COSIA Land EPA

2015 Mine Site Reclamation Research Report

April 2016

Introduction

This report summarizes progress for projects related to mine site reclamation of the Canada's Oil Sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA).

Please contact the Industry Champion identified for each research project if any additional information is needed.

COSIA Land EPA 2015 Mine Site Reclamation Research Report. Calgary, AB: Canadian Natural Resources Limited; Imperial; Shell Canada Energy; Suncor Energy Inc.; Syncrude Canada Ltd.; Teck Resources Limited.

Prepared For:

Canadian Natural Resources Limited

Imperial

Shell Canada Energy

Suncor Energy Inc.

Syncrude Canada Ltd.

Teck Resources Limited

April 2016

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Instrumented Watersheds

Applying Natural Analogues to Constructing and Assessing Long-term Hydrologic Response of Oil Sands Reclaimed Landscapes.

COSIA Project Number: LJ0215

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborator: Canadian Natural Resources Limited

Status: Year 1 of 4

PROJECT SUMMARY

The Utikuma Region Study Area (URSA) research sites, in the Boreal Plains (BP) region, have been the focus of ecohydrological and hydrogeological research for nearly 15 years (e.g. TROLS, HEAD, HEAD2, SFMN projects, etc.) that are informing the Oil Sands industry on the natural functioning of aquatic, peatland and forestland systems with heterogeneity in vegetation and geology representative of the Ft. McMurray region. The recently burned Utikuma region encompasses much of the URSA transect, providing a natural analogue for a range of future reclaimed Oil Sands landscapes in the initial years post construction; when risk of landscape failure is most significant. The understanding of local and regional processes and controls on hydrology and ecosystem development of natural and disturbed sites can be used to develop design criteria in constructing initial and sustainable ecosystems on Oil Sands leases.

Limits on water use and distribution on constructed Oil Sands landscapes are key issues in initial and final closure plan developments, and we hypothesize that:

- on any landscape water use (actual evapotranspiration (ET)) and availability is proportional to the spatial weighting and interaction (perimeter–area) of hydrologic units (HU) (i.e. wetland–forestlands), successional state; and
- the storage and connectivity (release for other systems) is proportional to the spatial weighting of hydrologic response area (HRA) (i.e. landform material), temporally modulated by climate cycles.

The large scale, and range in degree, of disturbance at URSA will test the role of soil type/depth and vegetation (wetland–forestlands, HUs) and geology (equivalent material storage – HRAs) interactions with climate cycles on the timing and location of water and chemical storage and connectivity at the landscape scale in the BP.

Developing equivalent ecosystems and ensuring water needs on reconstructed Oil Sands landscapes requires investigating:

- whether BP ecosystems (wetlands–forestlands) develop and interact to minimize overall water use or develop to maximize productivity;
- how water use vs. productivity varies in succession (or development) of wetland vs. forestland ecosystems; and
- the role of organic (peat) depth vs. local (soils) and regional (HRA-connectivity) geology on the successional trajectory of natural and constructed wetlands and forestlands. By testing this on natural ecosystems in succession following watershed burning we can provide an understanding of the controls on the maintenance of ecosystem function.

These findings can be used directly in developing landscape design criteria at both the local and oil sands lease scale to ensure long-term resilience of constructed ecosystems.

Specific objectives to address the hypotheses and questions are addressed in 3 Scopes of research and 8 objectives:

I. Scope 1: Catchment response to long-term climate cycles

Objective 1: Background Hydrology and Hydro-chemistry: a) continue long-term monitoring of natural systems at URSA to aid in the setting of baselines and acceptable ranges in hydrology and chemistry of surface and subsurface waters for reclaimed landscapes, and b) determine how these vary with large-scale disturbance (i.e., wildfire).

Objective 2: Determine a) the range in runoff response to climate cycles of natural landforms (HRAs) and wetland: Forestland (HUs) and b) determine the proportion of headwater ephemeral draw or wetland to forestland required to provide adequate surface water inputs and/or groundwater discharge for larger wetlands or aquatic systems.

II. Scope 2: Hydro-ecological Investigations of Disturbed watersheds

Objective 3: **Forestland Hummocks.** Determine the influence of the configuration, height and size of forestland hummocks composed of fine- and coarse-textured material to sustain forest and wetland ecosystems.

Objective 4: **Peatland/Wetland Development.** Compare the physical and eco-hydrological properties of surface organic (vegetation and peat) layers of different natural and burned peatland types (bogs/fens), and examine how sites with a range of disturbance severity recover and re-vegetate following wildfire.

Objective 5: **Ephemeral Draws.** Determine the role of ephemeral draws in generating moisture surplus and delivering water to wetlands and adjacent forests in natural and thus constructed landscapes.

Objective 6: **Wetland-Forestland Interface (WFI) and Riparian Areas.** Determine the role of riparian vegetation and root distribution on the dynamics of water and chemical movement to or from the hummocks and adjacent wetland or aquatic system.

Objective 7: **Ecosystems interactions change with tree re-growth.** From the research noted above, determine how the catchment scale linkages of wetlands, riparian and forestlands change from before and directly after wildfire disturbance, and ecosystem interaction with tree recruitment.

III. Scope 3: Integrated Modelling for Catchment Design And Application

Objective 8: Integrate the research questions and results from the larger catchment runoff responses and process field studies to parameterizing “fuzzy box models” for different landform and landscape configurations to determine the initial configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems that are more sustainable and resilient.

PROGRESS AND ACHIEVEMENTS

This project represents the continuation of research initiated in the summer 2012 with funds from Syncrude Canada Ltd and the principal investigators (PIs). All projects listed for the objectives or deliverables have been initiated and preliminary results are presented in the Outcomes section and in the first set of scientific publications listed below. The COSIA funds have been incorporated into an NSERC-CRD grant that was recently accepted (1 July 2015). The NSERC-CRD will provide matching funds primarily to focus more research on the role of wetland and forestland interfaces and parameterizing landscape models on energy flow and eco-hydrologic interactions in BP catchments.

Ducks Unlimited Canada, Boreal Program, have collaborated with funds and personnel on objective 2 a) (see below) and related research.

OUTCOMES AND LESSONS LEARNED

This is the first year and one half of the study and field instrumentation and analyses are ongoing. However, some of the salient outcomes for each task (objective) from the overall body of research are provided, and when available the scientific article(s) listed in publications are referenced.

I. Scope 1: Catchment response to long-term climate cycles

Objective 1 (a&b), The background Hydrology and Hydro-chemistry of HRA and HU surface and ground-water during climate cycles and with fire disturbance:

- Hydro-chemical sampling was conducted across the URSA sites, completing a 15-year data set from 1999–2014, sampled through a dry, mesic and wet climate cycle.
- Basic analyses indicate that a large range in nutrients and salinity naturally occurs (both spatially and temporally with climate cycles) between HRAs and between HUs (Plach et al. In Press). Salt concentrations can be high, with electrical conductivity (EC) greater than 2000 uS common in shallow groundwater, and some surface streams.
- Regional analyses revealed large differences in the recharge/discharge function of lakes and wetlands across difference HRAs and landscape position, however, lake and wetland chemistry and isotopic characteristics indicate limited interaction between surface waters and deeper groundwater.

Objective 2 a) Determine the range in runoff response to climate cycles of natural landforms (HRAs) and wetland: Forestland (HUs)

- Regional runoff estimates from natural HRAs and HUs of the central mixed wood boreal forest have been completed and indicate that local process do scale up, with higher runoff from course textured HRAs, enhanced flow from peatlands, and reduce runoff from aspen ecosystems.
- There is a large variation in runoff with climate cycles but in general runoff is low, which is a critical consideration for designing landscapes.
- The manuscript is to be submitted to a scientific journal in early February

Objective 2 b) Determine the proportion of headwater ephemeral draw or wetland to forestland required to provide adequate water for larger wetlands or aquatic systems.

- Work is still on going, but preliminary analyses indicate that stand and HRA water balance will be influenced by the configuration of HUs and wetland-forestland interfaces.

II. Scope 2: Hydro-ecological Investigations of Disturbed watersheds

Objective 3, **Forestland Hummocks.** Determine the influence of the configuration, height and size of forestland hummocks composed of fine- and coarse-textured material to sustain forest and wetland ecosystems.

- The studies of forested and regenerating aspen forest show that in general runoff and recharge is low, but does vary greatly with substrate texture (HRA), texture layering (coarse over fine) and height of hummock.
  - Movement from peatland to forestland occurs in all HRAs and hummocks are sinks as often as not (Thompson et al 2015).
  - In coarse-textured landscapes the groundwater flow is influenced by the regional groundwater gradient not local hillslope configuration (Hokanson et al. 2015)

Objective 4, **Peatland/Wetland Development.** Compare the physical and eco-hydrological properties of surface organic (vegetation and peat) layers of different natural and burned peatland types (bogs–fens), and examine how sites with a range of disturbance severity recover and re-vegetate following wildfire.

- Most of the research for this objective is in progress.
- Over-layering soils with high storage (low density) on soils with low storage (high dense) above in wetlands, of both mineral or organic (Kettridge et al 2014, Lukenbach et al. submitted) may keep the water elevation below the surface- greatly reducing evaporation and creating accessible water.
  - This has promise to behave as an effective capping material and generate surplus fresh water.
- The hydrological and geochemical responses of peatlands to and its evolution following soil and vegetation disturbance by fire is complex.
  - Early field work indicates little net increase in surface peat nutrients or mobile carbon following fire (see also Olefeldt et al. 2013)
  - Moisture distribution is influenced as much by vegetation type and structure (Sphagnum vs feather moss) and burn severity that control capillary connections or "breaks" as it is by ground elevation and depth to water table (Lukenbach et al. in press).

Objective 5, **Ephemeral Draws.** Determine the role of ephemeral draws in generating moisture surplus and delivering water to wetlands and adjacent forests in natural and thus constructed landscapes.

- Instrumentation of the un-burned ephemeral draw has been completed. Preliminary research indicates that ephemeral draws can both provide runoff at times for down slope ecosystem and supply adjacent forestlands.

Objective 6, **Wetland-Forestland Interface (WFI) and Riparian Areas.** Determine the role of riparian vegetation and root distribution on the dynamics of water and chemical movement to or from the hummocks and adjacent wetland or aquatic system.

- Preliminary studies of water use and flow of mature and regenerating aspen on hummock tops and mid-slope position and the adjacent peatland, indicate large water demand and use in mid-slope position and peatland areas by riparian aspen. This indicates that water and nutrients do move from peatlands into riparian areas and up into forestlands. The magnitude is not known. Research for this objective is in progress

Objective 7, **Ecosystems interactions change with tree re-growth.** From the research noted above, determine how the catchment scale linkages of wetlands, riparian and forestlands change from before and directly after wildfire disturbance, and ecosystem interaction with tree recruitment.

- These objectives rely largely on further progress in the earlier objectives, and have just been initiated. We have determined that a regime shift may occur if water supply is insufficient (Kettridge et al., In Press).

III. Scope 3: Integrated Modelling for Catchment Design And Application

Objective 8, **Catchment Design And Application.** Parameterization of "fuzzy box models" in use for design and construction to maximize water use for sustainable, resilient catchments.

- Initial refinement of existing and developing alternative conceptual models for numerical model development are on going.

PRESENTATIONS AND PUBLICATIONS

Publications

Scientific Publications – Research

Hokanson, K.J., M.C. Lukenbach, K.J. Devito, N. Kettridge, R.M. Petrone, J.M. Waddington. 2015. *Groundwater connectivity controls peat burn severity in the Boreal Plains.* Ecohydrology, doi: 10.1002/eco.1657.

