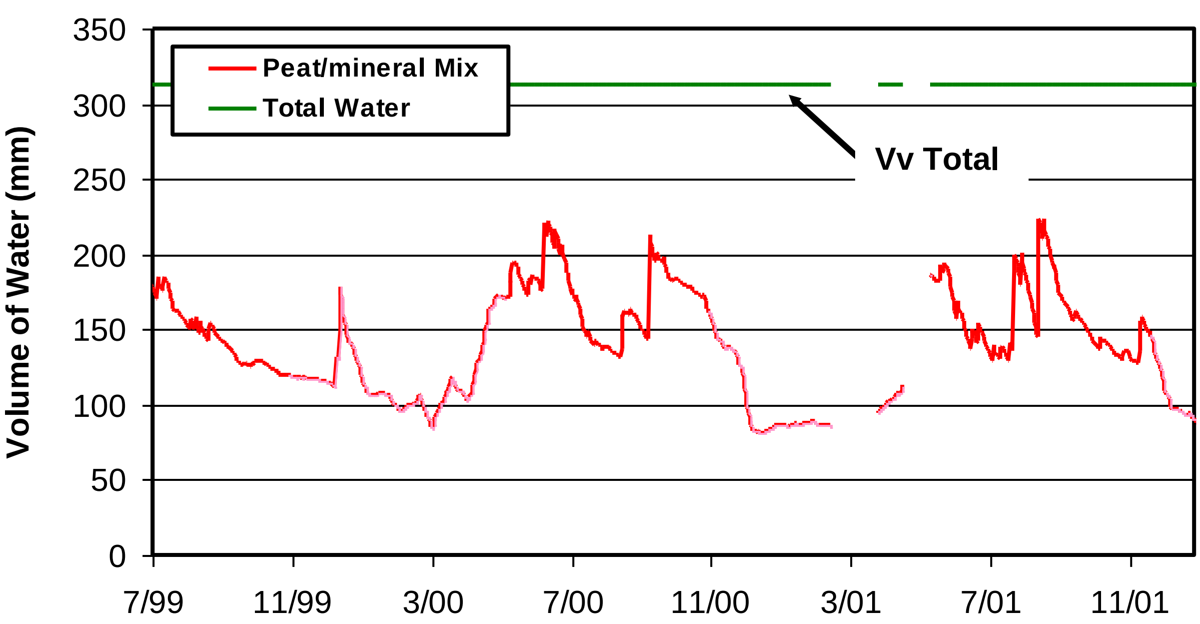

Figure 10. Calculated water volumes for Bill's Lake (100 cm mixed) cover.

A few general observations can be obtained from Figures 7 to 10. The soil stations were completed in June 1999 and monitored for the remainder of the growing season. Vegetation was not established on the covers during this time and, therefore, a slow decrease in stored water volume was experienced until freeze up. Similar trends in stored water volumes can be seen in all covers during 2000 and 2001. Similarities in the stored water content within the covers between the two years can be attributed to comparable vegetation coverage and precipitation values.

Cover water volumes show a rapid response to snowmelt and rainstorm events and the drying effect of vegetation. This is particularly noticeable in the peat layer, while the response in the secondary till layer is relatively subdued. The peat layer is noticeably affected by evapotranspiration, experiencing a rapid decrease in water storage during peak vegetation maturity in July and August. This rapid response is not as apparent in the D3 cover as in the other two prototype covers. The surface layer on D3 was found to contain inclusions of secondary within the peat layer and as a result, less vegetation was established in 2000. The behavior of the thinner D1 (50 cm) and D2 (35 cm) covers appears to be quite similar. When the peat layer storage is 'used up' (at a value between 30 and 40 mm), vegetation looks for other sources of water and the water storage in the till begins to decrease. When the peat wets up again the transpiration demand is again met by this material, the more readily accessible source of water.

Interflow

The interflow collection system was installed at the base of the prototype covers in June 2000 and limited data was collected before freeze up. In spring 2001 the collection barrels were found to be full and frozen. The collection barrel for each of the three covers was inspected frequently and was emptied using a pump equipped with a flow meter to estimate interflow water volumes. Each time the system was pumped a water sample was taken for a general chemical ion sweep. Cumulative volumes from the collection barrel for each cover are presented in Figure 11. Collection rates were initially high but tapered off toward the end of May. Flow from the thinner D2 cover was the first to stop at the beginning of June with flow from the remaining covers stopping at the end of June. It is interesting to note the cumulative volumes produced relative to cover thickness, with the D3 (1m) cover producing the most volume and the thinnest D2 (35 cm) cover producing the least volume of water.

