RISK-BASED ASSESSMENT OF THE SUSTAINABILITY OF THE RECLAMATION STRATEGY – First Progress Report

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CANSIM SERIES REPORT NO. CAN-07-01

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November, 2007

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

This is the first progress report on the project entitled “Risk-based assessment of the sustainability of the reclamation strategy”. The project is progressing as planned. The goal of this project is to assess the sustainability of the oil sands reclamation strategy in light of the uncertainty imposed by the climatic variability. To attain this goal, the specific objectives of this project are: (i) to calibrate and modify the SDW model to simulate the hydrological processes; especially daily soil moisture and actual evapotranspiration, on various reclaimed sites that represent different development stage; (ii) to calibrate and modify the SDW model to simulate the hydrological processes on various natural sites from the boreal forest that represent different species of vegetation; (iii) to simulate the hydrological processes in the various reclaimed and natural sites over a long period of time (50 -60 years); (iv) to quantify the long term hydrologic performance of the various sites using the probabilistic approach; and (v) to assess the performance of the reclaimed sites using the natural sites as a reference for the comparison. The tasks of the first year (2007) of the project have been completed. Hydrometeorological studies on the reclaimed SBH, the reclaimed jack pine forest (RJF), the reclaimed South West Sand Storage (SWSS), and the newly reclaimed Suncor (NRS) sites have been conducted. Two new eddy covariance towers were instrumented in 2007 (NRS and RJF) along with the continued operation of SBH (now with 5 years of data) and the SWSS. For 2007, the surface energy balance, evapotranspiration and preliminary water balance are completed for SBH, RJF and NRS sites.

The SDW model has been modified and calibrated (MSDW model) to simulate the SBH and the natural old aspen (OA) sites. Both sites have been simulated and the simulation results are provided in this report. A historical meteorological record of 50 years has been used with the MSDW model to produce daily soil moisture content and evapotranspiration values over 50 yeas. Subsequently, frequency curves of both soil moisture storage and annual evapotranspiration have been constructed for both sites. Even though the analysis and the results provide a solid basis for comparing natural and reclaimed sites, it is recommended, at this stage, to take the numbers with caution until the MSDW model and analyses of all sites are completed.

1. INTRODUCTION

The oil sands mining industry in Canada has made a commitment to restore mining areas to an equivalent capability to that which existed prior to mining. One of the central requirements in the design of reclamation soil covers in order to meet this goal is that the soil cover has a sufficient Available Water Holding Capacity (AWHC) to allow for evapotranspiration requirements over the summer moisture deficit typical in the region. In situations where evapotranspiration demands exceed the AWHC, vegetation is susceptible to increased stress and mortality, elevating the risk of ecosystem failure. Currently, various soil cover alternatives are subject to classification and evaluation based on the Land Capability Classification System (LCCS) for Forest Ecosystems in the Oils Sands (Leskiw, 2004). The LCCS uses AWHC to identify the soil moisture regime of the soil cover required for the development of various target ecosystems.

Recently, work has been initiated to present an alternative probabilistic approach for the assessment of the hydrologic performance and design of these reclamation soil covers. A previously developed site specific water balance model (the SDW model by Elshorbagy et al., 2005; 2007) for monitored prototype reclamation covers (the SB30 cover) has been used along with the historical meteorological record to estimate the maximum soil moisture deficit that various soil covers are able to sustain over the growing season. Frequency curves of the maximum annual moisture deficit are used to assess the probability that the cover is not capable of providing a particular threshold of moisture demand (Elshorbagy and Barbour, 2007).

To establish the maximum annual moisture deficit for different ecosites, the factors affecting the timing and magnitude of water balance components, particularly evapotranspiration, must be determined. This hydrological information can then be used to calibrate and test the SDW model, which upon validation is driven by long-term climate data to generate the frequency curves for assessing the probability of cover failure. However, the likelihood of cover failure will vary based upon cover design, vegetation species and age. Therefore, it is necessary to examine different covers at discrete stages of development. It is also important to assess the hydrologic performance of the reclaimed covers in comparison with natural sites for a complete assessment of restoration strategies.

The goal of this project is to assess the sustainability of the oil sands reclamation strategy in light of the uncertainty imposed by the climatic variability. To attain this goal, the specific objectives of this project can be stated as follows: (i) to calibrate the SDW model to simulate the hydrological processes; especially daily soil moisture and actual evapotranspiration, on various reclaimed sites that represent different development stage; (ii) to calibrate the SDW model to simulate the hydrological processes; especially daily soil moisture and actual evapotranspiration, on various natural sites from the boreal forest that represent different species of vegetation; (iii) to simulate the hydrological processes in the various reclaimed and natural sites over a long period of time (50 -60 years); (iv) to quantify the long term hydrologic performance of the various sites using the probabilistic approach; and (v) to assess the performance of the reclaimed sites using the natural sites as a reference for the comparison.

2. THE RESEARCH FRAMEWORK

This research study involves both field and modeling components that will occur simultaneously. Reclamation and natural sites were identified for the study based on their contrasting ecohydrology and risk of failure. Hydrometeorological studies and data collection are planned to be conducted on the following reclamation sites: (i) the flat top of the South Bison Hill (**SBH**), which is capped with a 20 cm of peat-mineral mix over 80 cm of glacial till over shale; (ii) the South West Sand Storage (**SWSS**), which consists of mine tailings sand overlain with 40-80 cm of mixture of peat and secondary mineral soil; (iii) newly reclaimed Suncor (**NRS**) site that has a 12:1 slope of 20 cm of peat over sand; (iv) the 15-year old jack pine forest (**RJF**) (Mildred Lake North Side), which is 50 cm of peat over tailing sand; and (v) the Syncrude LFH over sand site (**LFH**). At all sites, eddy covariance (EC) will be or has been used to directly measure exchanges of energy, water, heat, and CO_2 between the surface and the atmosphere. Concomitant measurements of air and ground temperature, solar and terrestrial radiation, wind, precipitation, humidity, and soil moisture will be used to complete water balances for a minimum of two years per site. The Waste Area 1A Suncor site of 14 year-old spruce forest was removed from the study due to the technical difficulty of setting up an EC tower on the site due to the presence of high-voltage TransAlta power lines. Three natural forested sites from the Boreal Atmosphere Exchange Study (BOREAS) (Sellers et al., 1995) and the Boreal Ecosystem Research and Monitoring Sites (BERMS) program (http://berms.ccrp.ed.gc.ca; McCaughey et al., 2000) will be used to study the hydrologic performance of the natural sites for comparison purposes with reclaimed sites. The natural sites are (i) old jack pine (**OJP**) site, located approximately 100 km NE of Prince Albert, Saskatchewan; (ii) old black spruce (**OBS**) site, located in a muskeg forest near White Swan Lake, Saskatchewan; and (iii) old aspen (**OA**) site, located near the south end of Prince Albert National Park, Saskatchewan. Initially, five natural sites were proposed for this study, but later it was restricted to only three sites due to data limitations.

The SDW model will be modified and recalibrated to simulate the hydrological processes in the five reclaimed as well as the three natural sites. The end goal of this step is to develop a generic model, rather than the existing site specific model, that can simulate the hydrological processes in any of the existing or hypothetical sites. Upon validation, the SDW model will be used to simulate the hydrological processes in the eight sites over an extended time period (e.g., 60 years) using the available historical records of meteorological data as model inputs. The long-term simulations will be used to produce frequency curves representing the annual evapotranspiration and the annual maximum soil moisture deficit values. The resulting frequency curves will be used to quantify the hydrological performance of the various sites in probabilistic forms.

3. TASKS OF YEAR 1 (2007)

The following tasks were proposed to be completed within year 1 (2007):

3.1 Hydrometeorological study on the reclaimed SBH site, which will be the fifth year (DY5) of data collection on this site;

3.2 Hydrometeorological study on the newly reclaimed Suncor (NRS) site, which will be the first year (DY1) of data collection on this site;
3.3 Hydrometeorological study on the reclaimed 15-year old jack pine forest (RJF), which will be the first year (DY1) of data collection on this site;
3.4 Adaptation and calibration of the SDW model for the SBH site;
3.5 Adaptation and calibration of the SDW model for the SWSS site; and
3.6 Adaptation and calibration of the SDW model for the three natural sites.