Ketcheson S., J.S. Price, R.M. Petrone, S. Carey, K.J. Devito. 2015. *Can fen peatlands be successfully constructed in post-extraction oil sands landscapes?* Accepted with Revisions August 2015. Hydrological Processes.

Kettridge N., A.S. Tilak, K.J. Devito, R.M. Petrone, C. Mendoza, J.M. Waddington. 2015. In Press. *Moss and peat hydraulic properties are optimized to maximise peatland water use efficiency.* Accepted 17 Nov 2015 , Ecohydrology, ECO-15-0028

Kettridge N., M.R. Turetsky, J.H. Sherwood, D.K. Thompson, C.A. Miller, B.W. Benscoter, M.D. Flannigan, M. Wotton, J.M. Waddington. 2015. *Moderate drop in water table increases peatland vulnerability to post-fire regime shift.* Nature Scientific Reports, 5.

Lukenbach M.C., K.J. Hokanson, P.A. Moore, K.J. Devito, N. Kettridge, D.K. Thompson,, B.M. Wotton, R.M. Petrone, and J.M. Waddington. 2015. *Hydrological controls of deep burning in a northern forested peatland.* Hydrological Processes, 29: 4114-4124.

Lukenbach M.C., K.J. Devito, N. Kettridge, R.M. Petrone, J.M. Waddington. 2015. *Hydrogeological controls on post-fire moss recovery in peatlands.* Journal of Hydrology, doi: 10.1016/j.jhydrol.2015.09.075.

Lukenbach M.C., K.J. Devito, N. Kettridge, R.M. Petrone, J.M. Waddington. 2015. In press. *Burn severity alters peatland moss water availability: Implications for post-fire recovery.* Ecohydrology.

Petrone R.M., L.E. Chasmer, C. Hopkinson, U. Silins, S.M. Landhäuser, N. Kjlun, K.J. Devito. 2015. *Effects of harvesting and drought on CO2 and H2O fluxes in an aspen-dominated western boreal plain forest: early chronosequence recovery.* Canadian Journal of Forest Research, 45(1): 87-100, 10.1139/cjfr-2014-0253.

Plach J.M., J.M. Ferone, Z. Gibbons; B. Smerdon; A. Mertens; C. Mendoza; R. Petrone; K. Devito. 2016. In Press. *Influence of glacial landform hydrology on phosphorus budgets of shallow lakes on the Boreal Plains.* Accepted 19 Jan 2016, Journal of Hydrology.

Rooney R., D. Robinson, R.M. Petrone. 2015. *Megaproject reclamation and climate change.* Nature Climate Change, 5: 963-966.

Schneider R., K.J. Devito, N. Kettridge, E. Bayne. 2015. In Press. *Moving beyond bioclimatic envelope models: integrating upland forest and peatland processes to predict ecosystem transitions under climate change in the western Canadian boreal plain.*, Ecohydrology. DOI: 10.1002/eco.1707

Thompson C., C.A. Mendoza, K.J. Devito, R.M. Petrone. 2015. *Climatic controls on groundwater-surface water interactions within the Boreal Plains of Alberta: Field observations and numerical simulations.* Journal of Hydrology. 527:734-746.

Waddington J.M., P.J. Morris, N. Kettridge, G. Granath, D.K. Thompson, P.A. Moore. 2015. *Hydrological feedbacks in northern peatlands.* Ecohydrology 8: 113-127, doi: 10.1002/eco.1493.

Conference Proceedings, Reports, Non-Refereed Articles, Submitted Papers:

Chasmer L., C. Hopkinson, R.M. Petrone, K.J. Devito. 2015. *Linkages between climate warming/drying trends and vegetation decline in Central Alberta, Canada.* Submitted July 2015. Ecosystems.

Petrone R.M., K.J. Devito, L.E. Chasmer, N. Kljun, C. Thackeray, M.D. Flannigan, D.T. Thompson, J.M. Waddington. 2015. *Regional Scale CO2 Exchange in a Boreal forest during wildfire.* Submitted March 2015. International Journal of Wildland Fires.

Plach J.M., R.M. Petrone, J.M. Waddington, N. Kettridge, K.J. Devito. 2015. *Hydroclimatic influences on peatland CO2 exchange following upland forest harvesting on the Boreal Plains.* Submitted October 2015. Ecohydrology.

Sutherland G., L.E. Chasmer, N. Kljun, K.J. Devito, R.M. Petrone. 2015. *Using high resolution LiDAR data and a flux footprint parameterization to scale evapotranspiration estimates to lower pixel resolutions.* Submitted December 2015. Remote Sensing of the Environment.

Graduate Theses

Lukenbach, M.C. 2015. *Hydrogeological and ecohydrological controls on peatland resilience to wildfire.* PhD, McMaster University (School of Geography and Earth Sciences). 202pp.

Presentations

Chasmer L.E., C. Hopkinson, K.J. Devito, R.M. Petrone. *Quantifying ecosystem resilience to climate change in the Western Boreal Plains.* 26th International Union of Geodesy and Geophysics General Assembly, Prague, Czech Republic, June 22 – July 2, 2015.

Chasmer L.E., C. Hopkinson, R.M. Petrone. *Quantifying the Impacts of 23-years of Warming and Drying Trends on Peatland Succession in Central Alberta.* American Geophysical Union – Canadian Geophysical Union Joint Assembly, Montreal, Quebec, May 3 – 7, 2015.

Depante, M., Venue: AGU/CGU Joint Assembly. Abstract . Publisher: American Geophysical Union. May 2015.

Devito, K.J., K.J. Hokanson, P.A. Moore, A. Anderson, N. Kettridge, C. Mendoza, R.M. Petrone, U. Silins, J.M. Waddington. *Threshold responses in regional runoff from a heterogeneous low relief terrain – Western Canada's Boreal Plains.* AGU/CGU Joint Assembly. Abstract H33A-02. Publisher: American Geophysical Union. May 2015.

Devito,K.J. I*ntroduction to Wetland Hydrology and Conceptualizing Water movement on the boreal plain: implications for water fowl management.* One Day Workshop, Ducks Unlimited Canada, Boreal Program. Edmonton, AB April, 14, 2015.

Hokanson, K., J. Carrera-Hernandez, K. Devito, C. Thompson, C. Mendoza. *The influence of glacial landforms on subsurface and surface hydrology and chemistry across a heterogeneous Boreal Plain landscape.* AGU/CGU Joint Assembly. Abstract H42A-07. Publisher: American Geophysical Union. May 2015.

Lukenbach M., K.J. Devito, N. Kettridge, R.M. Petrone, J.M. Waddington. *Hydrogeological controls on post-fire moss recovery in peatlands.* European Geosciences Union Annual Meeting, Vienna, April 12-17, 2015.

Petrone R.M., S.K. Carey, J. Straker. *Water, Energy and Carbon Balance Research: Recovery Trajectories for Oilsands Reclamation and Disturbed Watersheds in the Western Boreal Forest.* Canadian Oil Sands Innovation Alliance Land EPA 2015 Land Workshop, Calgary, Alberta, January 29 – 30, 2015.

Petrone R.M., S.K. Carey, J. Straker. *Water, Energy and Carbon Balance Research: Recovery Trajectories for Oil Sands Reclamation and Disturbed Watersheds in the Western Boreal Forest.* 26th International Union of Geodesy and Geophysics General Assembly, Prague, Czech Republic, June 22 – July 2, 2015.

Petrone R.M.. *Productivity and Water Availability: Balancing the Role and Needs of Peatlands in Landscape Reclamation.* University of Waterloo Water Institute Symposium, Waterloo, Ontario, April, 2015.

Plach J.M., K.J. Devito, R.M. Petrone. *Hydroclimatic Controls on Peatland CO2 Exchange Following Adjacent Forest Harvesting on the Western Boreal Plain.* American Geophysical Union – Canadian Geophysical Union Joint Assembly, Montreal, Quebec, May 3 – 7, 2015.

Waddington J.M., N. Kettridge, J. Sherwood, G. Granath. *Altered peat hydrophysical properties following drainage and wildfire increases peatland vulnerability to ecosystem regime shift.* European Geosciences Union Annual Meeting, Vienna, April 12-17, 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta[1], University of Birmingham[2], University of Waterloo[3], McMaster University[4]

Principal Investigator: Kevin Devito[1] and Carl Mendoza[1], Nick Ketrridge[2], Rich Petrone[3], Mike Waddington[4]

Collaborators: Julienne Morissette, Ducks Unlimited Canada, Boreal Program

Name	Institution	Degree	Start Date	Completion Date
Craig Thompson	University of Alberta	PhD	Jan 2010	Dec 2015
Max Lukenbach	McMaster University	PhD	Sept 2011	Sept 2015
Brandon MacKinnon	McMaster University	MSc	May 2013	April 2016
Mika Little-Devito	University of Alberta	Undergraduate	May 2013	Sept 2014
Sarah Irvine	McMaster University	Undergraduate	May 2013	Sept 2013
Cierra Hoecherl	University of Birmingham	MSc	Oct 2013	Oct 2014
Janina Plach	University of Waterloo	PDF	Nov 2013	Oct 2015
Samantha Probert	University of Birmingham	Undergraduate	March 2014	Feb 2015
Kele Little-Devito	University of Alberta	Technician	April 2014	April 2016
Paul Moore	McMaster University	PDF	April 2014	March 2016
Corina Zuber	McMaster University	Undergraduate	May 2014	April 2015
Greg Carron	University of Waterloo	Undergraduate	May 2014	April 2015
Kelly Hokanson	University of Alberta	Research Hydrologist	May 2014	April 2018
Rhoswen Leonard	University of Birmingham	PhD	May 2014	April 2017
Sarah Irvine	McMaster University	Undergraduate	May 2014	April 2015
Silvia Folegot	University of Birmingham	PhD	May 2014	April 2017
Sophie Wilkinson	McMaster University	Undergraduate	May 2014	April 2015
Cameron McCann	McMaster University	Ecohydrology Techn	Sept 2014	August 2018
Lindsay James	University of Alberta	MSc	Sept 2014	Sept 2017
Midori Depante	University of Waterloo	MSc	Sept 2014	Sept 2016
Emily Jones	University of Alberta	Undergraduate	April 2015	Dec 2015
Joseph Hopkins	University of Alberta	Undergraduate	April 2015	Sept 2015
Lucas Poitras	University of Alberta	Undergraduate	April 2015	Dec 2015
Madison Chamzuk	University of Alberta	Technician	April 2015	April 2016
Max Lukenbach	University of Alberta	PDF	Oct 2015	Oct 2017

Industry Lead: Dallas Heisler; Syncrude Canada Ltd and Ira Sherr CNRL Horizon Oil Sands

Aurora Soil Capping Study: Program Overview

COSIA Project Number: LJ0201

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

The Aurora Soil Capping Study (ASCS) is a study to address two issues for oil sands mine operators in the Athabasca Oil Sands Region: 1) the abundance of naturally-occurring petroleum hydrocarbons (PHCs) in soil reclamation materials and overburden, and 2) the appropriate use of coarse-textured reclamation materials to re-establish unique vegetation species and communities in the area. The study is a multi-disciplinary, collaborative field study involving research scientists from the University of Alberta and University of Saskatchewan, with the support of Syncrude Canada Ltd. (Syncrude) personnel and environmental consultants.