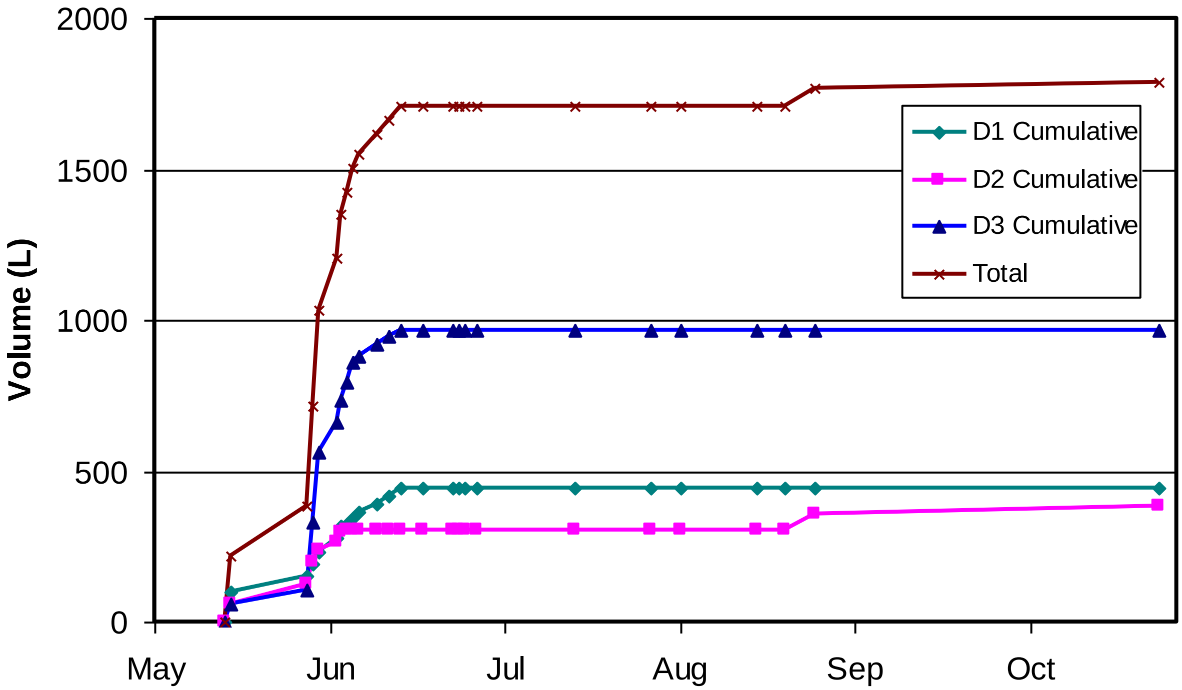

Figure 11. Interflow system water volumes for 2001.

<u>Hydraulic Conductivity – Deep Percolation</u>

A Guelph permeameter was used to measure the insitu hydraulic conductivity (Kf) of the cover materials at both study sites during 2000 and 2001. The hydraulic conductivity of the shale was measured in 2000 using tap water as well as saline water obtained from adjacent wells. Measured Kf values with the Guelph permeameter using both water sources gave results that were not considered to be statistically different, therefore, tap water was used for all measurements in 2001. The test results were tabulated for each year and a comparison was made to to establish if Kf values for the two years were statistically different (Table 1). A paired t-test was used to evaluate changes in Kfs assuming equal and unequal variance, with both methods in agreement (Meiers 2002).

Table 1. Hydraulic conductivity values for Bills Lake and Prototype covers for 2000 and 2001(Meiers 2002).