A slight modification has been made, where instead of just calibrating the model for various sites, an emphasis has been placed on only two sites: the reclaimed SBH site and the natural OA site. Even though tasks 3.5 and 3.6 have been partially achieved, this has been compensated by achieving some of the tasks of year 2008 and year 2009 of this study. The SDW model has been adapted and calibrated to simulate both SBH and the natural OA sites, long term simulation has been also conducted, and the soil moisture deficit and the evapotranspiration frequency curves have been constructed. This way, more tangible results have been achieved during year 1 (2007) of the project.

4. METHODOLOGY

4.1 Hydrometeorological studies

Two new towers were instrumented in 2007 (NRS and RJF) along with the continued operation of SBH (now with 5 years of data). Two years of data have previously been collected for SWSS. After the 2008 field season, the tower will be moved from either the NRS or RJF to the LFH site based on which site is most poorly characterized by two years of data (likely the RJF site). At each site, an eddy covariance system is placed above the canopy or surface to measure fluxes of sensible heat, evapotranspiration and CO_2. Supplemental measurements of solar radiation, net radiation, air temperature, relative humidity, wind speed, soil heat flux, soil temperature, soil moisture and soil suction at various depths are recorded every half hour. Sites run from early May through early October to characterize the complete growing season. In 2008, sites will begin operation in April to characterize the water balance before plant growth begins in earnest. Biometric parameters such as leaf area index, above ground biomass, stand density and composition, and species diversity is recorded at each site along with weekly photographic records from fixed locations. This information provides the required variables and parameters for the SDW model, and provides detailed information on the ecohydrology of the study sites and its controlling factors. By having at least two years of data from each site (with 8 from SBH), it is anticipated that the natural variability in ecohydrology will be captured for the site at that stage of development. The methods used here are the same as those used at the natural BERMS and BOREAS sites, allowing direct inter-comparison.

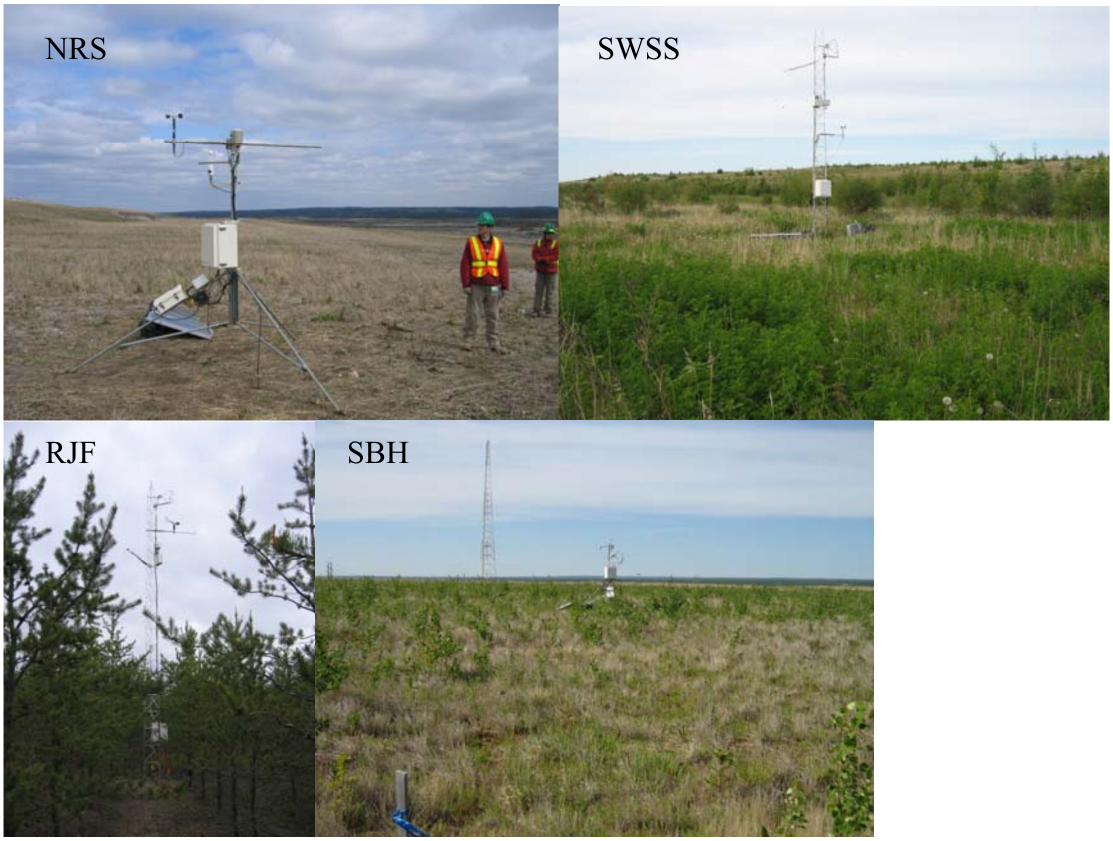


Figure 1: Composite photographs of meteorological towers and sites.

4.2 Hydrological modeling

The site-specific SDW model has been modified in this study to suit the flat terrain and to account for the canopy interception. In this section, the main modification, which is the addition of the canopy module, is explained. The resultant model is named the MSDW, referring to the modified system dynamics watershed model.

Canopy interception

Interception is the process by which precipitation is intercepted on the vegetation surface, where it evaporates directly to the atmosphere (E_c). Interception losses depend mainly on the precipitation intensity, duration, and frequency. Moreover, these losses are also affected by the vegetation type and its maturity stage, which can be expressed as Leaf Area Index (LAI). Since the interception loss can range from 10 to 40% of various plant communities (Dingman, 2002), and because of the uncertainties and the inflexibility associated with the various methods of measuring the interception loss, there is a need for developing a conceptual model that simulates the interception loss in many hydrological models.

The site specific SDW model (Elshorbagy et al., 2007; 2005) did not include a canopy interception module. Efforts were made in this study to modify the existing SDW model with a canopy interception module on a daily time step. This module is a simplified approach to the Valente et al. (1997) conceptual model, in which the watershed is partitioned into a fraction (percentage of total area) covered with vegetation (F) and a complementary fraction of bare soil (1-F). Figure 2 depicts the Valente et al. (1997) conceptual model, which includes many physical parameters as the canopy storage (Sc), stem storage (St), fraction of the total evaporation that occurs from the trunk (ε), and the fraction of drainage that drips from the canopy (1-ρ). These parameters are based on detailed information of the vegetation structure.