The ASCS is located at Syncrude's Aurora North (AN) mine, and situated on the Fort Hills overburden dump. The overburden of Fort Hills dump consists dominantly of lean oil sand (LOS) which contains PHCs that generally range from <1% oil in soil (10,000 mg/kg soil) to approximately 7% oil in soil. LOS is removed in the mine process to expose the oil sand ore body and is disposed in constructed overburden landforms. Soil materials available for reclamation at the AN mine are generally coarse-textured, glaciofluvial surficial geologic materials. They also contain oil sand materials in variable proportions of the soil matrix, in the form of discrete bands (layers) or aggregated particles of PHCs that can range in size from pebbles to as large as a small vehicle. The oil sand materials present in the soil reclamation material have measurable PHC concentrations; however, their total concentration within the entire soil reclamation matrix is significantly lower than the PHC concentration present in LOS.

The ASCS tests a number of soil reclamation cover designs and capping depths on LOS. There are a total of 12 treatments that are replicated in triplicate in 1 hectare (ha) cells, resulting in a total study area of approximately 36 ha. Each cell has been vegetated to a mix of trembling aspen, white spruce and jack pine to a standard density of 1,800 stems/ha; a mix of understory species was also included in the planting. Within each cell there are 25 m by 25 m vegetation subplots. These subplots have individual tree species (trembling aspen, white spruce and jack pine) and a mix of the tree species in a standard density of 2,000 stems/ha, as well as a higher density of 10,000 stems/ha. Within the cells and vegetation subplots, an array of instruments have been installed to measure parameters such as soil moisture, temperature, groundwater presence and water quality. Other individual research programs have also installed a number of instruments to conduct their research within the study area. A meteorological station has been installed at the site to capture climate data.

Some research programs began in 2010 and the remainder of the projects began when the site construction was completed in May 2012. Data collection has taken place each year since construction and will continue until the conclusion of the research programs.

RESEARCH TEAM AND COLLABORATORS

The ASCS has involved a number of research disciplines for study within the project area. A list of these research projects, including the primary investigator and their classification within COSIA are provided in the table below. A

more detailed description of the individual projects and their results to date can be found in their accompanying sections of this document.

Project Type	COSIA Project Number	Project Title	PI(s)
Joint Industry	LJ0099	Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected Reclamation Soils	Bing Si and Lee Barbour (University of Saskatchewan)
Joint Industry	LJ0219	Hydrocarbon Degradation and Mobility	Ian Fleming (University of Saskatchewan)
Joint Industry	LJ0100	The Roots of Succession: Relations among Plants, Soil and Mycorrhizal Fungi in a Reclaimed Site	Simon Landhäusser and Justine Karst (University of Alberta)
Single Industry	LJ0201	Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils	Sylvie Quideau (University of Alberta)
Single Industry	LJ0201	Re-Establishment of Forest Ecosystem Plants, Microbes and Soil Processes in Coarse Textured Reclamation Soils	Derek MacKenzie (University of Alberta)
Single Industry	LJ0201	Water and Carbon Isotope Methods Development	Lee Barbour and Jim Hendry (University of Saskatchewan)

Aurora Soil Capping Study: Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected, Reclamation Soils

COSIA Project Number: LJ0099

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Suncor Energy Inc., Shell Canada Energy, Canadian Natural Resources Ltd., Imperial, Total E&P Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

As part of the Aurora Soil Capping Study (ASCS), this research program focuses on evaluating the soil water dynamics within the various cover designs at the research site with a specific focus on how the presence of hydrocarbons and soil material layering may affect soil water dynamics and nutrient transport. The research project has been divided into laboratory and field studies. The laboratory studies focus on material characterization that can be done relatively rapidly in a laboratory setting. The longer term field research relies on the interpretation of site monitoring data which has been collected since 2012. The laboratory studies provide an initial assessment of the soil water dynamics within the different cover designs and help to further define the issues to be addressed in the long term field studies. The field studies verify the hypotheses established in the laboratory studies and provide aggregated data for evaluating overarching questions regarding soil water dynamics, plant growth and nutrient transport. The methods of characterization (hydrophobicity and preferential flow), monitoring and modelling proposed in the project are unique and will provide valuable insight into the mechanisms controlling performance of these types of mine closure reclamation covers.

The objectives of the project are the following:

1) a better understanding of the physics of water retention and energy balance in these reclamation cover prescriptions over lean oil sand overburden;
2) determine the optimal soil cover design options and placement thickness(es) of peat-mineral mix and upland surface soil which will result in reclamation soil cover designs having an equal capability to pre-disturbance conditions in terms of soil water in natural a/b ecosites of the region;
3) evaluate the possibility of separate placement of mineral soil layers (Bm, deeper subsoil lifts) for improving soil water retention and being worthy of consideration for salvaging separately; and
4) develop a hydraulic model for soil cover designs consisting of coarse textured, hydrocarbon-affected soils over lean oil sand overburden.

PROGRESS AND ACHIEVEMENTS

Effects of Petroleum Hydrocarbon Content (PHC) and Bulk Density on the Hydraulic Properties of Lean Oil Sand (LOS) Overburden

Trent Pernitsky (M.Sc.) conducted a study to determine the impact of bulk density and petroleum hydrocarbon (PHC) concentration on the hydraulic properties of lean oil sand (LOS). The study is a laboratory trial using soil materials collected from the ASCS. Water retention, saturated hydraulic conductivity (Ks), pore size distribution and texture of the LOS materials across a range of PHC concentrations at two packed bulk densities were tested. Details of these results are published in his M.Sc. thesis (see below) and a journal paper publication of this information is currently underway.

Observations of Soil Moisture Retention Associated with Hydrocarbon Affected Coarse Textured Soils

Meghan Johnson (M.Sc. candidate) conducted a laboratory study using the range of subsoils present in the ASCS. Various treatments were created with these materials, amended with a range of proportions of naturally-occurring aggregated oil sand materials (AOSM) and different layering schemes. The studies included material characterization through organic carbon and particle size analysis, hydrophobicity studies on the hydrocarbon affected material and reclamation soil material with contact angle analysis and the water droplet penetration time (WDPT) test. Water retention studies were also performed, along with larger scale column studies. Soil water content and hydraulic conductivity were measured and a chloride tracer was performed to address hydrocarbon leaching concerns. The outflow solution was analyzed to detect the hydrocarbon type and concentration leached through the columns.

Reporting is currently underway. The study will attempt to determine if varying proportions of oil sand materials present in soil reclamation materials increase or decrease soil water retention of the soil matrix. The study is also investigating if soil layering or AOSM within different soil reclamation materials increases or decreases the soil water retention of the soil reclamation cover matrix.

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

Eric Neil (M.Sc. candidate) is investigating the water repellency and hydraulic properties of AOSM. The study objectives are to: 1) investigate potential soil water repellency of AOSM and soil matrix materials; 2) characterize hydraulic properties, such as unsaturated and saturated hydraulic conductivity, of AOSM from various soil salvage depths and variability across portions of the AOSM (inner and outer); and 3) determine if texture, bulk density, and hydrocarbon content and type have a predictable effect on the repellency and hydraulic properties of AOSM and soil matrix. The degree and persistence of soil water repellency (SWR) of air-dry AOSM can inform us of the maximum or potential SWR of these materials, as well as how long this repellency will persist once water is introduced to its surface and as they weather with time.

In 2013 and 2014 AOSM and soil matrix was collected from different soil reclamation material types and salvage depths of the soils that comprise the different treatments of the ASCS. The degree (contact angle) and persistence (water drop penetration time) of SWR was determined for collected samples using a contact angle goniometer and auto-pipette. The study is further focusing on testing the repellency of inner and outer portions of AOSM to assess the relationship between SWR and depth within aggregates. Infiltration tests using a miniaturized infiltrometer have also been performed in order to characterize the hydraulic conductivity of these materials under various matric potentials.

Study tests have been completed and analysis is currently underway. The study will determine if there are relationships between SWR as well as hydraulic properties of AOSM and their salvage depth (and depth into AOSM).

These tests will provide insight into the change in SWR and hydraulic properties of AOSM as they weather after salvage, stockpile and later use in soil reclamation covers.

The Interactions of Jack Pine Trees and Soil-water at Depth in Natural Soils of the Region

Ivanna Lee Faucher (M.Sc. candidate) is working in natural "a1" ecosites to better understand how jack pine trees utilize soil water at depth. The first objective of the study is to determine if jack pine trees are contributing to changes in soil-water content at different depths through hydraulic redistribution (HR), which is the process of tree roots passively redistributing soil water from areas of high soil-water potential to areas of low soil-water potential. The study is determining if HR of soil-water by jack pine from deeper soil depths (>1 m) to near the surface (<1 m) occurs in water limited ecosites. The second objective is to study how jack pine trees utilize and store internal water within their elastic and inelastic tissues. Knowledge from this study may help in understanding how planted jack pine forests on reclamation sites with coarse textured soils utilize limited plant-available water.

Fieldwork was conducted from June to October 2015, on three sites north of Fort McMurray, AB, in the Athabasca oil sands region. The sites were located in "a1" ecosites of different jack pine stand ages (10-15, 10-45 and 65-75 years). A dual-isotope method was used to investigate if jack pine trees are contributing to changes in soil water content at different depths through HR. Soil water was labelled at different depths with known concentrations of ^{2}H or ^{18}O, soil and tree samples were then collected and analyzed to determine the movement of soil water. To study how jack pine trees utilize and store internal water within their elastic and inelastic tissues, heat pulse probes were installed to measure the direction and rate of sap flow within jack pine trees and circumference dendrometers were installed to measure the diurnal fluctuations and tree growth. Data analysis from the 2015 field season is currently underway conducted and field work is scheduled for 2016.

Utilizing the Cosmic-ray Soil Moisture Probe to measure Soil Water Content and Snow Water Equivalent

Mark Sigouin (M.Sc. student) is testing the use of the Cosmic-ray Soil Moisture Probe (CRP) to measure soil water content (SWC) and snow water equivalent (SWE) in a reclamation landscape. The CRP is a relatively new, non-invasive and passive instrument that takes advantage of the relationship between the water content in soil and the resulting above-ground, low-energy neutron cloud. The measurement footprint of the CRP is a circular area with a radius of approximately 300 m. The main objectives of this study are: 1) to evaluate if CRP can be used to monitor SWE; and 2) to evaluate the SWC measurement efficacy of the CRP at a heterogeneous reclamation site.

In November 2013 a CRP was installed at an agriculture field in Saskatoon, SK. Snow surveys were performed in the field during the winter of 2013/14 and the CRP recorded neutron counts per hour throughout the winter. A calibration equation was developed from the relationship between snow sampled SWE and neutron counts to predict SWE from neutron counts. The CRP was re-installed at the Saskatoon field site for the winter of 2014/15 to test the accuracy of the calibration equation.

In May 2014, a CRP was installed near the center of the ASCS site and calibrated to assess the efficacy of the CRP in terms of monitoring SWC at a heterogeneous reclamation site (i.e., various reclamation treatments, tree species and densities, and activities). Soil samples were collected within the CRP footprint throughout the summer to compare to the data collected by the CRP. In May 2015, the CRP was re-installed at the ASCS site. CRP-estimated SWC was compared to soil sampled water content and in-situ SWC probes throughout the 2015 summer. Also, the wide area CRP-estimated SWC reading from 2014 was downscaled to represent individual plots of the ASCS site using the HYDRUS-1D model. This study will provide an assessment of the accuracy of the CRP and its potential use for monitoring reclaimed landscapes. Data collection is now complete and Mark is currently completing his M.Sc. thesis.