	Geometric Mean (cm/s)			**Arithmetic Mean (cm/s)**			**Statistically Different**
	2000	**2001**	**Ratio**	**2000**	**2001**	**Ratio**	**(Y/N)**
Prototype Covers							
Peat	8.4 E-04	4.1 E-03	5	1.2 E-03	4.8 E-03	4	Y
Secondary	2.5 E-06	2.2 E-04	87	4.7 E-05	5.8 E-04	12	Y
Shale	2.2 E-07	1.9 E-06	9	4.6 E-07	7.8 E-06	17	Y
Bill's Lake							
Peat secondary mix	2.2 E-05	8.3 E-05	4	1.0 E-04	1.6 E-04	2	N
Shale	8.9 E-08	1.9 E-06	21	9.4 E-08	5.3 E-06	56	Y

The hydraulic conductivity of the secondary material within the prototype covers and the shale at Bill's lake increased in 2001 by one to two orders of magnitude compared to 2000 measurements. This increase is likely due to changes in soil structure as a result of freeze-thaw and wet-dry cycles and the development of a diverse root zone. Roots were observed to migrate through the soil covers into the shale. The hydraulic conductivity of the secondary layer at the prototype cover increased rapidly to a value quite similar to that of the peat/mineral mix at Bill's Lake. The cover at Bill's Lake was placed five years ago and has a strongly developed, stable vegetation layer. It appears that the newer prototype covers (3 years old) are rapidly reaching a similar equilibrium condition to this older cover layer.

In 2000, three major rainfall events occurred over the summer which led to a small amount of runoff in the D3 and D1 weirs. No runoff was recorded from the D2 weir for any of the events. Summer 2001 did not see rains of this intensity and no runoff data was recorded was recorded of any significance in any of the four weirs.

Analysis

A preliminary water balance for the covers can be performed using Equation 1:

$$\Delta S = PPT - R - P - I - AET \quad (1)$$

which can be re-written as:

$$AET = PPT - \Delta S - R - I - P \quad (2)$$

where:

PPT is precipitation, ΔS is stored soil moisture, R is measured runoff, P is deep percolation, I is interflow, and AET is the actual evapotranspiration. All measurements are recorded in mm.

Components of this water balance can be approximated using the database generated by the monitoring program described in the previous sections. All measured units are converted into equivalent values of mm/day and applied to the entire area of the cover. Values contributing to the water balance by interflow and runoff when compared to the total area of the covers are insignificant and considered to be negligible. A maximum rate of deep percolation through the shale can be estimated from field measurements of hydraulic conductivity assuming a downward gradient of unity. Percolation into the shale was also assumed to be negligible. Change in storage was taken from data obtained from the soil stations that is presented in Figures 7 to 10.

Cumulative measured AET (from the Bowen Ratio Station) and calculated daily AET (from the change in soil storage and precipitation) for 2000 and 2001 are shown in Figures 12 and 13. The Bowen station was set up at Bills Lake for the later part of the season (July to October) in 2000 and the early part of the season (May to July) in 2001. In 2001, the thermocouples, which are key components in Bowen ratio measurement, suffered damage and could not be repaired in time to acquire data in the early part of the season. Measurements for 2001 begin July 19 when the station was relocated to the Prototype covers. Because of the delay in Bowen AET measurement, the cumulative AET was assumed to have the same value as the D3 cover on July 19.