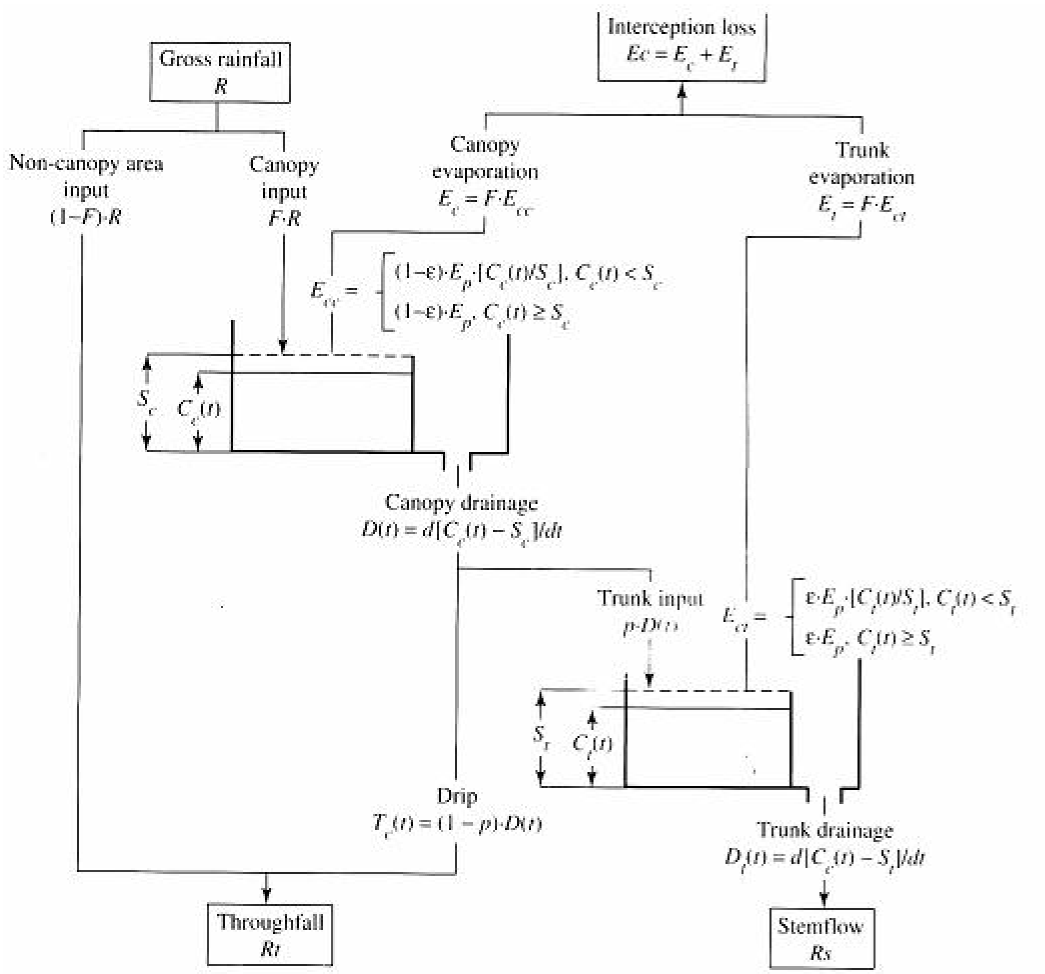


Figure 2. the schematic diagram proposed by Valente et al. (1997) for canopy interception loss (Dingman, 2002).

In this conceptual module; the gross rainfall (R) is partitioned into two parts; the first part goes directly as part of the through fall to the ground while the other part is intercepted by leaves and branches. As soon as the canopy storage (Sc) reaches its maximum capacity, the excess water is drained as dripping water from leaves and branches and contributes partially to the through fall. The dripping water, also, contributes to the trunk flow. Similarly, the trunk interception is divided into two parts; trunk drainage and trunk evaporation. As pre-mentioned in the canopy storage, when the trunk storage (St) exceeds its maximum capacity the excess amount contributes to the stemflow (Rs). Finally, the interception loss from canopy (E_c) is computed as the sum of both trunk and canopy evaporation. The Penman equation was used to compute the rate of evaporation of intercepted water.

The module adopted in the SD model uses simpler approach, due to the difficulty in obtaining the required detailed inputs; e.g. Sc and St. In this approach the total Precipitation is assumed to be divided into two main components; (i) Canopy Interception (I_c), and (ii) Through fall (TF). Figure 3 is a demonstration of the simplified approach, which is used in the SD model. Part of the through fall (TF) is assumed to contribute to the overall Canopy Interception; this part is intercepted by the letter on the floor. This portion of intercepted precipitation is estimated based on the canopy cover.

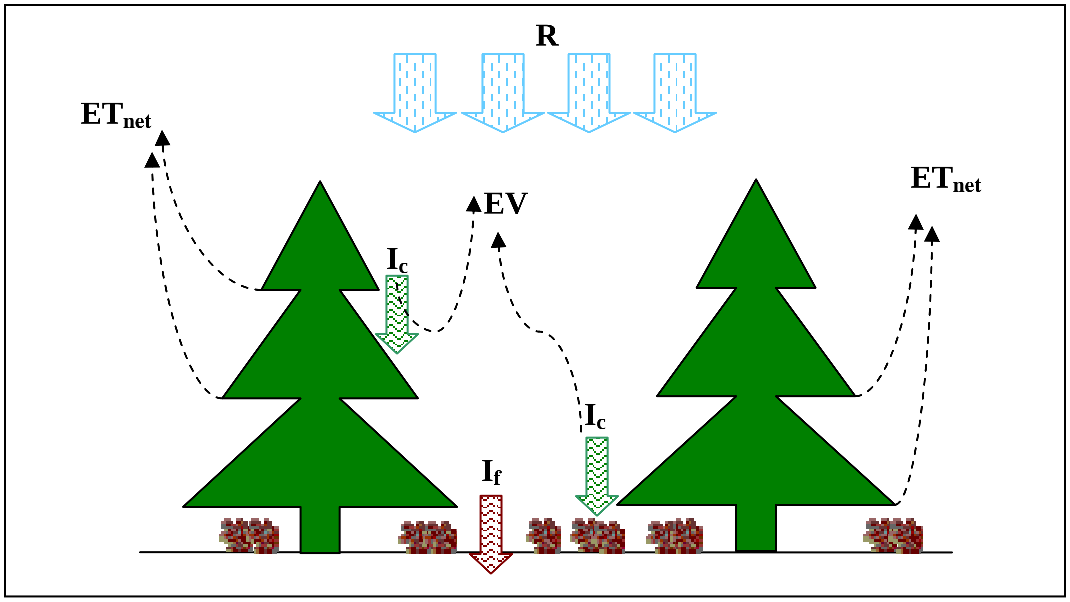


Figure 3. A schematic diagram of the simplified interception module in the MSDW model.

The canopy cover factor, which is used to estimate the amount of the intercepted precipitation, takes into account the contribution of the stem flow. The remaining part of the through fall (TF) represents the amount of precipitation reaches the watershed floor (I_f). It is assumed that all the intercepted water evaporates (EV) and represents a portion of the actual evapotranspiration losses (AET). Both the evaporated water (EV) and the evapotranspiration from the vegetation and the bare soil (AET_{net}) represent the actual evapotranspiration losses (AET).

5. RESULTS AND PROGRESS

5.1 Hydrometeorological studies

For 2007, the surface energy balance, evapotranspiration and preliminary water balance are completed for SBH, RJF and NRS sites. At present, only data until mid-August has been analyzed as O'Kane Consultants have not updated their database (for precipitation, soil temperature and suction data) to include the mid-August to early October period. Historical analysis for SWSS (2005-2006) and SBH (2003-2006) has been completed and a manuscript describing the energy and water balance for SBH for the first three years (2003-2005) has been accepted pending revisions in academic journal Hydrological Processes (Carey, in revision). Results presented here for 2007 will focus on the RJF site as it has received the most attention to date. It is important to note that similar data sets exist for all sites and analysis is ongoing.

2007 was slightly warmer and drier than the 30 year normal for Fort McMurray (Figure 4). A dry May and June was followed by considerable precipitation in July and August (Figure 5), and then a dry September. This contrast provides an excellent opportunity to evaluate how each ecosystem responded to drought that occurred mid-summer, and the subsequent recovery following rainfall in July and August.

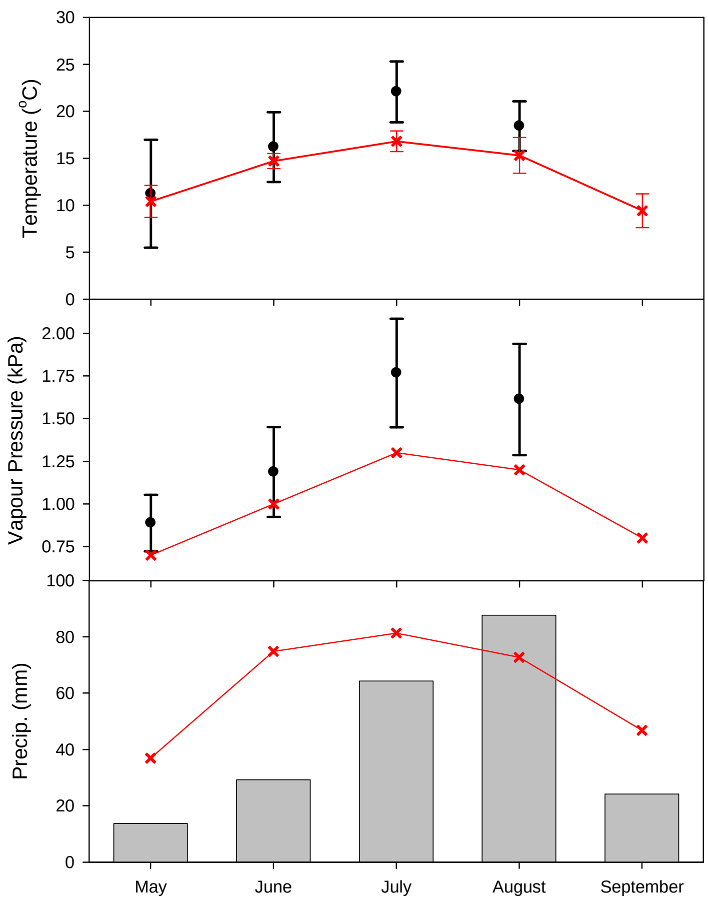


Figure 4. 2007 Growing season climate variables. Red values are the 30-year normal values from Fort McMurray, AB.