The Effects of Oil Sands Reclaimed landscapes on Preferential Flow

Brianna Zoerb (B.Sc. student) is evaluating the prevalence and degree of preferential flow at the ASCS site. In August 2015, water containing tracer dye was applied to an upland surface soil coversoil treatment plot and a peat coversoil treatment plot at the ASCS to simulate a large rainfall event. Twenty-four hours after the first rainfall application, a second rainfall simulation was applied containing a different tracer to see the effect of varying antecedent water contents on the occurrence of preferential flow. Soil pits were excavated 24 hours after the second rainfall application to allow photos to be taken of the soil profiles to analyze the wetting fronts. The same rainfall and dye applications were performed at a natural reference site for comparison purposes. Fieldwork is complete for this study and data analysis is currently underway. Results from this study will help to understand the magnitude of preferential flow that takes place in different coversoil materials and layered soil covers treatments at the ASCS, in relation to a natural analogue soil profile of the region.

Thermal properties of peat-mineral mixtures measured by the dual-probe heat pulse method

Min Li (Ph.D. Student) is measuring the thermal properties of peat and peat-mineral mix (PMM) coversoil reclamation material at various ranges of temperature, bulk density, water content, and peat-mineral ratios in order to understand the change in thermal properties with varying mineral-organic matter proportions. A number of soil reclamation materials have been taken from the ASCS site and from a reclamation area approximately 10 years of age near the ASCS with vibrant vegetation growth to test varying mineral-organic PMM ratios. Eight different peat-mineral ratios were created from the peat and mineral soils and their thermal properties are being measured in the laboratory by three-needle heat pulse probes. The results from this study will help inform on the change in soil thermal properties that occur with varying peat-mineral mix ratios and attempt to establish an appropriate peat-mineral range that should be employed for PMM coversoil design. Laboratory studies are currently underway.

Effects of Oil Sands Reclamation Covers on Soil Water Storage and Soil Temperature

Wei Hu (Postdoctoral Fellow) evaluated the effects of oil sands reclamation covers on soil water storage (SWS) and soil temperature (ST) at the ASCS. Twelve treatments were constructed in the ASCS by using different combinations of reclamation materials from the 0 to 150 cm layer, overlying lean oil sand as overburden substrate. Daily SWS and mean ST of cover soil (0 to 30 cm) and subsoil (30 to 150 cm) collected from the field instruments were used to evaluate and compare the difference in SWS and ST of soil treatments with peat and upland surface soil material, as well different subsoil materials. The effect of variable placement depth of these materials was also investigated. Data analysis and reporting is currently underway.

Modelling the effects of tree species type, soil cover design soil bulk density and petroleum hydrocarbon content of lean oil sand overburden on soil-water recharge

Wei Hu and Eric Neil are developing a numerical model to simulate water dynamics in layered, coarse textured soils containing oil sand material over lean oil sand substrate. This work will incorporate the findings of the previous studies, as well as other related studies, into the HYDRUS 1-D model. The model will consider such variables as bulk density and tree species (different leaf area index ranges) with regional climate data. Modelling is currently underway to understand the role that soil physical characteristics (bulk density, presence of oil sand materials in soil reclamation materials and presence of lean oil sand) and planting scheme (species and density) have on soil water available for revegetation and potential for drainage of water (percolation) through the soil cover and into the underlying lean oil sand substrate.

OUTCOMES AND LESSONS LEARNED

Trent Pernitsky has completed his M.Sc. program and the highlights of his research are:

- Increases in bulk density and PHC concentration reduces the saturated soil water content and saturated hydraulic conductivity of LOS, but has negligible effects on soil water retention parameters.
- Increases in PHC concentration of LOS decreases the saturated hydraulic conductivity, which retains more water and nutrients in the overlying soil reclamation cover profile.

Other research is still ongoing and is not yet at the stage to report any outcomes and lessons learned.

PRESENTATIONS AND PUBLICATIONS

Publications

Pernitsky, T. 2015. Effects of petroleum hydrocarbon concentration and bulk density on the hydraulic properties of lean oil sand overburden and water storage in overlying soils. M.Sc. Thesis. University of Saskatchewan. Saskatoon, Saskatchewan. 122 pages.

Presentations

B.C. Si and S.L. Barbour. 2015. Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured Hydrocarbon Affected Reclamation Soils. COSIA Land and Water Workshop (Invited). Jan. 29. Calgary.

Posters

Neil E. and B.C. Si. 2015. Characterize hydraulic parameters and water repellency of oil sand materials. COSIA Land and Water Workshop, Jan. 29-30, 2015. Calgary, Alberta.

Pernitsky T. and B.C. Si. 2015. Effects of petroleum hydrocarbon content and bulk density on the hydraulic properties of lean oil sand overburden. COSIA Land and Water Workshop, Jan. 29-30, 2015. Calgary, Alberta.

Sigouin M and B.C. Si. 2015. Measuring soil water content and snow water equivalent using a Cosmic Ray Soil Moisture Meter. COSIA Land and Water Workshop, Jan. 29-30, 2015. Calgary, Alberta.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Bing Si; Co-investigator: Lee Barbour

Name	Institution or Company	Degree or Job Title	Degree Start Date (for students)	Completion Date (For Students Only)
Trent Pernitsky	University of Saskatchewan	M.Sc	Sept. 2011	December, 2015
Meghan Johnson	University of Saskatchewan	M.Sc	Jan. 2012	Ongoing
Henry Chau	University of Saskatchewan	Ph.D	Sept. 2008	March, 2014
Lindsay Tallon	University of Saskatchewan	Ph.D	Sept. 2010	April, 2014
Min Li	University of Saskatchewan	Ph.D	Sept. 2011	Ongoing
Eric Neil	University of Saskatchewan	M.Sc	May. 2013	Ongoing
Wei Hu	University of Saskatchewan	Post-Doctoral Fellow	Sept. 2013	November, 2015
Mark Sigouin	University of Saskatchewan	M.Sc	Sept. 2013	Ongoing
Ivanna Faucher	University of Saskatchewan	M.Sc	Sept. 2014	Ongoing
Brianna Zoerb	University of Saskatchewan	B.Sc.	Sept. 2012	Ongoing

Aurora Soil Capping Study: Hydrocarbon Degradation and Mobility

COSIA Project Number: LJ0219

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial, Shell Canada Energy, Suncor Energy Inc., Total E&P Canada Ltd.

Status: Year 6 of 7 year duration

PROJECT SUMMARY

This study focuses on two aspects of the Aurora Soil Capping Study (ASCS) related to hydrocarbon degradation and mobility:

1) Degradation rates of petroleum hydrocarbons (PHC) present in lean oil sand (LOS) overburden and near surface soil reclamation materials as a result of microbial activity and the effect of such processes on the reclamation performance at the ASCS; and
2) Rates of gas flux from the LOS to the surface through the reconstructed soil profile, as an indicator of, and factor potentially controlling subsurface microbial degradation of PHC and reclamation performance.

The project consists of laboratory-based studies, as well as field studies at the ASCS. A M.Sc. study (Tomasz Korbas) was completed in 2013 and a Ph.D. study (Kyle Scale) is currently underway.

PROGRESS AND ACHIEVEMENTS

In 2011, Kyle Scale began a M.Sc. that has since been extended to a Ph.D. program. His study focuses on the temporal and spatial variability in gas flux and methane oxidation potential of reconstructed soils of the ASCS. The study is evaluating gas production and oxidation for a range of LOS PHC concentrations to determine if there is a relationship of gas-related toxicity to plant growth that could be encountered in LOS overburden reclamation. The interrelationships of soil properties (e.g., hydraulic conductivity, texture and bulk density), ambient conditions (e.g., temperature, water content) and LOS PHC concentration has on gas production and oxidation will be evaluated to develop a numerical predictive and explanatory model to estimate the risk of gas-related toxicity to plant growth during the revegetation phase of LOS reclamation.

Field work which involved measuring gas concentrations in various coversoil treatments using flux chambers and soil vapour probes was completed in 2015. A laboratory study measuring methane oxidation rates from soil columns consisting of soil reclamation material from the ASCS is currently underway.

OUTCOMES AND LESSONS LEARNED

There are no outcomes or lessons learned to report in this reporting period.

PRESENTATIONS AND PUBLICATIONS

There were no presentations and publications during this reporting period.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Ian Fleming

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Tomasz Korbas	University of Saskatchewan	M.Sc.	2010	September 2013
Kyle Scale	University of Saskatchewan	Ph.D.	2011	Ongoing

Aurora Soil Capping Study: Re-Establishment of Forest Ecosystem Plants, Microbes, and Soil Processes in Coarse Textured Reclamation Soils

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 3 of 5

PROJECT SUMMARY

A number of research priorities related to land reclamation in the Athabasca oil sands region (AOSR) have been identified by Syncrude Canada, Ltd. The following is a short list of those priority areas as they relate to work conducted in the Pyrogenic Ecosystem and Restoration Ecology Lab (PEREL) at the University of Alberta:

1) The ability to re-establish some of the drier ecosites (a/b) of the region in oil sands reclamation using coarse textured soil reclamation materials;
2) The effect of using salvaged soil material which contains naturally occurring oil sand materials on nutrient availability; and
3) The effect of different soil capping depths and soil cover types, over lean oil sands, on plant growth and nutrient availability.

Based on these target areas, the following studies were developed:

Study 1 – Impact of different capping materials and canopy type on soil-plant relations

Research Question 1 – How does plant nutrient availability and uptake by tree species vary in the different soil cover types and depth treatments?

Research Question 2 – How does rhizosphere microbial ecology relate to nutrient availability and uptake by tree species in the different soil cover types and depth treatments?

Study 2 – Impact of different horizon sequences and canopy types on soil-plant relations

Research Question 1 – How does plant nutrient availability and uptake by tree species vary with horizon sequence?

Research Question 2 – How does rhizosphere microbial ecology relate to nutrient availability, uptake and horizon sequence?

Study 3 – Spatial pattern analysis of soil-plant relations to determine the success of land

Research Question 1 – What are the spatial patterns associated with plant nutrient availability and uptake?

Research Question 2 – What are the spatial patterns associated with microbial community structure?

Research Question 3 – Are there ways to tie recognition of spatial patterns into tracking successional trajectories and therefore defining land reclamation success?

Study 4: Effect of variable peat/mineral mix ratio on soil biogeochemistry and plant growth

Research Question 1 – How does mixing these soil-types affect the molecular microbial ecology of this greenhouse experiment?

Research Question 2 – How does mixing these soil-types affect the nutrient environment both in foliar material and soils?

Benchmark Sites: Appropriate benchmarks for the study in the boreal forest of Alberta include sites recovering from wildfire as well as human disturbance activities such as harvesting. This study will incorporate a range of benchmark conditions to understand their site characteristics, potential to recover after disturbance and if they are appropriate analogues for comparison to specific oil sands reclamation situations (focusing on soil biogeochemical processes).

PROGRESS AND ACHIEVEMENTS

Study 1 – Mark Howell (M.Sc.) examined 5 treatments at Aurora that compared different application depths of Peat and Forest Floor Mineral Mix (FFM) over subsurface material. He compared data from these treatments to a natural harvested site as a benchmark for comparison of ecosystem functional properties. Instruments were installed and samples were collected in the summer of 2013 from three different depths (5, 15, 35 cm). A 20 L volume of soil was removed from each sample location and placed by horizon into a pail. Instruments including soil temperature and moisture probes, and bioavailable nutrients were measured by installing PRS probes. The pail was replaced to preserve the sample profile and to reduce gas and water movement. Samples were collected in August 2013 and analyzed for microbial community structure (PLFA) and function (CLPP). Mark successfully defended his MSc thesis in May 2015.