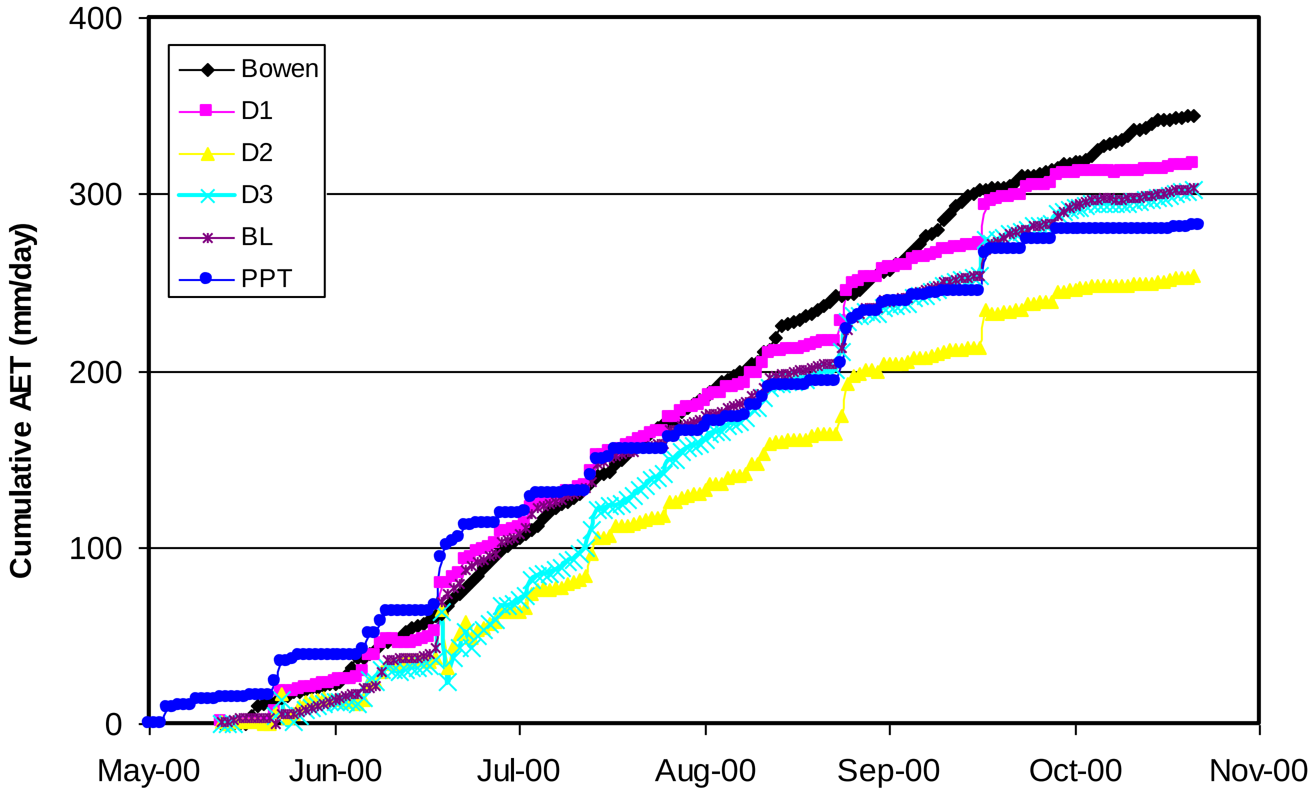

Figure 12. Cumulative AET for all covers 2000.