With regards to the RJF, the average daily energy fluxes from mid May to mid August are shown in Figure 6. Fluxes of net radiation were portioned between sensible, latent and ground heat. At the onset of measurement, sensible and latent heat fluxes were almost equal as the forest was able to draw water from the soil moisture reservoir replenished during snowmelt. As summer continued, the lack of rainfall resulted in an increase in sensible heat and a decline in latent heat as the forest became water restricted. Following the considerable precipitation input after around Day of Year 200, latent heat began increasing compared

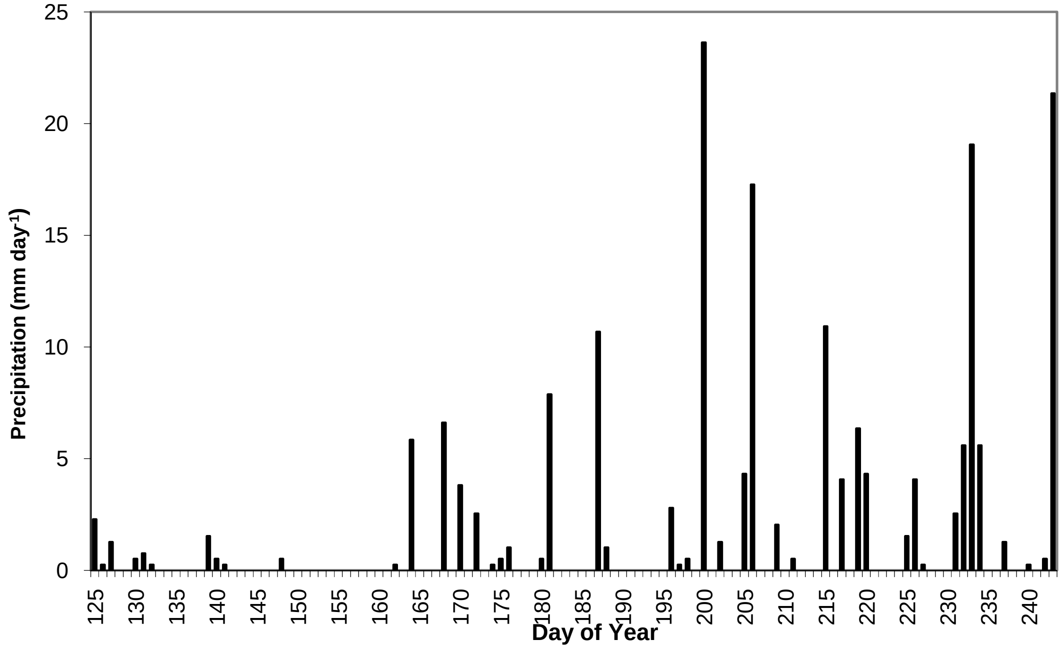


Figure 5. Daily precipitation, RJF site.

with sensible heat and was the greatest consumer of energy by mid August. Similar patterns are reflected in evapotranspiration (Figure 7). During the early part of the study season, evapotranspiration fluctuated around average values of just less than 2 mm per day, and declined slightly as soils dried. Following the mid-season rains, evapotranspiration increased to a rate approaching 3 mm per day. Soil moisture patters for various depths are shown in Figure 8, exhibiting a marked decline in the early summer, only being gradually replenished after mid-season rains to levels in early spring. The information collected at this, and all other sites, will allow for a complete growing season water balance.

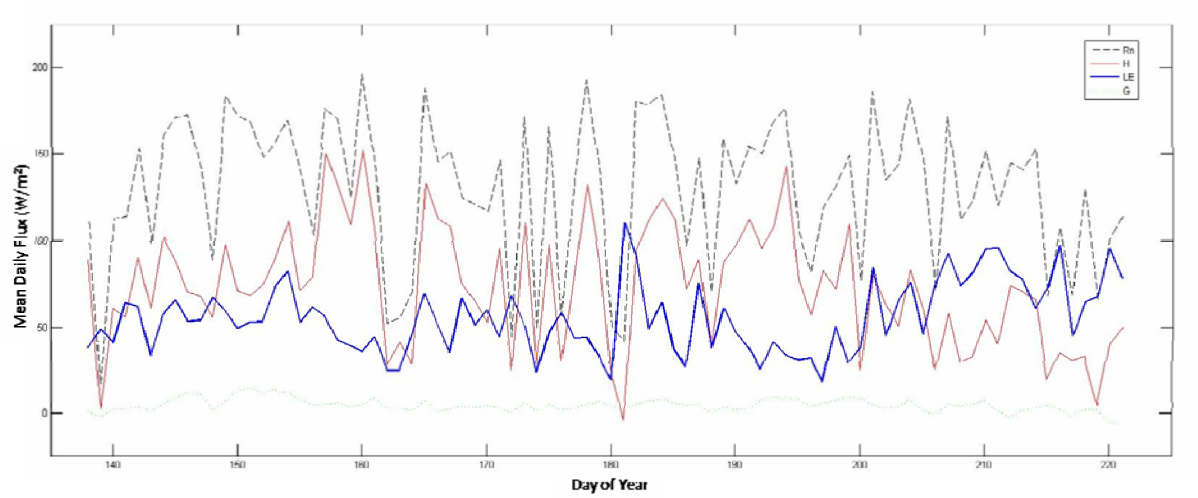


Figure 6. Surface energy balance for RJF, 2007.

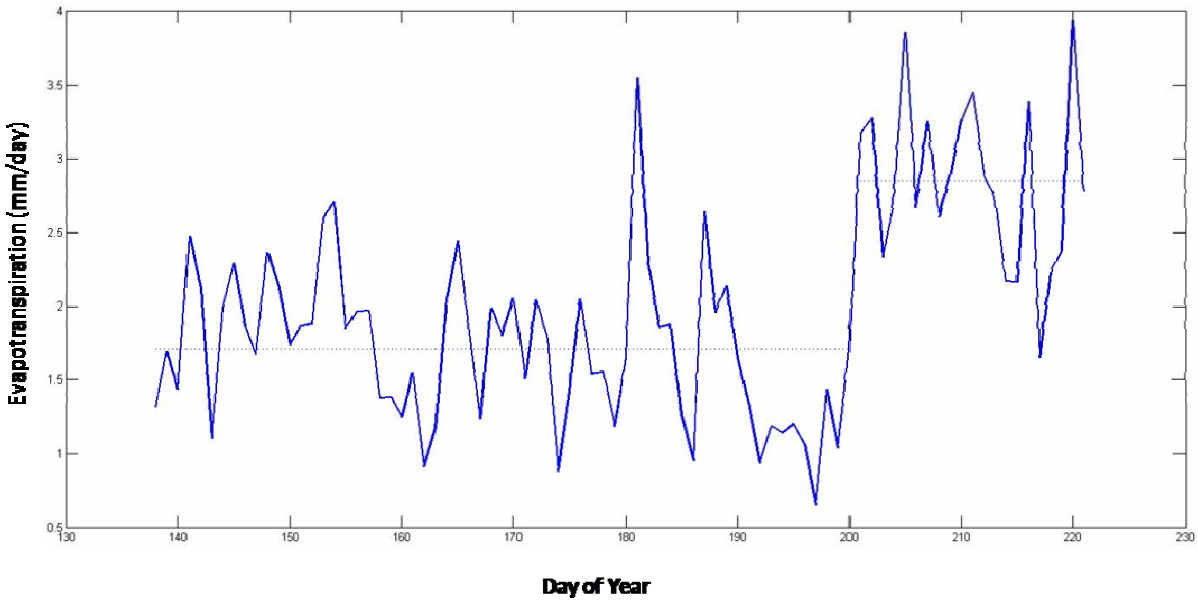


Figure 7. Daily Evapotranspiration for RJF, 2007.