Study 2 – Jeff Hogberg (M.Sc. candidate) collected samples in June 2015 from all of the treatments at Aurora by vegetation type and depth (coversoil and below). Samples were collected at a group of 6 reference sites (a and a/b ecosites, post-fire, post harvesting, and mature) from the forest floor (LFH), A and B horizons. Samples were processed to examine total nutrient pools by digestion and available nutrient pools by laboratory incubation. Incubation analysis included bioavailable nutrients (PRS), soil respiration, and microbial biomass post incubation. Foliar material was collected in August 2015 at the Aurora Soil Capping Study (ASCS) site and reference sites, and the heights of representative trees were measured at the ASCS site. Foliar nutrition is currently being analyzed and data interpretation is also underway.

Study 3 – Sebastian Dietrich (Ph.D. candidate) established two spatial plots at the ASCS site in 2013 on peat and FFM coversoil over subsoil, and 3 spatial plots were established on benchmark sites (a and a/b ecosites, post-fire and post-harvest). Seasonal soil respiration and bioavailable nutrients using plant root simulator (PRS) probes were collected in 2013, and seasonal soil respiration and soil samples for microbial biomass were collected in 2014. Field data collection is now complete and laboratory analysis and data interpretation are currently underway.

Study 4 – Will Kirby (M.Sc. candidate) conducted a greenhouse experiment to test the effect of admixing peat and subsoil, both collected from the ASCS, at various ratios (peat, 8:1, 4:1, 2:1, 1:1, 2:1, and subsoil). Potted trials also included FFM from the ASCS and peat/mineral mix from a previously reclaimed area (approximately 10 years of age) near the ASCS that hosts a vibrant plant community. Aspen were grown from seed and used as a bioassay for the potential of different soil treatments to provide plant nutrients for uptake. Soil respiration was measured weekly for the entire experiment and bioavailable nutrients were measured in pots, with and without trees, to determine

plant uptake. After 16 weeks of growth, the trees were harvested for total biomass (roots, shoots and leaves). Leaves were processed for foliar nutrition, and soil samples were collected. Soils were partitioned into rhizosphere and bulk soil and used for microbial community structure and function analysis. Structure is being examined by DNA extraction and analysis, and function is being examined by substrate induced respiration (CLPP). Laboratory analysis and interpretation is currently underway.

OUTCOMES AND LESSONS LEARNED

Study 1 – The following outcomes emerged from the study:

- Macro nutrients are available in similar proportions between FFM and a natural, harvested analogue, while peat has greater nitrogen, sulfur, and calcium availability, but lower phosphorus and potassium availability.
- Microbial community structure and function were found to vary by cover soil type more than application depth, with FFM more similar to a natural, harvested analogue.
- Shallow peat and FFM coversoil applications (10 cm) rather than deeper applications (20 cm – FFM, 30 cm – peat) had soil microbial function more similar to a natural, harvested analogue.

Study 2, 3, and 4 – Ongoing: No outcomes and lessons available at this time.

PRESENTATIONS AND PUBLICATIONS

Dietrich, Sebastian T. and M.D. Mackenzie. 2015. Spatial Pattern of Soil Respiration and Soil Microbial Biomass: Indicators for Reclamation Success. Oral presentation at the Soils Science Society of America conference, Minneapolis, MN.

Howell, D.M. and M.D. MacKenzie. 2015. Assessment of coarse-textured topsoil application depths on microbial community structure and function in oil sands reclamation. Poster presentation at the Alberta Soil Science Workshop, Edmonton AB.

Howell, D.M. 2015. Influence of amendments and soil depth on available nutrients and microbial dynamics in contrasting topsoil materials used for oil sands reclamation. M.Sc. Thesis. University of Alberta. Edmonton, AB. 136 pages.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: M Derek MacKenzie

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Sawyer Desaulniers	University of Alberta	BSc	May 2013	Sept. 2013
Nicole Filipow	University of Alberta	BSc	May 2013	Sept. 2013
Arezoo Amini	University of Alberta	MSc	May 2013	Dec. 2013
Simmon Hofstetter	University of Alberta	PDF	May 2014	Sept. 2014
Maksat Igdyrov	University of Alberta	BSc	Jan. 2014	Dec. 2014
Mark Howell	University of Alberta	MSc	Sept. 2012	May 2015
Sebastian Dietrich	University of Alberta	PhD	Jan. 2014	On-going
Nduka Ikpo	University of Alberta	PDF	Apr. 2013	Nov.2015
Jhon Enterina	University of Alberta	Lab Coordinator	Nov. 2015	On-going

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Monica Shandel	University of Alberta	BSc	May 2015	On-going
Sylyanne Foo	University of Alberta	BSc	May 2015	On-going

Aurora Soil Capping Study: The Roots of Succession: Relations Among Plants, Soils and Mycorrhizal Fungi in a Reclaimed Site

COSIA Project Number: LJ0100

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Shell Canada Energy Inc., Imperial, Total E&P Canada Ltd.

Status: Year 3 of 5

PROJECT SUMMARY

The link between vegetation and the soil environment is a major driver of community and ecosystem processes. Thus, forest restoration following landscape disturbances such as oil sands mining cannot be considered in isolation of soils and the biota contained within. A key revegetation objective for oil sands mine reclamation is to re-establish tree species native to the region. However, the appropriate species selection and planting density are dependent on the quality of the soil cover design and the underlying landform substrate. Conversely, the tree species selection, growth rates, and their planting densities can have an influence on the subsequent understory development, underlying soil development and cycling processes of the reclamation soil profile.

Through improved access to soil resources, tree species may depend on symbiotic microbes such as ectomycorrhizal fungi for establishment and survival. Ectomycorrhizal fungi differ widely in their influence on tree hosts such that shifts in the composition of ectomycorrhizal fungal communities may have important consequences for tree and stand productivity. The extent to which we can manage vegetation and cover soils to restore diverse communities of ectomycorrhizal fungi is poorly understood.

At the Aurora Soil Capping Study the composition and density of tree species across capping treatments has been varied to understand how the manipulation of vegetation (planted tree species and colonizing vegetation) to yield rapid canopy development and a diverse community of ectomycorrhizal fungi can be performed. The objectives are to investigate the effects and potential of different soil cover and capping depth treatments on:

1) tree establishment and growth, including rooting behaviour;
2) plant communities; and
3) the composition of ectomycorrhizal fungal communities.

As part of objective 3), successional trajectories of ectomycorrhizal communities created through reclamation with those of selected ecological references are being compared. The research will inform the understanding of linkages among capping materials, tree establishment, and ectomycorrhizal community development for reclamation of upland boreal forests.

PROGRESS AND ACHIEVEMENTS

Objective 1: Effects of capping treatments on tree establishment and growth, including rooting behaviour

Jana Bockstette (MSc candidate) has led growth measurements of all trees in the capping treatments in 2012, 2013 and 2014. Jana is in the process of writing her thesis and will use the data collected up to 2014. These data are described in the COSIA Land EPA 2014 Mine Site Reclamation Report (Golder Associates Ltd., 2015). Briefly, overall seedlings mortality was low at the site (<6 %). In 2014, the height of aspen, jack pine and white spruce was greater for seedlings grown in FFM (forest floor material) than in peat. Thickness of the peat cover influenced height growth of aspen, jack pine and white spruce. There were no foliar nitrogen concentration deficiencies for aspen grown in all cover treatments. However, aspen foliar P and K concentrations indicated some level of deficiency in all cover soils but were markedly reduced in peat cover soils. Jana is currently compiling this information for her thesis. In 2016 we will collect additional tree data (including leaf nutrition) to explore seedlings performance over the first five growing seasons since the trial establishment.

Rooting behavior as a function of capping materials and the configuration of their placement is being investigated by Simon Bockstette (PhD candidate). Images collected from the installation of minirhizotrons forms the basis of determining how roots of tree species respond to type, depth, and interface between capping materials, and to inter- and intraspecific competition. Water and temperature sensors, and nutrient probes have also been installed in the same subset of treatments as minirhizotrons to elucidate mechanisms underlying patterns in root growth. In 2015, one final round of minirhizotron images was collected at the end of the growing season. All minirhizotron images have been analysed to date; results indicate roots respond differently to capping treatments. A total of 180 seedlings were also destructively sampled in fall 2015 to determine root mass, root:shoot ratio and other relevant parameters. Additional soil cores were taken to determine rooting depth and distribution in response to capping material types and their arrangement. Analysis of these data is ongoing, but initial results show that total root biomass was strongly influenced by capping treatment for aspen and jack pine, while roots of white spruce were less responsive.

Objective 2: Effects of capping treatments on plant communities

As part of assessing the response of tree seedlings to capping treatments, we also expanded this objective to include vegetation surveys on the early development of colonizing plant communities on this site (under the IRC in Land Reclamation [COSIA Project LE0012]). Caren Jones (MSc candidate) leads this work and the 2015 data indicates that apart from obvious differences in vegetation development in response to the surface cover soil materials, the underlying subsoil material appears to start impacting the development of the vegetation community in 2015. Application thickness of the surface material did not influence the initial vegetation development. The planted tree species initially had no effect on the colonizing plant community, however subsequent effects have emerged. Specifically, in peat surface soils white spruce plots had higher species richness than aspen and plots of mixed tree species. In addition planting density became more important after four growing seasons particularly in areas with FFM surface materials (overall more vegetation cover) where low density plots had higher percent vegetation cover than high density plots. Also included in Caren's research are field experiments testing whether areas covered with FFM can act as nucleation islands to promote the dispersal of understory species into the surrounding peat capped areas which at this time have much lower cover and species richness.

Objective 3: Effects of capping treatments on the composition of ectomycorrhizal fungal communities

Shanon Hankin (MSc) found that FFM, peat and subsoil contain propagules of ectomycorrhizal fungi when assayed by aspen, white spruce and jack pine in the field and growth chamber (2012 survey results). All assayed seedlings

had relatively few roots colonized by ectomycorrhizal fungi (~20%). The species of fungi colonizing seedlings was primarily driven by host species. These results are now published in Botany (see below). To determine how the assembly of fungal communities created through reclamation practices compare with that of selected benchmarks, in 2013 Stefan Hupperts (MSc candidate) collected ectomycorrhizal root samples from seedlings grown in the three cover soils at Aurora (peat, FFM and subsoil) as well as references sites. Reference sites captured a gradient of aboveground disturbance over otherwise intact soils. Specifically, reference sites included an intact jack pine forest, a jack pine forest harvested approximately 9 years ago, and a similarly harvested site with the forest floor removed. From the 2013 survey, approximately twenty taxa of ectomycorrhizal fungi were found at Aurora, an increase of fifteen from the previous survey in 2012. From the 2013 seedling assay of soils, host species again had the most influence on the ectomycorrhizal community composition at Aurora, with a small effect of cover soil. At the reference site, ectomycorrhizal community composition was unaffected by aboveground disturbance, and seedlings assayed found many of the same fungal species found at the Aurora Soil Capping Study. A final assay of ectomycorrhizal fungal communities at Aurora and the reference sites was completed in 2015 by Natalie Scott (MSc candidate) and results are pending.

OUTCOMES AND LESSONS LEARNED

- Choice of surface substrates affects colonizing vegetation communities and cover, seedling establishment and early growth; however, responses might not manifest themselves early on (e.g., 1st and 2nd growing season) and their persistence if found are unknown.
- Early tree growth performance suggests aspen is more sensitive (responsive) to surface and sub-surface soil conditions compared to spruce and pine. Soil conditions which aspen are sensitive to are still being investigated.
- Peat, forest floor material and subsoil are reservoirs for propagules of ectomycorrhizal fungi.
- The species of ectomycorrhizal fungi colonizing roots of seedlings are primarily influenced by host species rather than cover soil type.
- Planting a range of tree species may promote the recovery of a diversity of ectomycorrhizal fungi.

