Evaluation of Comparative Hydrological Sustainability of Reconstructed and Natural Watersheds

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1. Background

- Mining is an environment threatening human activity disturbing thousands of acres of landscapes, and one of the remedial activities of this issue is the reclamation of the disturbed lands.
- In the design process of reclaimed landscapes, a major concern is the hydrological sustainability, which includes ability of storing enough soil moisture for the vegetation growth and land-atmospheric moisture fluxes.
- Comparative evaluation of the hydrological sustainability of the reclaimed (reconstructed) watersheds with natural watersheds is required as the goal of the reconstructed watersheds is to bring them back to the level of natural watersheds in all respects.
- This helps to understand the queries such as "Do reconstructed watersheds have a similar ecohydrological response to climatic conditions as the natural systems do?" .

2. Objectives

- To simulate the hydrological processes of reconstructed and natural watersheds; and
- To compare the hydrological sustainability using long term simulations with the help of the probabilistic approach for understanding the relative sustainability of the reclaimed landscape with reference to the natural watershed.

3. Materials and Methodology

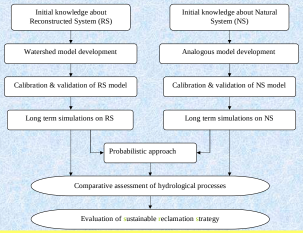

Fig 1. Overview of the adopted methodology for evaluation of the comparative hydrological sustainability

- A system dynamics approach based mechanistic, semi-empirical, lumped watershed model named System Dynamics Watershed (SDW) model developed by Elshorbagy et al., (2005), is used as basis in this study.
- A canopy interception module and other modifications have been added to the model to simulate soil moisture and evapotranspiration processes effectively.
- The top of an experimental reclaimed watershed of an oil sands industry in the Athabasca basin located in northern Alberta, Canada, called South Bison Hill (SBH) of about 2 km^2 base area is considered to represent the reconstructed watershed in this study.

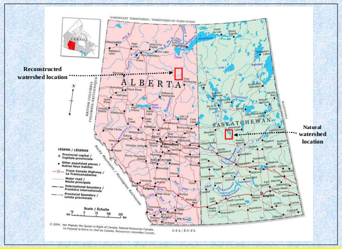

Fig 2. Location of the reconstructed and natural watershed study areas

- The reconstructed watershed was constructed with a peat-mineral mix of 20 cm thick on a secondary (glacial till) of 80 cm thick overlying on a shale formation.
- A matured boreal forest site located in the central Saskatchewan, Canada, named Old Aspen (OA) site is considered to represent the natural watershed in this study.
- The soil formation of the natural watershed includes an A-horizon with sandy loam texture, 25 cm thick; a B-horizon with sandy clay loam, 45 cm; and a C-horizon with mixture of sandy clay loam and loam, 40 cm thickness.

4. Simulation of Hydrological Processes of RS and NS

- The daily soil moisture and cumulative evapotranspiration are simulated over growing period (mid May to mid Oct) in 2005-2006 and 1999-2000 for RS and NS, respectively, using the available meteorological data.
- Performance of both models is evaluated based on root mean squared error (RMSE), and mean relative error (MRE), in addition to the visual inspection.

Table 1. Model error performance measures of RS

	MARE		RMSE		AET (mm)		
	Peat	Till	Peat	Till	Measured	Simulated	
	%	%	mm	mm		AET net	AET gross
Calibration (2006)	4.33	3.50	4.1	10.0	276.3	271.2	280
Validation (2005)	9.64	3.91	9.0	12.0	276.76	280.3	290.8

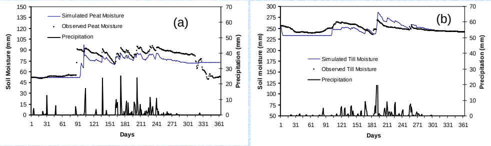

Fig 3. Peat (a) and Till (b) layer moisture dynamics of RS of validation year (2005).

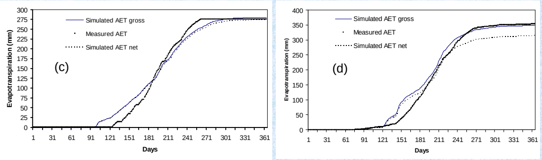

Fig. 4. Cumulative evapotranspiration (ET) fluxes of validation years of RS (c) and NS (d). Note: AET gross is total ET from soil and canopy, AET net is AET gross minus evaporation from canopy.

- In both RS and NS cases, models characterized the hydrological processes (Soil moisture and evapotranspiration) reasonably well.

Table 2. Model error performance measures of NS

	MARE			RMSE			AET (mm)		
	A-horizon	B-horizon	C-horizon	A-horizon	B-horizon	C-horizon	Measured	Simulated	
	%	%	%	mm	mm	mm		AET net	AET gross
Calibration (2000)	6.23	6.40	13.62	6.3	12.1	20.1	344.49	301.73	335.04
Validation (1999)	13.93	5.68	8.52	10.5	9.8	15.3	355.13	314.19	349.1

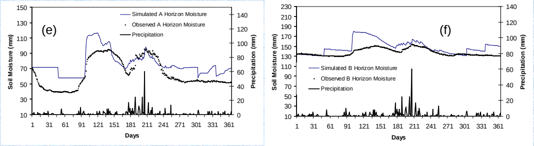

Fig 5. A- soil horizon (e) and B- Soil horizon (f) moisture dynamics of NS of validation year (1999).

5. Long Term Hydrological Performance

- Calibrated and validated models of RS and NS are used for the long term hydrological simulations by using 50 years meteorological data.
- The daily moisture deficit (D_i) is estimated, which could be attributed to evapotranspiration as follows (Elshorbagy and Barbour, 2007):

$$\Delta S = S_t - S_{t+1} \quad \text{Eq. (1)}$$

$$D_i = \Delta S - P_r \quad \text{Eq. (2)}$$

where S_t is the soil moisture content on day t, and S_{t+1} is the soil moisture on day $t+1$, and S, and percolation, (P_r) are in mm.

- The D_i is accumulated over the growing period in each year, and the maximum value is the annual maximum soil moisture deficit, D_m.
- Cumulative probability distribution curves using D_m and the annual AET values for RS and NS are derived, with the help of @Risk best fit software by testing over 20 distributions.

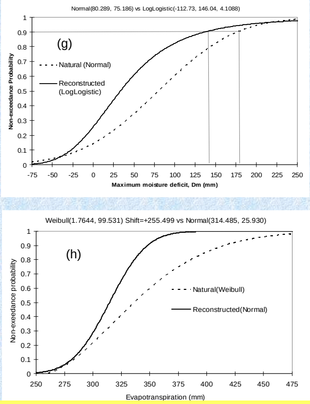

Fig. 6) Cumulative probability distributions (best-fit) of D_m (g) and AET net (h) of RS and NS

6. Conclusions

- The study shows that the reclaimed watershed (RS) provides less moisture for evapotranspiration requirements than the natural watershed (NS).
- Less annual maximum soil moisture storage (D_m) is observed in the reconstructed watershed than the natural watershed for a designed probability (e.g., 90%) of the soil cover failure.
- These could be attributed to the reason that the reconstructed site is still in the process of restoration and it may take a few more years to get closer to the natural watersheds behavior in terms of the hydrological sustainability.
- The study also demonstrates the utility of the system dynamics approach for modeling the ecosystems.
- Adding a vegetation growth model to the hydrological model would contribute more in the characterization of the reconstructed ecosystem and its processes, and would be helpful in developing sustainable reclamation strategies.

7. References

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.

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