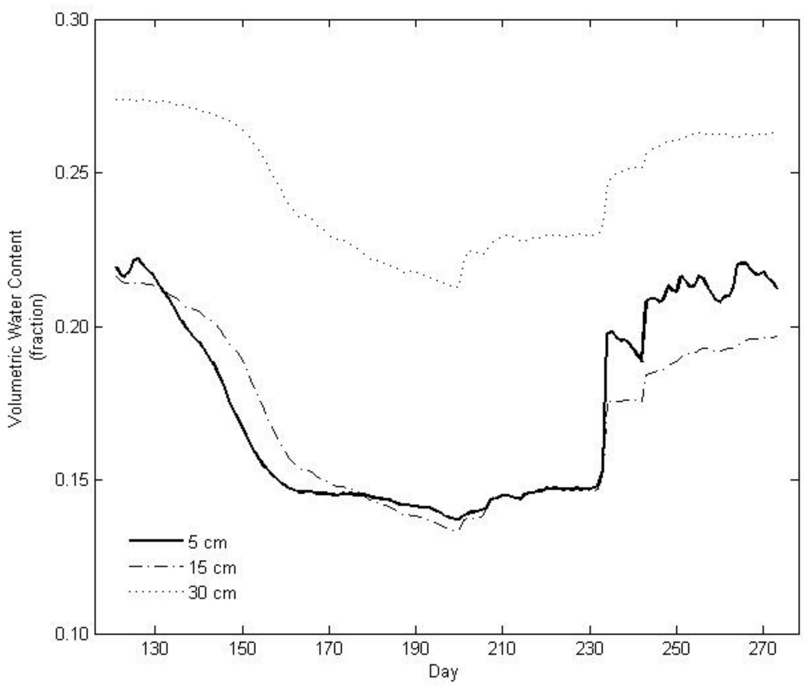


Figure 8. Soil moisture for RJF, 2007.

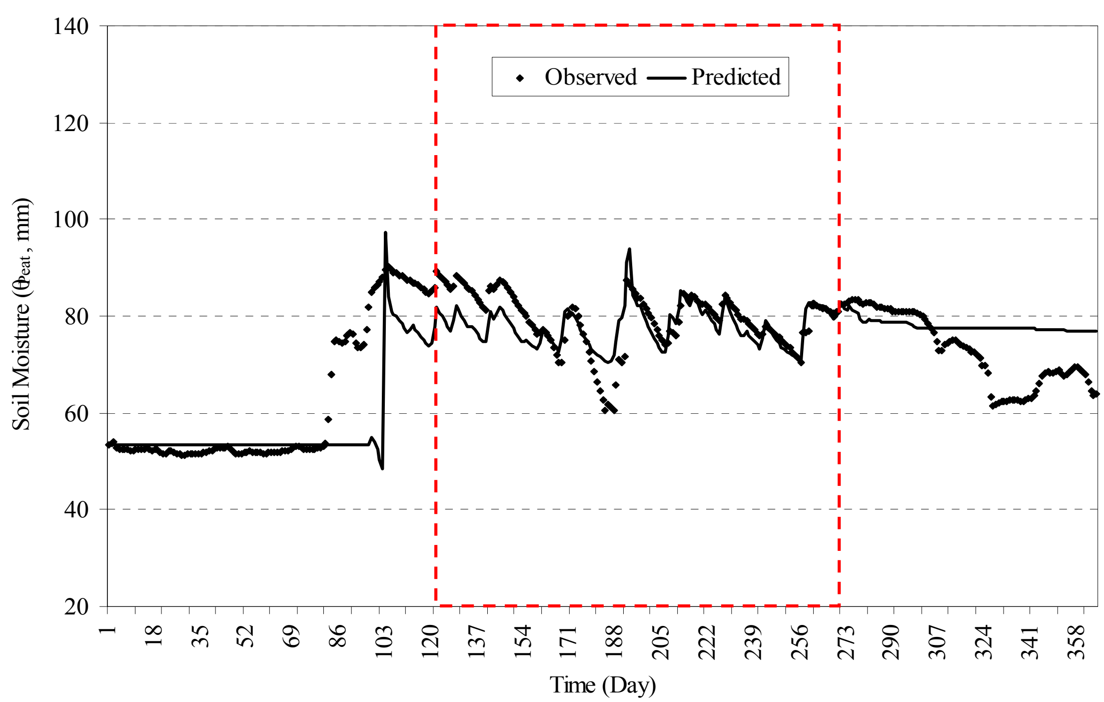
5.2 Hydrological modeling

The simulation and the hydrological performance of both the reclaimed SBH and the natural boreal OA sites are provided below.

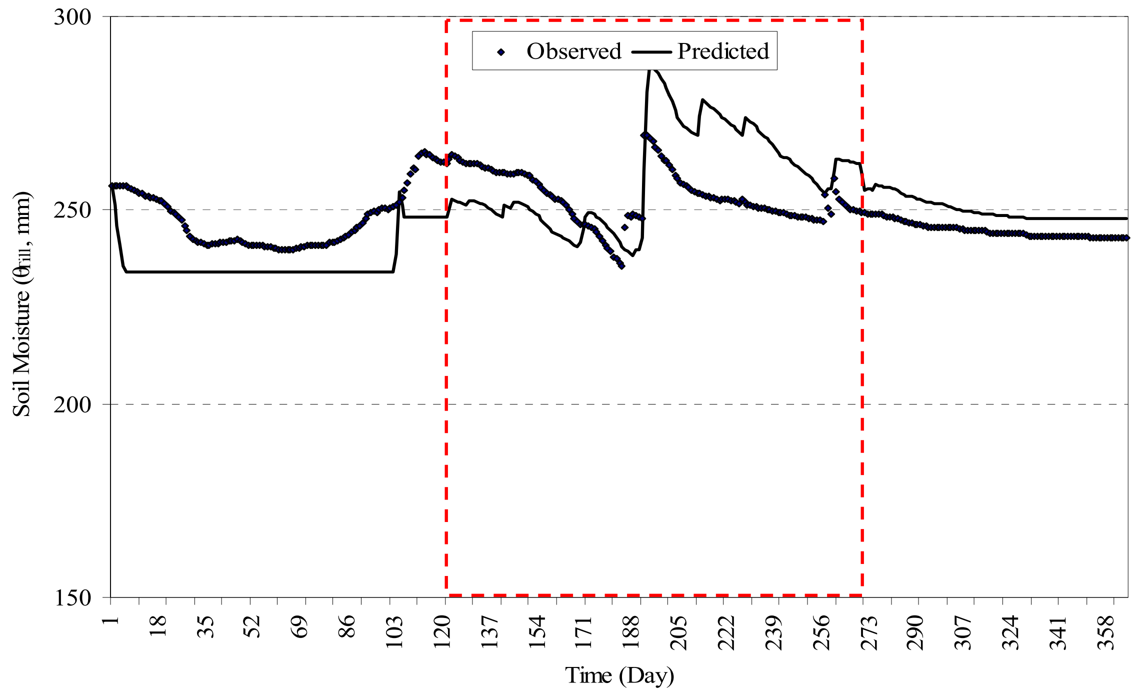
5.2.1 The reclaimed SBH site

The MSDW model was calibrated and validated to simulate the various hydrological processes in the reclaimed SBH site using data from years 2005 and 2006. The observed and predicted soil moisture contents in the 20 cm thick upper peat layer and the 80 cm thick lower glacial till layer of the validation year (2006) are shown in Figure 9. It is important to notice that the observed values outside the growing season (shown in the figure as a rectangular box) are not reliable due to the frozen conditions most of the time. Therefore, the model performance is assessed based on the predicted values within the growing season (May 1^{st} – October 1^{st}). The match between the observed and predicted soil moisture values is weaker in the till layer. However, one should realize that the model is a lumped model that produces depth-averaged soil moisture content. Given the significant spatial variability of the in-situ soil moisture measurements, the thickness of the till layer (80 cm), and the good match within the upper peat layer as well as between the observed and predicted actual evapotranspiration (Figure 10), it can be concluded that the MSDW model performance is quite good.