PRESENTATIONS AND PUBLICATIONS

Publications:

Gaster, J., Karst, J., & Landhäusser, S.M. 2015. The role of seedling nutrient status on development of ectomycorrhizal fungal communities in two soil types following surface mining disturbance. Pedobiologia 58: 129-135.

Hankin, S., Karst, J. & Landhäusser, S.M. 2015. Influence of tree species and salvaged soils on the recovery of ectomycorrhizal fungi in upland boreal forest restoration after surface mining. Botany 93: 267-277

Barber, L.A., Bockstette, J., Christensen, D.O., Tallon, L.K., & Landhäusser, S.M. 2015. Impact of soil cover system design on cover system performance and tree establishment. Mine Closure 2015 proceedings in TRCR's library.

Presentations:

Hupperts, S., Karst, J. & Landhäusser, S.M. 2015. Recovery of ectomycorrhizal fungi following reclamation of boreal forest, Botany 2015, July 25-29, Edmonton

Landhäusser, S.M., Karst, J., Bockstette, J., & Hankin, S.L. 2015. The influence of cover soil design on early upland forest development in heavily disturbed boreal mine sites. 10th North American Forest Ecology Workshop, June 14-18, 2015, Veracruz Mexico

Jones, C., & Landhäusser, S.M. 2015. Early plant community development and migration in upland boreal forest mine reclamation. North American Forest Ecology Workshop (NAFEW), Veracruz, Mexico.

Jones, C. & Landhäusser, S.M. 2015. Influence of soil capping design on early plant community development in upland boreal forest mine reclamation. Society of Ecological Restoration (SER) Conference, Manchester, UK.

Theses:

Gaster J.R. 2015.The role of nutrient and carbon reserve status of aspen seedlings in root-soil interactions. M.Sc. Thesis, University of Alberta, 84 pages.

Hankin S.L. 2015 Native tree seedling interactions with variations in edaphic properties in upland boreal forest restoration. M.Sc. Thesis, University of Alberta, 142 pages.

REFERENCE

Golder Associates Ltd., 2015. COSIA Land EPA 2014 Mine Site Reclamation Research Report. Calgary, AB: Canadian Natural Resources Limited; Imperial; Shell Canada Energy; Suncor Energy Inc.; Syncrude Canada Ltd.; Total E&P Canada Ltd.; Teck Resources Limited.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser and Justine Karst

Name	Institution or Company	Degree or Job Title	Degree Start Date (for students)	Completion Date (For Students Only)
Justine Karst	University of Alberta	Research Associate, PhD	August 2011	December 2015
Simon Bockstette	University of Alberta	PhD	September 2011	ongoing
Shanon Hankin	University of Alberta	MSc	September 2012	January 2015
Jake Gaster	University of Alberta	MSc	September 2012	April 2015
Jana Bockstette	University of Alberta	MSc	September 2013	ongoing
Caren Jones	University of Alberta	MSc	September 2013	ongoing
Stefan Hupperts	University of Alberta	MSc	January 2014	ongoing
Natalie Scott	University of Alberta	MSc	September 2015	ongoing

Aurora Soil Capping Study: Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Alberta Innovates-Bio Solutions; Alberta Innovates-Energy and Environment Solutions

Status: Year 2 of 4 year duration

PROJECT SUMMARY

This project will help to develop appropriate soil reclamation cover designs using coarse-textured (sandy loam to sand texture) reclamation materials. Re-establishment of forest land capability associated with water and nutrient limited coarse-textured reclamation soils, similar to ecosites present in the region, is a key target for oil sands mine reclamation. Using the reconstructed soils at the Aurora Soil Capping Study (ASCS), the project will also investigate if nutrient additions are required to re-establish nutrient limited soils similar to a natural a/b ecosite.

The following three objectives to be addressed within the overall ASCS project plan were defined:

1) Characterize the potential linkages between soil textural layering, soil nutrients, and site productivity in natural coarse-textured analogs;
2) Quantify the fate of water and nutrients (i.e., soil retention versus nutrient losses) following nutrient additions to soils; and
3) Investigate the interactions between water (and nutrient) redistribution within soil profiles, and plant root development.

The research will provide knowledge on the quantitative relationship between the different mineral substrates and organic cover types currently used to reconstruct coarse-textured soils, and the response of key receptors, including plant and soil, to nutrient addition and water movement. This will allow the definition of sustainable reclamation strategies that will both maximize plant uptake and minimize water and nutrient losses from reconstructed coarse-textured soils.

PROGRESS AND ACHIEVEMENTS

Objective 1. Characterize the potential linkages between soil textural layering, soil nutrients, and site productivity in natural coarse-textured analogs

Brunisolic soils developed from coarse-textured parent material are the second most common upland soil type in the Athabasca Oilsands region. While these soils are typically moisture-limited, possess poor nutrient regimes and are generally associated with relatively low productivity jack pine-lichen communities, they can also be associated with more productive aspen and white spruce communities with a more diverse array of understory species. Increased textural heterogeneity in these sandy soils has been linked to increased water storage. What is far less understood, however, is the potential linkage between textural layering, soil nutrients and site productivity.

To address this study objective, William Barnes (M.Sc. candidate) selected twenty sites derived from coarse-textured parent material in an attempt to capture the natural range of variation in forest productivity found in the region. Sites were selected to minimize influence of topography, aspect and ground-water table interactions on soil development. One pit was excavated per site and a full morphological characterization to a depth of 2 m was conducted. Soils were sampled by morphological horizon for laboratory analyses, and plant root simulator (PRS) probes were placed to measure in the field available nutrients at the soil surface. In the lab, soil properties measured included texture by the hydrometer method; total and available carbon (C), nitrogen (N), and phosphorus (P) in the B horizon; pH; electrical conductivity (EC); cation exchange capacity (CEC); and base cation concentrations. A suite of forest productivity characteristics were also measured within a 100 m^2 area surrounding the soil pit, including diameter at breast height (DBH) of all trees; tree height; site index; shrub biomass; and canopy cover using a LAI 2200 plant canopy analyzer from LI-COR Biosciences. Potential relationships between soil and forest properties were explored based on these measured variables. It was hypothesized that soil textural discontinuities found in many of the sites are influencing site productivity and canopy type through their alteration of water and nutrient fluxes. Types of discontinuities found within the soil profiles included clay lenses, lenses of naturally occurring oil sands deposits and horizon texture differences related to parent material changes.

All field activities and laboratory analyses were concluded in 2015. Analysis of the information, focusing on the relationship of aspen and jack pine stand growth (site index) to nutrient stocks/dynamics and soil textural discontinuities, is currently underway.

Objective 2. Quantify the fate of water and nutrients (i.e., soil retention versus nutrient losses) following nutrient additions to soils

While drainage can be very rapid in homogeneous coarse-textured soils, even small variations in texture may change the soil hydraulic properties, in particular at the interface of the two textural layers. Through this objective we will investigate the relationship between water redistribution and nutrient retention resulting from soil column textural discontinuities. To address this objective, fully instrumented laboratory soil columns (30 cm diameter by 60 cm height) are being used. Time-domain reflectometry (TDR) soil moisture measurements are collected at 1.5 cm intervals for water content profiling. In addition, the columns are equipped with four vacuum soil suction samplers for depth profiling of nutrients and five tensiometers to estimate soil matric potential through the soil column. Effluent will also be collected at the base of the soil column.

In preparation of the soil column work, potential nutrient release through mineralization was measured in 2015 for the two coversoil types (Forest floor material [FFM] and peat/peat mineral mix) which are used at the Aurora Soil Capping Study. Samples collected from the study site passed through a 4 mm sieve to achieve homogeneity and kept at 4 °C until the incubation started. Ten replicates of each material were incubated in the dark at room temperature (24-25 ˚C) using microlysimeters. Potential mineralization rates (C, N, and P) of the materials were determined weekly by: 1) quantification of the CO_2 evolved through analysis of the headspace samples, and 2) simultaneous measurements of the nitrate, ammonium, and phosphate leached from the lysimeters. The incubation experiment was terminated in November 2015 after 325 days. Soil column work will continue in 2016.

Objective 3. Investigate the interactions between water (and nutrient) redistribution within soil profiles, and plant root development.

This objective will provide a detailed understanding of rooting behavior and root distribution within different reclamation materials, in particular in relation to the textural discontinuities found within the soil columns. One important aspect of this work will attempt to maximize water uptake by plants as compared to deep drainage. Work will commence in 2016, and is expected to continue until June 2018.

OUTCOMES AND LESSONS LEARNED

The studies described above are ongoing and are at various stages of completion. Outcomes and lessons learned are not available for public release at this time.

PRESENTATIONS AND PUBLICATIONS

Barnes* W, Quideau SA, Swallow M. Sandy soils of the Athabasca Oil Sands Region: what's driving productivity? Abstract and presentation given at the Canadian Soil Science Meetings, Montreal, Quebec. July 5-10, 2015

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigators: Sylvie Quideau; co-PIs: Miles Dyck and Simon Landhäusser.

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
William Barnes	University of Alberta	M.Sc.	Sept 2013	Ongoing
Najmeh Samadi	University of Alberta	Ph.D.	Sept 2013	May 2015
Sarah Thacker	University of Alberta	B.Sc.	May 2015	Dec 2015
Chengtao Yan	University of Alberta	B.Sc.	May 2015	Dec 2015
Mathew Swallow	Mount Royal University	Assist. Professor		

Aurora Soil Capping Study: Water and Carbon Isotope Methods Development

COSIA Project Number: LJ0201

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Complete

PROJECT SUMMARY

The objective of this research was to develop a method of tracking water movement through unsaturated overburden dumps through the use of a portable spectrometer to measure the stable isotope of water signature of pore-gas water vapour. The rate at which these dissolved constituents are flushed from a lean oil sand (LOS) overburden dump will be largely controlled by the rates and distribution of net percolation into the dump. The measurement of the stable isotopes of water offers a novel opportunity to quantify real-time net percolation by tracking the movement of recharging meteoric water through the measurement of pore-gas water vapour δD_{H2O} and $\delta^{18}O_{H2O}$ profiles. The goal was to develop a methodology to sample pore-gas through in-situ gas sampling probes and provide a real-time measure of pore-gas water vapour δD_{H2O} and $\delta^{18}O_{H2O}$, to quantify net percolation rates through the Fort Hills dump of the Aurora Soil Capping Study (ASCS). Ideally, this could be measured from infiltrating meteoric water if it has a distinct isotopic signature from interstitial water within the LOS overburden of the dump. However, if a sufficient contrast is not available between the two waters, an artificially spiked solution of water can be applied at the surface as a tracer.

Sampling and analytical methodologies must be developed before a field method can be tested. The following phased approach has been developed to demonstrate the applicability of these approaches at the ASCS:

- **Phase 1, Standardizing pore-gas water vapour sampling methods** – Development of sampling and analytical methods; verification and standardization of procedures such as selection of appropriate sample bags, acceptable sample storage times, re-use of sample bags and cross-contamination issues during sampling.
- **Phase 2, Infiltration column testing** – Use of existing instrumented soil columns at the University of Saskatchewan to test proposed field methods before field deployment.
- **Phase 3, Develop techniques for δD_{H2O} and $\delta^{18}O_{H2O}$ spectrometer corrections for methane-affected pore-gas** – Challenges with measuring pore-gas δD_{H2O} and $\delta^{18}O_{H2O}$ measurements in the presence of methane have been identified in previous work at the ASCS. Methane has been measured in the LOS overburden at ASCS, and thus, protocols for correcting methane interference needs to be developed.
- **Phase 4, Reporting and paper preparation** – Results of the experiment will be published in a peer-reviewed scientific journal.

