WATER, ENERGY AND CARBON BALANCE RESEARCH: RECOVERY TRAJECTORIES FOR OIL SANDS RECLAMATION AND DISTURBED WATERSHEDS IN THE WESTERN BOREAL FOREST

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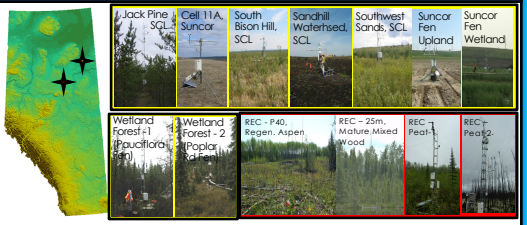
INTRODUCTION AND OBJECTIVE

- In the approvals and closure process, it is incumbent upon the operators to provide evidence that ecosystems are operating at certain equivalency-levels.
- This program is based on the assertion that one of the most effective ways of measuring success is by examining the water, energy and carbon balance of reclaimed ecosystems and comparing them with other non-oil sands disturbance sites that are recovering (i.e. harvesting, burn) along with mature ecosystems.
- Changes in these properties along a reclamation trajectory may act as sentinels in that certain patterns of water/carbon/energy balance are precursors to ecosystem and vegetation stress.
- This project will directly assist in the approvals process and provide information assisting in the certification of reclaimed land. In addition, information can be used to improve technical operations surrounding reclamation.
- The overall objective of this research program is to evaluate how fluxes of water and carbon dioxide from ecosystems can be used to establish equivalent capability in an oil sands reclamation framework.

STUDY AREA



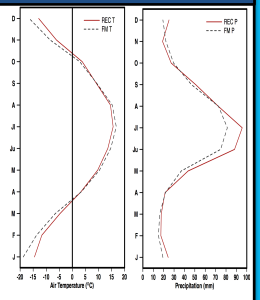
- Oil Sand Region (OSR) of North-Central Alberta within sub-humid climate of the Boreal Plains ecozone (slight long-term moisture deficit regime).
- Each study site located in the Fort McMurray area (FMA) & Red Earth Creek (REC) regions to ensure consistency in climatic conditions, & represent long-term research sites of the authors.
- All sites represent a range of upland & more recently wetland systems, spanning a range in different soil types & forest (reclamation, regeneration & natural) systems (Table 1).

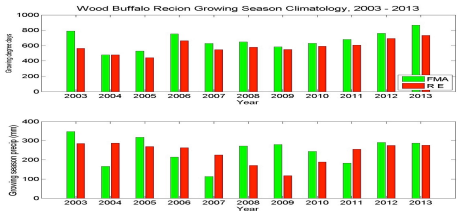
Site	Years of Measurement	Soils	Year of Establishment /Disturbance	Canopy species
South Bison Hill	~12	Peat (20 cm) / till/secondary (1 m) over shale overburden	2003	Aspen
Cell 11A Suncor	6	Peat/mineral mix (35 cm) over tailings sand	2008	Mixed Shrub
Jack Pine Overburden	7	Till/secondary (90 cm) over tailings sand	2007	Jack Pine
Southwest Sand Dumps	4	Till/secondary cover (90 cm) over tailings sand	1995	Mixed Shrub
Watershed Fen Control 1	2	Peat/mineral mix (1 m) over clay	2012	N/A
Watershed Fen Control 2	2	Peat/mineral mix (1 m) over clay	2014	N/A
Watershed Fen Upland	2	Peat/mineral mix (1 m) over clay	2013	N/A
Suncor Fen Upland	2	Peat/Mineral Material (LFH, S and Tailings	2013	Spruce
Suncor Fen Wetland	2	Peat, Pt Sand, Tailings, Clay	2013	N/A
Wetland Forest 1 (Ft. McMurray)	3	Peat	-	Spruce
Wetland Forest 2 (Ft. McMurray)	3	Peat	-	Spruce
REC P40-SFS	9	Dry, Coarse Till & Sand, 10cm LFH	2007	Aspen
REC P40-NFS	3	Dry, Coarse Till & Sand, 10cm LFH	2009	Aspen
REC P40-25	7	Mixture of Coarse Till & Sand & peat assoc. 10cm LFH in forested areas		Aspen, Spruce
REC P40-SFS	7	Dry, Coarse Till & Sand, 10cm LFH	-	Aspen
REC Peat	7	Peat	-	Spruce
REC P40-Peat	6	Open Water	-	N/A
REC Peat	3	Peat	2011	Spruce
REC Peat 2-17	3	Peat	-	Spruce

Table 1. Summary of historical, existing and potential research sites. Oil sands reclamation sites are in italics. REC denotes the Red Earth Creek sites.