According to the eddy covariance (EC)-measured evapotranspiration, the cumulative seasonal actual evapotranspiration (observed AET) was 277 mm, whereas the predicted value (predicted AET) was 273 mm. The predicted AET includes transpiration from the vegetation (predicted AET_{net}), which was around 260 mm and evaporation of the intercepted water (273-260 = 13 mm).



(a)



(b)

Figure 9. Observed and predicted soil moisture content in the SBH site: (a) upper layer (peat); (b) lower layer (till)

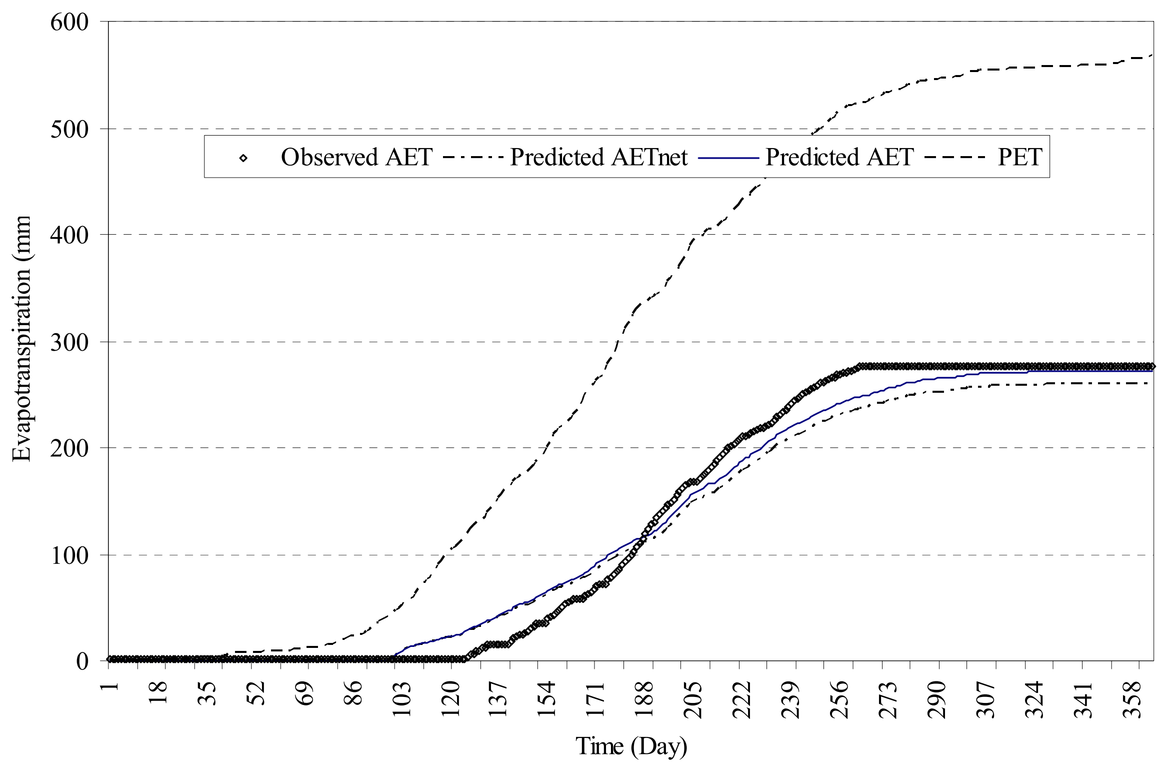
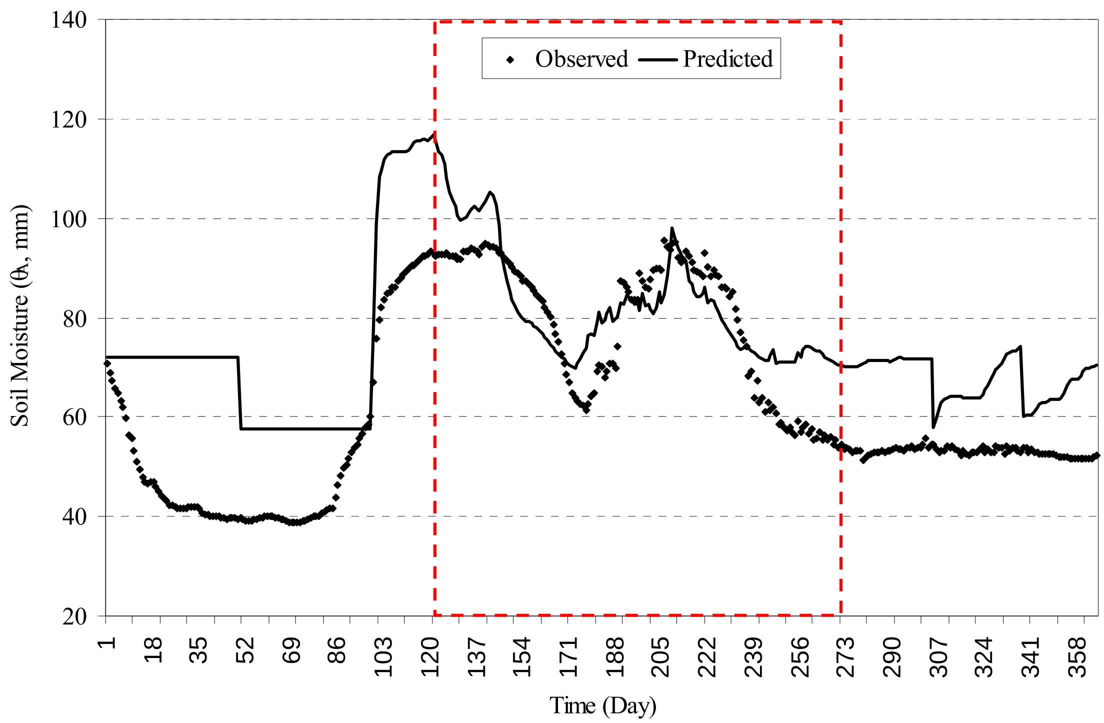


Figure 10. Observed and predicted Evapotranspiration (mm) in the SBH site.