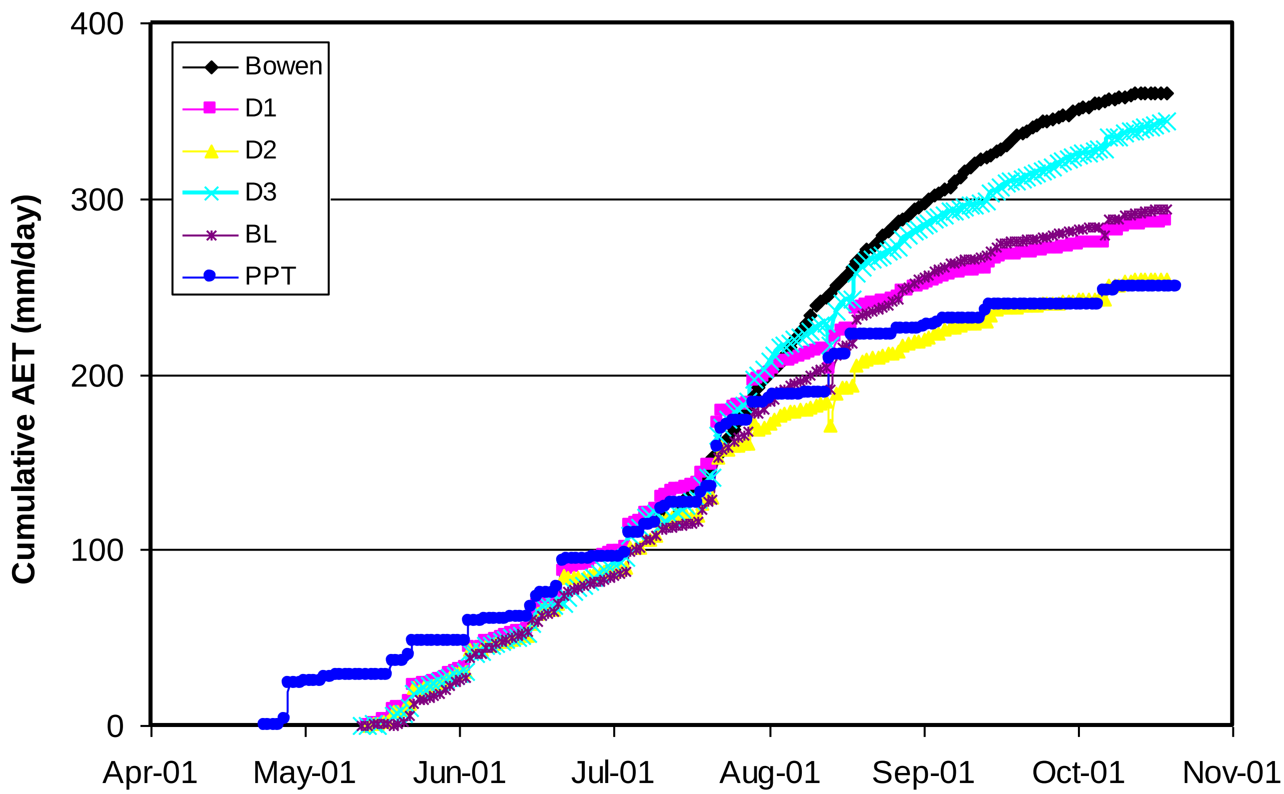

Figure 13. Cumulative AET for all covers 2001.

In May 2000, the beginning of the growing season, all covers lagged slightly behind the measured Bowen AET where the covers were 'recovering' from the previous year's dry conditions. The calculated AET values for the D3 and D2 covers continue to fall, however the AET values for D3 begin to recover early in August, suggesting a slight delay in vegetation maturation. The prototype covers were vegetated with a foxtail grass that was not uniformly distributed across all three covers, with the D3 cover initially more sparsely vegetated as a result of the inadvertent inclusions of secondary material within the peat. The D1 and Bill's Lake covers performed similarly throughout the season, although the thicker, homogeneous, Bill's Lake cover did not appear to outperform either of the thinner prototype covers.

In 2001 slightly more water was available at the beginning of the season, thus the covers developed higher rates of AET much earlier in the spring. Again, the D2 cover in 2001 does not seem to have the capability to sustain healthy growth for the entire summer as AET values for this cover are the first to begin to drop in the beginning of August. The D3 cover does not show a delay in peak values in 2001. Vegetation on the covers was found to be more diverse in 2001 and an obvious difference in vegetation density was not apparent at peak times in the growing season as was noticed in 2000. The homogeneous Bill's Lake cover seems to perform better than the D2 (35 cm cover) sustaining AET values later in the season, but again does not outperform either the 50 or 100 cm layered covers. In fact, the performance of the 50 cm layered cover is quite comparable to that of the thicker, single layer cover at Bill's Lake through most of the summer of 2001.

A water deficit of 60 mm in 2000 and 90 mm in 2001 developed through the growing season (May to October). This deficit must be made up through precipitation in the fall and spring and snowmelt infiltration in order for the cover vegetation to be sustainable. If this deficit is related to the thickness of each of the prototype covers then the changes in volumetric water content required to store this water can be calculated, as shown in Table 2.

Table 2. Average change in water content for prototype covers.

Average Change in Water Content			
	50 cm cover	35 cm cover	100 cm cover
2000	**12%**	**17%**	**6%**
2001	**22%**	**31%**	**11%**

A change in storage over summer requires greater change in water content in till/peat. From this we can conclude that a deeper depth of soil layer is more effective than a thinner layered system.

Conclusions

An ongoing field program carried out at the South Hills reclamation site at the Syncrude mine site is monitoring the performance of soil covers. Instrumentation installed at the research site is measuring at the performance of the covers and parameters to conduct an overall water balance for the area.

Covers placed in 1999 appear to be still reaching a stable soil structure with changes of hydraulic conductivity in the till and the shale changing an order of magnitude over 1 year. Further hydraulic conductivity field tests in the remaining years of the monitoring program will help to determine to what degree the hydraulic conductivity of these covers has stabilized.

A simple summer water balance conducted on results collected in 2000 and 2001 indicate that through the growing season, AET values exceed precipitation values by 60 to 90 mm and the volume of water stored in the covers is controlled by precipitation and actual evapotranspiration. Runoff and interflow volumes are considered to be insignificant to the water balance, but may play a role in regards to salt distribution. It appears from this analysis that the 'thinner' layered covers perform equally well to thicker single layer covers, although the thinnest cover (35 cm) seemed to lack sufficient moisture storage to prevent wilting point stress on plants established on these covers. It appears that layering soil covers contributes to improved system performance from a moisture holding standpoint.

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