STUDY AREA

- FMA & REC sites have large variation in growing season & monthly P during the 2003 – 2013 study window.
- Growing season P (May – August) was greatest in 2005 (278 mm) & least in 2007 (81 mm at FMA).
- Air temperatures - less variability than P, & most growing seasons (Ta) in FMA slightly warmer than the 30-year climate normal.
- Seasonally, no apparent relationship between P and Ta.

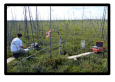


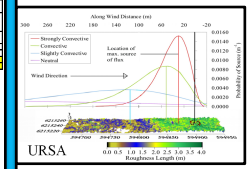


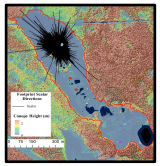
- Growing degree-days (GDD) indicate FMA has a slightly warmer climate than REC.

METHODS

- When water-limited, plant productivity determined by amount of water available & water use efficiency by plant
- Water-use efficiency (WUE) = ratio of photosynthesis : transpiration → indicator of ecosystem functioning
- Eddy Covariance (Fluxes of heat, H_2O, CO_2)
  - Further partitioned into respiration, photosynthesis, transpiration, & soil evaporation using chambers & standard biometeorological techniques
- Meteorological (All-wave radiation, temperature, wind speed and direction, humidity)
- Soils (Moisture and suction at various depths, properties, water table)







- Vegetation (LAI, Canopy Height, Density)
- Fluxes extracted for validation from daily flux footprints

RESULTS

- Inter-annual variability in ET can be synthesized by examining relation to Growing Degree Days (GDD) & P
- Reclamation sites - weak +ve relation between GDD & ET (Fig. 1a).
- Regeneration sites (REC) - overall +ve relationship between GDD & ET (Fig. 1b).
- Relation as expected between growing season precipitation & JJA ET (Fig. 2a,b).
- Reclamation sites - low P years correspond with low ET years.
- Regeneration sites - growing season P did not as strongly influence regeneration ET, suggesting that moisture limitation at these sites was not critical in influencing inter-annual variability in ET (Fig. 2b)

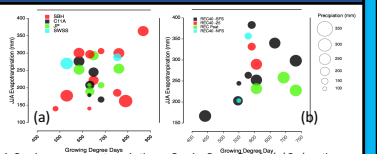


Fig. 1: Growing season evapotranspiration vs. Growing Degree Days for (a.) Reclamation & (b.) Regeneration sites.

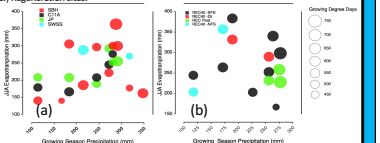


Fig. 2: Growing season evapotranspiration vs. Growing Season Precipitation for (a.) Reclamation & (b.) Regeneration sites.

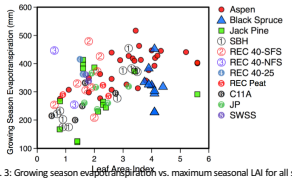


Fig. 3: Growing season evapotranspiration vs. maximum seasonal LAI for all sites.

- ET on average increases with LAI for all sites including those from literature (Fig. 3).
- For the reclamation sites, stands in the early stages of reclamation sites show greatest variability in LAI (Fig. 3).
- Recovery sites had similar LAI but a larger range of ET values, with an overall trend of peak growing season LAI is a first-order estimate of annual ET.
- All sites were within expected range of fluxes, however a clear trend in increasing sequestration since time of disturbance is observed due to LAI development & root establishment.
- Reclamation sites where material used for placement has typically been stockpiled, & labile organic C has been decomposed, have reduced respiration & microbial activity
- Regenerating sites have largest WUE – more well established root systems (Fig. 4).
- Other sites have a similar WUE range except the peatland & mixed-wood systems, which have less inter-annual variability and respond subtly to changes in seasonal P (Fig. 4)

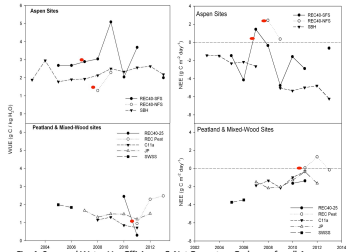


Fig. 4: Seasonal Water Use Efficiency & Net Ecosystem Exchange for all Aspen, Peatland & Mixed-Wood sites.

DISCUSSION/CONCLUSIONS

- Reclamation ecosystems are highly dynamic – changes in water use & carbon uptake occur rapidly during early succession.
- Reclamation sites have similarities with disturbed & natural sites in terms of water use and carbon uptake, but follow a different recovery trajectory from harvest sites due to different baseline conditions.
- Vegetation type and soils make a difference, & successful upland forests appear attainable based on data to date.
- Considerable variability in NEE & ET associated with vegetation establishment, with enhanced ET losses over-riding any significant changes in C uptake, suggesting that long-term mine water management must consider ecosystem pathways if down-gradient wetlands and end of pit lakes are to be sustained.

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