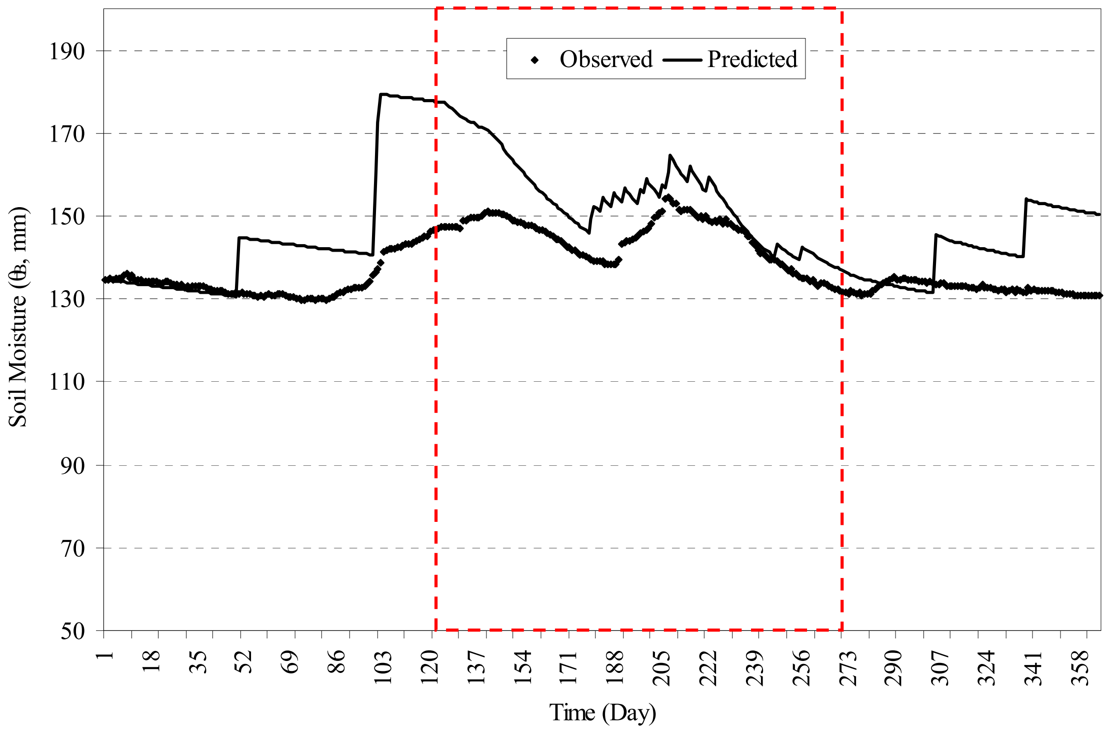
5.2.2 The natural OA site

The MSDW model was calibrated and validated to simulate the various hydrological processes in the natural boreal old aspen (OA) site using data from years 1999 and 2000. The observed and predicted soil moisture contents in the 25 cm thick upper A-horizon layer and the 45 cm thick lower B-horizon layer of the validation year (2000) are shown in Figure 11. It is important to notice that the observed values outside the growing season (shown in the figure as a rectangular box) are not reliable due to the frozen conditions most of the time. Therefore, the model performance is assessed based on the predicted values within the growing season (May 1st – October 1st). The match between the observed and predicted soil moisture values is slightly worse in the B-horizon. However, one should realize that the model is a lumped model that produces depth-averaged soil moisture content. Given the significant spatial variability of the in-situ soil moisture measurements, the thickness of the B-horizon (45 cm), and the reasonable match within the upper A-horizon as well as between the observed and predicted actual evapotranspiration (Figure 12), it can be concluded that the MSDW model performance in the OA site is quite satisfactory.

According to the eddy covariance (EC)-measured evapotranspiration, the cumulative seasonal actual evapotranspiration (observed AET) was 356 mm, whereas the predicted value (predicted AET) was 348 mm. The predicted AET includes transpiration from the vegetation (predicted AET_{net}), which was around 315 mm and evaporation of the intercepted water (348-315 = 33 mm).



(a)



(b)

Figure 11. Observed and predicted soil moisture content in the Old aspen natural site: (a) A-horizon; (b) B-horizon.

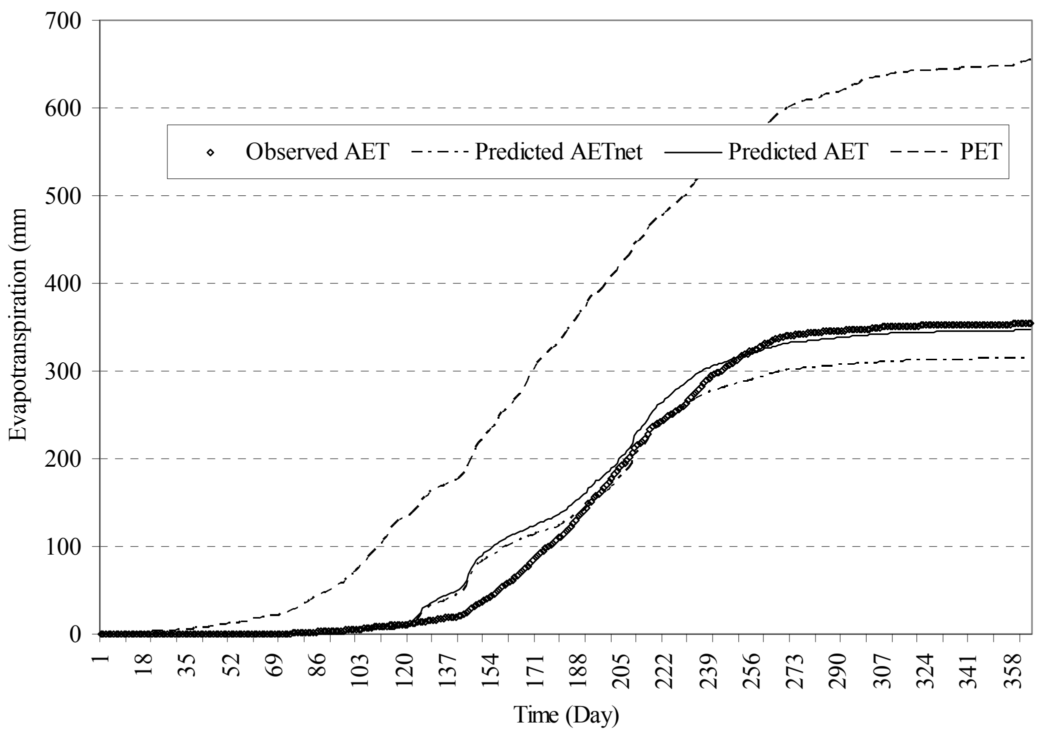


Figure 12. Observed and predicted evapotranspiration (mm) in the natural old aspen site.

5.3 The long-term performance of the sites

The methodology developed by Elshorbagy and Barbour (2007) was adopted in this study to assess the long-term hydrological performance of both the reclaimed SBH and the natural OA sites. A historical meteorological record of 50 years was used with the MSDW model to simulate the daily soil moisture and the actual evapotranspiration over 50 years. The annual values of AET and the amount of moisture that was stored and released by the soil (D_m) were calculated from daily values. Frequency curves of AET and D_m values were constructed for both the reclaimed SBH and the natural OA sites (Figures 13 and 14). It is evident that the OA natural site has higher ability of storing and releasing water for vegetation. On average (at 50% probability), the SBH site stores around 18 mm of water during rainy days and make them available for vegetation during the drier days. This value goes up to 48 mm of water in the OA site (Figure 13). Similarly, the SBH site allows for 320 mm of annual Evapotranspiration, whereas the OA site may provide as high as 350 mm of water. These values are around the 50% probability; however, the OA site seems to have a greater flexibility and ability to allow for much more evapotranspiration if needed and when water is available (Figure 14).

It should be noted that the above-mentioned values are based on the current vegetation maturity level as well as the physical conditions of the watersheds. It is expected that with the growth of vegetation on the SBH site, the dynamics of moisture movement and the evapotranspiration will continue to develop. Therefore, the two frequency curves might get