PROGRESS AND ACHIEVEMENTS

Phases 1 and 3 of the project were complete as of the 2014 reporting. Application of the results from these two phases has been incorporated into a series of publications. The preparation of these publications was jointly supported by this project as well as COSIA Project LJ0160 (Coal Watershed Research) and LJ0210 (Barbour IRC). These publications include:

- Methods for determining stable isotopic composition of pore water from core samples (Hendry et al. 2015),
- Methods for determining stable isotopic composition of pore water from vapour sampling (Pratt et al. 2015, 2016; Lu, 2014), and
- Field profiling of stable isotopic composition of pore water in mine waste (Barbour et al. 2016, Huang et al. 2015).

A profiling tool to measure water contents to depths of more than 10 meters is under development as part of COSIA Project LJ0210 (Barbour IRC). This tool combines a Time Domain Reflectometry (TDR) shaft with conventional Cone Penetration Testing (CPT). The new CPT/TDR has also been combined with vapour sampling to measure stable isotopic composition of pore water using real-time vapour sampling. Field trials of this newly developed tool was undertaken at 2 field sites, one outside of Saskatoon, and one at Syncrude's Southwest Sand Storage (SWSS) facility. Following further refinement of the method over the winter, a full scale field trial is planned for SWSS in the summer of 2016.

Phase 2 of the project is near completion. This phase of the project is being undertaken by MSc Student, Matthew Buchynski. This phase involves a column test in which isotopically enriched water is infiltrated into a column of unsaturated sand and is then allowed to redistribute as a result of diffusion of the isotopes through both the liquid and vapour phases of the column. Repeated sampling of the profile following infiltration is used to measure the movement of the isotope over time. A numerical model of water migration and isotope redistribution has been developed and is being used to interpret the data. Two column tests have been completed with final data analyses and thesis writing underway. Data analysis and reporting are currently underway.

OUTCOMES AND LESSONS LEARNED

The following lessons were learned:

1) Standardized methods to collect the stable isotope of water composition of pore water through either water, soil or vapour sampling;
2) Developed methods to use analytical equipment in the field for in-situ measurements of the stable isotope composition of pore water through vapour sampling; and
3) Verification of the ability to simulate advective/diffusive transport of the stable isotopes of water in combined aqueous/vapour phases of an unsaturated soil.

PRESENTATIONS AND PUBLICATIONS

Barbour, S.L., Hendry, M.J., Carey, S.K. (2016). High-Resolution Profiling of the Stable Isotopes of Water in Unsaturated Coal Waste Rock. Accepted with revisions by Journal of Hydrology.

Buchynski, M., Barbour, S.L., Hendry, M.J. (2015). "Characterizing the transport of the stable isotopes of Water in unsaturated mining waste". In: 'Mining Waste Management and Environmental Geotechnology: Mine Waste Disposal', GeoQuebec 2015, 68th Canadian Geotechnical Conference, Quebec City, Sept. 20-23.

Hendry, M.J., Schmeling, E.E., Wassenaar, L.I., Barbour, S.L., Pratt, D.L. (2015). "Determining the stable isotope composition of pore water from saturated and unsaturated zone core: Improvements to the direct vapor equilibration laser spectroscopy method", Hydrol. Earth Syst. Sci. (HESS), 19(11): 4427-4440, 2015, www.hydrol-earth-syst-sci.net/19/4427/2015/doi:10.5194/hess-19-4427-2015;

Huang, M., Hilderman, J.N., Barbour, S.L. (2015). "Transport of stable isotopes of water and sulphate within reclaimed oil sands saline-sodic mine overburden", Journal of Hydrology, August, doi: 10.1016/j.jhydrol.2015.08.028

Lu M. Development of Methodology for In-situ Vapour Sampling for Stable Isotopes of Water [M.Eng. thesis]. Saskatoon, SK: University of Saskatchewan; 2014.

Pratt, D., Lu, M. Barbour, S.L., Hendry, J.M. (2016). An evaluation of materials and methods for vapour measurement of the isotopic composition of pore water in deep, unsaturated zones. Accepted for publication Isotopes in Environmental & Health Studies.

Pratt, D.L., Lu, M., Barbour, S.L., Hendry, M.J. (2015). "Development of in-situ vapour sampling for stable isotopes of water within unsaturated mine waste". Poster 098p, Internat. Symp. On Isotope Hydrology (IAEA), Vienna, Austria, May 13.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Lee Barbour and Jim Hendry

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Matthew Buchynski	University of Saskatchewan	MSc student	September 2013	April 2016
Dyan Pratt	University of Saskatchewan	Research Engineer	n/a	n/a
Mengna Lu	University of Saskatchewan	M.Eng.	January 2013	June 2014
Mingbin Huang	University of Saskatchewan	Research Scientist	n/a	n/a

Coal Watershed Research and Development Program

COSIA Project Number: LJ0160

Research Provider: University of Saskatchewan, Montana State University, McMaster University, SRK Consulting, Integral Ecology, O'Kane Consultants Inc., WorleyParsons Canada, BGC Engineering

Industry Champion: Teck Resources Limited

Status: Year 4 of 7

PROJECT SUMMARY

In 2011 Teck Resources Limited (Teck) embarked upon an applied research and development (R&D) program focused on managing constituents of interest (CIs), including, but not limited to, selenium, in mining-affected watersheds. The overall objectives of the program are to:

1. identify and develop new technologies and techniques, and/or enhance existing technologies, to manage water quality; and
2. communicate the results of this program through Teck's internal technology transfer process.

The technologies and techniques being advanced fall into two main categories:

1. the watershed focused applied R&D program to investigate contaminant sources and source control methods; and
2. the active water treatment technology program.

The watershed-focused applied R&D program is focused on research and development projects to advance source control, specifically related to mine design and water management strategies to manage CIs. A separate, but integrated, effort is the active water treatment technology program which is focused on the investigation of active water treatment technologies, including periodic surveys of new methods, to remove and reduce CIs present in mine-affected water.

In general terms, the watershed-focused applied R&D program is directed towards developing the scientific and engineering information required to inform geochemical, hydrological (including hydrogeological) and biological conceptual and numerical models that underpin or are directly used to plan mining activities or to evaluate their impacts, and to identify feasible methods to limit the production and release of CIs from mine wastes (source control). The active water treatment research is focused on identification of improvements for active water treatment technologies.

As highlighted above, rapid technology transfer is one of the two overall objectives of the applied R&D program. This focus is represented in the overall approach to research and development wherein there is:

- pro-active identification of opportunities to demonstrate and test promising practical strategies or technologies at a field scale (development) to rapidly work through and document the critical engineering design and construction questions and solutions (often the predominant issues) in a practices manual; and
- support of pilot- and full-scale applications with research projects, which address specific questions arising from the planning and implementation of the field tests, thereby focusing the research projects to clearly and directly support implementation of the specific practical strategies or technologies and to inform risk/benefit analyses.

In 2015, efforts in regards to Technology Transfer were focused on identifying potential applications and developing a database and evaluating the relative effectiveness of alternative water quality management technologies.

PROGRESS AND ACHIEVEMENTS

The original five focal research areas identified in the watershed R&D program include:

- ex-pit waste rock dump design and management;
- water balances to aid water management decisions;
- rock drain design and operation;
- ·aturated zone design and operation; and
- reclamation and Se management.

Substantial time and resources have been invested in sampling and instrumenting research areas to commence water, CI and energy balance data collection in support of these research areas. This program continues to answer major research questions and many of the original research projects continued through 2015. Additional focal areas were added in subsequent years, including research into nitrate management, and an increased focus on evaluating practical strategies for mine design. In 2015, the focus of the program was on the function and risks of one of the more promising alternatives to active water treatment for the mitigation of selenium and nitrate – saturated rock fills. Work also continued in calcite management and technology transfer.

Saturated rock fills – characterization of fill material

One of the key considerations in the use of saturated rock fills is related to the bulk hydraulic conductivity of the fill material, as well as whether there is an appreciable degree of heterogeneity or anisotropy. Each of these characteristics has the potential to effect flow paths through the saturated portion of the rock fill, as well as the degree of residence time for water moving through the fill and subsequently the reaction time for the deleterious constituents of interest.

In 2015, a project to evaluate the hydraulic characteristics of the fill material at one of the study sites was initiated and completed. The objective of the study was to conduct pumping tests to investigate the hydraulic characteristics of the fill material, as well as to test several geophysical methods that could be used in the future to provide reasonable approximations of key hydraulic parameters. The results of the study indicated that the hydraulic conductivity was high enough to support mine scale volumes of water moving through the fill volume over an appropriate retention time.

As a part of the overall characterization program, monitoring of gas and water samples was continued at other sites to develop a long term history of the performance of those rock fills.

Saturated rock fills – function at laboratory and field scale

The proposed use of saturated rock fills as a treatment for mine affected water is predicated, in part, on the assumption that an indigenous community of microorganisms in the waste rock is responsible for the reduction and removal of selenium and nitrate from the aqueous phase. To evaluate this assumption, a number of projects to monitor and analyze the reduction of selenium and/or nitrate were advanced during the course of the year. At the laboratory scale, column tests were constructed using representative samples of waste rock from a test site, and flooded with mine affected water to evaluate the efficacy of the microbiological community in reducing selenium and nitrate. Testing was also completed to evaluate if these same reactions happen under abiotic conditions.

At the field scale, one of the key studies for 2015 was the development of a hydrologic model for an operating saturated rock fill to evaluate water and contaminant inflow and outflow rates with the goal of using the model to identify reasons behind observed fluctuations in the concentration of constituents of interest. A second study, which was conducted in conjunction with the work on the characterization of fill material, was the instrumentation of a borehole through fill material such that a vertical profile of gas and water samples could be obtained.

Saturated rock fills – risk assessment

The use of saturated rock fills as a treatment for mine affected water is not without some level of risk. To evaluate the level of risk, a workshop was conducted in 2015 to identify and quantify risks associated with this technology. Results of the workshop were used to develop, where applicable, experiments to assess identified risks.

Risks were generally focused on biogeochemical issues that affected either water quality, or the release of gases that would affect human health and safety. Geotechnical risks associated with the stability of the saturated fills, as well as risks around stewardship and cost were also identified. Subsequent laboratory testing focused primarily on the biogeochemical issues, as these were the most amenable to controlled experimentation.

Calcite management

A review of treatment technologies for the management of calcite precipitation is on-going. In 2015, efforts were focused on the testing of antiscalants to control scale deposition, which included a pilot program to evaluate and compare dosage, water chemistry changes, toxicity, treatment cost, efficacy and environmental impact.

As well, the initial data collection for a passive system, consisting of a cascade into a settling pond, was conducted. Data collection for a similar study, in regards to the development of predictive tools as a function of water chemistry, was also initiated.

OUTCOMES AND LESSONS LEARNED

As noted in the project descriptions above, many of the projects are in mid stages with data synthesis underway. Outcomes and lessons learned are not ready for release to the public. Interim draft results are summarized in the Research and Technology Development Progress Report March 2015, which will be available to COSIA April 1, 2016.

PRESENTATIONS AND PUBLICATIONS

Bezuau, A., Carey, S. K., 2015, *The Influence of Site Conditions and Surface Vegetation on Snow Accumulation and Ablation in the Elk Valley, British Columbia, Canada*. Presentation given at the Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada and the Mineralogical Association of Canada, Montreal, Canada, May 3, 2015.