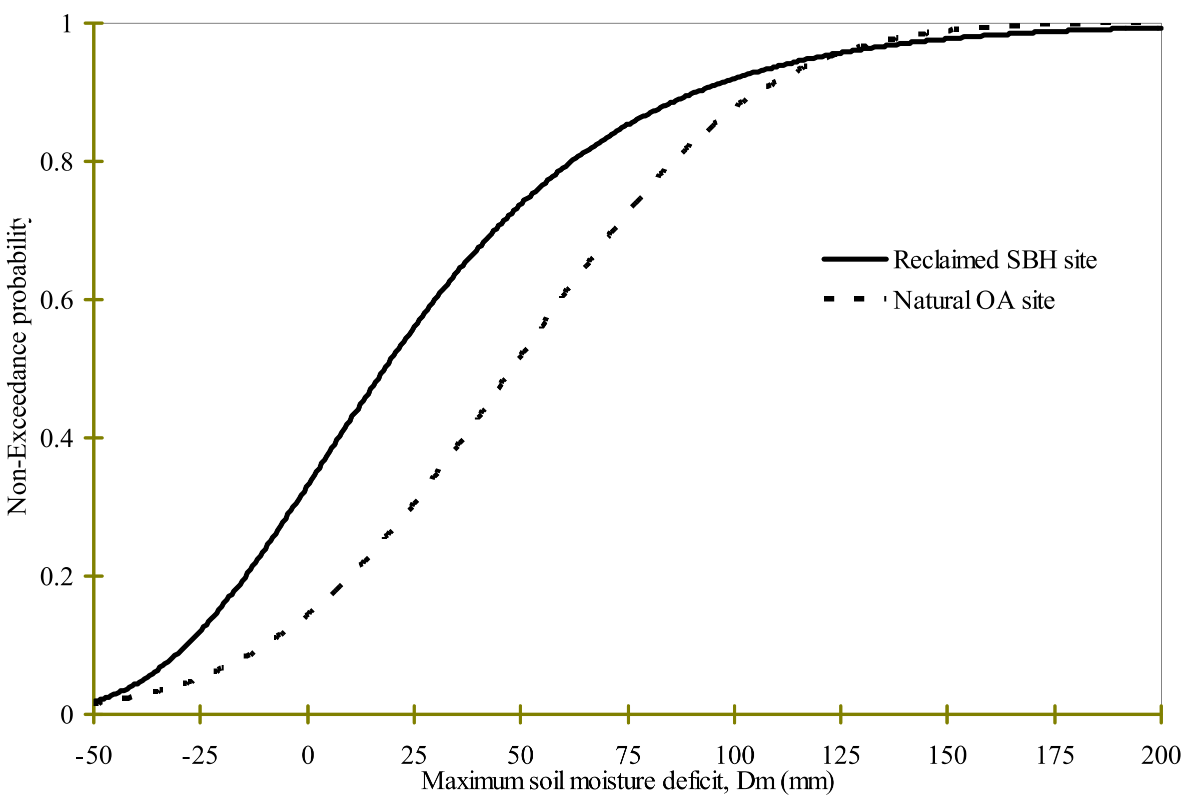


Figure 13. The frequency curves of the soil moisture store-and-release ability in both sites.

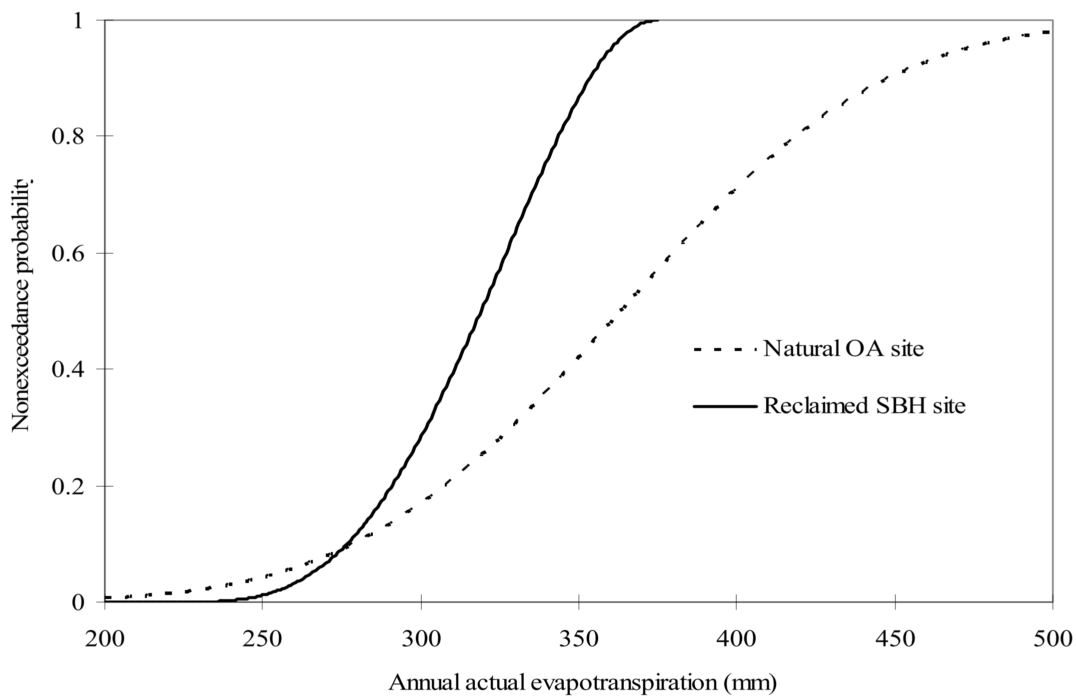


Figure 14. The frequency curves of the actual evapotranspiration in both sites

closer to each other. This can be confirmed by conducting similar analysis on other old reclamation sites, which is part of year 3 (2009) tasks.

6. WORK TO BE COMPLETED IN YEAR 2 (2008)

The following tasks are planned to be completed within year 2 (2008):

6.1 Hydrometeorological study on the reclaimed SBH site, which will be the sixth year (DY6) of data collection on this site;

6.2 Hydrometeorological study on the newly reclaimed Suncor (NRS) site, which will be the second year (DY2) of data collection on this site;

6.3 Hydrometeorological study on the reclaimed 15-year old jack pine forest (RJF), which will be the second year (DY2) of data collection on this site;

6.4 Adaptation and calibration of the SDW model for the SWSS site;

6.5 Adaptation and calibration of the SDW model for the OJP and the OBS natural sites; and

6.6 Conduct the probabilistic and risk analysis for the reclaimed SWSS and the natural OJP and OBS sites.

7. THE RESEARCH TEAM

The following personnel have been involved in this study:
University of Saskatchewan:

- **Amin** Elshorbagy (Principal investigator);
- **Ibrahim** El-Baroudy (Postdoctoral Fellow); part-time involvement in some of the SDW modeling, and directing the graduate students;
- **Lakshmi** Bachu (M.Sc. student); working full-time on adapting the SDW model to the SBH site and the OA natural site, and also conducting some of the probabilistic analysis; and
- **Nader** Keshta (Ph.D. student); working full-time on developing a generic form of the SDW (GSDW) model, which will be used for modeling the remaining reclaimed and natural sites.

Carleton University:

- **Sean** Carey (Co-investigator);
- **Michael** Treberg (Research Technician); part-time involvement in instrumentation design, tower set up, data QA/QC.
- **Paul** Moore (M.Sc. student); working full time on the micrometeorology of the RJF site.
- **Sean** Goodbrand (M.Sc student); working full time on the micrometeorology of the NRS site.

REFERENCES

Carey, S.K. In revision. Growing Season Energy and Water Exchange from an Oil sands Overburden Reclamation Soil Cover, Fort McMurray, Alberta, Canada. *Hydrological Processes.*

Dingman, S.L., 2002. “Physical hydrology/ second edition.” Prentice Hall, Upper Saddle River, New Jersey.

Elshorbagy, A., Jutla, A. and Kells, J. 2007. Simulation of the Hydrological Processes on Reconstructed Watersheds Using System Dynamics. *Hydrological Sciences Journal*, 52(3): 538-562.

Elshorbagy, A. and Barbour S. L. 2007. A Probabilistic Approach for Design and Hydrologic Performance Assessment of Reconstructed Watersheds. *Journal of Geotechnical & Geoenvironmental Engineering, ASCE,* 133(9): 1110-1118.

Elshorbagy, a., Julta, a., Barbour, L., and Kells, J. 2005. System dynamics approach to assess the sustainability of reclamation of distributed watersheds. Canadian Journal of civil engineering, (32): 144-158.

Leskiw, L. A. 2004. Land capability classification for forest ecosystems in the oil sands, *Paragon Soil and Environmental Consulting Inc.*, Alberta, Canada.

McCaughey, J.H., Barr, A., Black, T.A., Goodison, B., Hogg, E.H., Stewart, R.B., Amiro, B., Price, D.T., Stolle, N., Chen, J., and Gower, S.T., 2000. The Boreal Ecosystem Research and Monitoring Sites (BERMS) initiative: scientific accomplishments. *In* The Role of Boreal Forests and Forestry in the Global Carbon Budget. Abstracts. 8-12 May 2000, Edmonton, Alta. *Edited by* M.J. Apps and J. Marsden. Canadian Forest Service, Northern Forestry Centre, Edmonton, Alta. P. 116.

Sellers, P. et al. 1995. The Boreal Ecosystem-Atmosphere Study (BOREAS): an overview and early results from the 1994 field year, *Bull. Am. Meteorol. Soc., 76*, 1549-77.

Valente, F., J.S. David, and J.H.C. Gash, 1997. "Modelling interception loss for two sparse eucalypt and pine forests in central Portugal using reformulated Ruttter and Gash analytical models." Journal of Hydrology. 190:141-162.