Biswas, A., Hendry, J. M., Essilfie-Dughan, J. 2015 (submitted), *Abundance and Mineralogical Associations of Arsenic in Coal Waste Rock, Elk Valley, British Columbia, Canada: Implications for Arsenic Mobilization in Low Sulfide – High Carbonate Waste Rock*. Paper submitted for publication to Environmental Science and Technology.

Carey, S. K., Wellen, C. C., Shatilla, N. J., 2015, *The Influence of Surface Coal Mining on Runoff Processes and Stream Chemistry in the Elk Valley, British Columbia, Canada*. Abstract submitted to the American Geophysical Union Conference, San Francisco, United States, December 14-19, 2015.

Essilfie-Dughan, J., Hendry, J. M., Dynes, J. J., Hu, Y. Biswas, A., Barbour, S. L., 2015 (submitted), D*istribution and Evolution of Iron and Sulfur Phases in Coal Waste Rock, Elk Valley, British Columbia, Canada*. Paper submitted for publication in Journal of Applied Geochemistry.

Hendry, J. M., Biswas, A. Essilfie-Dughan, J., Chen, N., Day, S., Barbour, L., 2015 (in press), *Reservoirs of Selenium in Coal Waste Rock: Elk Valley, British Columbia, Canada*. Paper accepted for publication in Environmental Science and Technology.

Hendry, J. M., Schmeling, E., Wassenaar, L. I., Barbour, S. L., Pratt, D., 2015 (submitted), *Determining the Stable Isotope Composition of Pore Water From Saturated and Unsaturated Zone Core: Improvements to the Direct Vapor Equilibrium Laser Spectroscopy Method*. Paper submitted to Hydrology and Earth System Sciences.

Kuzyk, T., Barbour, S. L., Hendry, M. J., 2015, *A Conceptual Model for Effluent Release from Coal Waste Rock Piles in the Elk Valley, British Columbia, Canada*. Abstract and Presentation submitted to Canadian Geotechnical Conference (GeoQuebec), Quebec City, Canada, September 20-23, 2015 and the International Association of Hydrogeology Conference, Waterloo, Canada, October 27-30, 2015.

O'Kane, M., Birkham, T., Straker, J. Barbour, L., Carey, S. Klein, R., 2015, *Near-surface Water Balances of Coal Waste Rock Dumps*. Presentation given at International Conference on Acid Rock Drainage, Santiago, Chile, April 21-24, 2015.

Pratt, D. L., Lu, M., Barbour, S. L., Hendry, J. M., 2015, *Development of In-situ Vapour Sampling for Stable Isotopes of Water within Unsaturated Mine Waste*. Poster and paper given at the International Symposium on Isotope Hydrology in Vienna, Austria May 11-15, 2015.

Straker, J., Baker, T., Barbour, L., O'Kane, M., Carey, S., Charest, D., 2015, *Mine Reclamation and Surface Water Balances: a Hydroecological Classification system for Mine-affected Watersheds.* Presentation given at the International Conference on Mine Closure, Vancouver, Canada, June 1-3, 2015.

Schabert, M., Hendry, M. J., Barbour, S. L., 2015, *Application of Push-Pull Tests to Define Biogeochemical Controls on Selenium and Nitrate Attenuation in a Saturated Coal Waste Rock*. International Association of Hydrogeology Conference, Waterloo, Canada, October 27-30, 2015.

Szmigielski, J. T., 2015, *Characterizing a Groundwater System Downgradient of a Coal Mine Waste Rock Dump, Elk Valley, British Columbia, Canada.* Thesis Submitted to the College of Graduate Studies and Research for the Degree of Master of Science, University of Saskatchewan, September 2015.

Wellen, C. C., Carey, S. K., 2015a (submitted), *Regional Scale Selenium Loading Associated with Surface Coal Mining in the Elk Valley, British Columbia.* Paper submitted to Water Resources Journal for publication.

Wellen, C. C., Carey, S. K., 2015b, *The Influence of Surface Coal Mining on Hydrology and Solute Transport in the Elk Valley, British Columbia, Canada.* Presentation given at the Canadian Geophysical Union/American Geophysical Union Joint Assembly, Montreal, Canada, May 6, 2015

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Jim Hendry

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Jim Hendry	University of Saskatchewan	Principal Investigator		
Lee Barbour	University of Saskatchewan	Principal Investigator		
Brent Peyton	Montana State University	Principal Investigator		
Lisa Kirk	Montana State University, Enviromin	Principal Investigator		
Sean Carey	McMaster University	Principal Investigator		
Chris Kennedy	SRK Consulting	Principal Investigator		
Stephen Day	SRK Consulting	Principal Investigator		
Daryl Hockley	SRK Consulting	Principal Investigator		
Dan Mackie	SRK Consulting	Principal Investigator		
Dan Charest	Teck Coal	Env. Coordinator		
Ray Yost	Teck Coal	R&D Manager		
Rob Klein	Teck Coal	Technical Lead		
Toney Fedec	Teck Coal	Water Quality Eng.		
Justin Straker	Integral Ecology	Principal Investigator		
Mike O'Kane	O'Kane Consultants, Inc.	Principal Investigator		
Tyler Birkham	O'Kane Consultants, Inc.	Principal Investigator		
Randi Thompson	BGC Engineering, Inc.	Principal Investigator		

Evaluating the Success of Fen Creation

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial; Shell Canada Energy.

Status: Year 4 of 6

PROJECT SUMMARY

The primary research goal of Nikanotee Fen has been to assess success of a constructed fen design through a detailed examination of hydrological functioning, bio-geochemical interactions and ecological progression at the site, post-construction. This has occurred in tandem with the characterization of a series of reference fen (RF) systems in the Fort McMurray area, providing a background understanding of the range and variability of ecohydrological characteristics of natural regional fens, allowing for definable metrics of success.

The research has been established as three linked projects that investigate particular science questions associated with the creation of a hydrologically functioning, ecologically successful, carbon sequestering fen wetland incorporating processed tailings materials into the construction.

Broad-scale objectives of the Nikanotee Fen research have been to:

- identify strengths and weaknesses in the conceptual fen design;
- test the method for construction including materials, their placement and the sensitivity of design characteristics through modelling of water and contaminant flows;
- develop thresholds and milestones for hydrological, water quality and carbon sequestration rates or thresholds as monitoring tools;
- determine the most suitable vegetation communities and reintroduction methods for fen reclamation.

Specifically, sub-objective hypotheses are to:

- Determine if upland facilitates sufficient recharge flow to the fen, and if sodium salts (Na) and naphthenic acids (NAs) leach from cover soil and tailings and how quickly they flush from the tailings aquifer that forms the upland.
- Find if transport and attenuation processes in fen peat hold these contaminants below plant toxicity thresholds in the rooting zone.
- Determine if the fen sequesters carbon (C), and if revegetation strategies for the fen affect C accumulation. Owing to differing antecedent moisture and nutrient conditions, do different functional relationships exist for vegetation communities at the upland and fen?
- Identify the most successful and appropriate revegetation methods for respective species and how varying hydro-geochemical gradients and propagule inputs affect survival, composition, photosynthesis and transpiration. Determine whether microbial communities at the constructed fen reflect those at the reference fen sites, determining if these communities develop the ability to degrade NAs.

PROGRESS AND ACHIEVEMENTS

Definitions

- The project's reference sites are referred to as 'REF' in the course of this document. They are comprised of a 'rich' fen, a 'poor' fen and a 'saline' fen wetland. Rich and poor denote the dominant vegetation assemblages at the site.
- The Suncor Nikanotee constructed fen is hereby referred to as 'FEN' in the course of this document.
- The upland component of the constructed fen watershed is hereby referred to as 'UPLAND' in the course of this document.

Ecohydrological controls on evapotranspiration in reference (REF) fens.

The Regional Atmospheric Forest Large Eddy Simulation (RAFLES) model is being used to determine the importance of upland sheltering with regards to turbulent structures (trees) at the fen sites. The Virtual Canopy Generator (V-CaGe) model will use in-situ vegetation characteristics to parameterize the model to create the virtual 3-D vegetation canopy model needed to run RAFLES.

Controls on carbon flux and accumulation in reference (REF) fens.

Nitrogen (N) and phosphorus (P) availability and net mineralization rates (controls on carbon flux in the reference sites) fall along a moisture gradient. N and P dynamics within the sites are related to water table position, peat moisture content and temperature. P supply rates and total inorganic N pools and supply rates were elevated under wetter conditions, whereas nitrate (NO_3–) pools and supply rates and P pools did not vary along moisture gradients. In general, net immobilization was observed at REF (reference) sites with higher water tables at the saline and poor fen REF sites, where nutrient pools are elevated and net mineralization was observed at drier sites where nutrient pools were lower. Transformation rates were most strongly driven by warmer temperatures. Paleo core testing at the saline site suggests that initiation of the saline fen occurred ~3,900-4,100 years BP (before present). Shifts in microfossil assemblages suggest significant fluctuations in salinity during the last century, with periods of higher salinity between ~1900 to 1940 are shown by dominance of brackish diatoms, following a rise in freshwater species. This indicates a decline in salinity between ~1940 to 1975, interrupted by small increase in salinity ~1960. Subsequent increase in brackish species suggests gradual rise in salinity until 1990 and slight decline thereafter. A period of decreased salinity from ~1940 to 1970 agrees with the hydrogeological literature that saline spring features can 'switch off' on the landscape. For studying long-term carbon accumulation rate, two peat cores are being processed for macrofossil analysis, bulk density, C/N ratio and C mass analyses, loss on ignition (LOI), and lead-210 (^{210}Pb) and ^{14}C dating.

Identification and comparison of methanogenic and methanotrophic microbes.

Peat composition and nutrient availability of reference (REF) sites play large roles in determining methane production potential. Poor fen REF site samples displayed concentrations of headspace methane ten times greater than other samples. Similarly, poor fen REF site samples amended with contaminants, oil sands process affected water (OSPW, OSPW + NaCl) initially displayed methane production similar to that of the constructed fen (FEN). Over time, methane production amended samples began to increase but consistently produced significantly lower headspace methane concentrations (up to 10x lower) than the un-amended samples from the same site. Rich fen REF site behaved similarly to those from the poor fen site, albeit more slowly, with headspace methane concentration in

the un-amended samples exceeding the FEN by an order of magnitude. In amended samples, methane production was slower, with headspace methane concentrations exceeding that of the un-amended FEN samples by an order of magnitude by the end of the experiment.

Constructed FEN samples had consistently low headspace methane concentrations, except for those amended with 4 millimoles (mM) acetate, whose methane concentrations began to rise rapidly above other constructed FEN. Including acetate-amended FEN samples allowed the testing of whether measured low methane production at the FEN was due to the high sulfate concentration of the peat (which would prevent methanogenesis from occurring due to competitive inhibition) or due to poor substrate quality. As the acetate-amended sample displayed greater methane concentration than any of the other constructed FEN samples, poor substrate quality is likely responsible for the low rates of methane production at the FEN. The addition of contaminants is causing a temporary suppression of methane production at the FEN/REF sites, which is consistent with previous studies in oil sands mine tailings. The methanogenic capacity of the constructed FEN is far below two of the REF sites, likely related to quality substrate availability. Taxonomic assessment (genetic sequencing of microbial communities predominant at each site) is still ongoing.

Hydrological links between UPLAND & FEN.

Minor installations were made in the UPLAND in 2015 to expand the monitoring network, along the central East-West transect, where water tables were > 3 m below ground surface, in efforts to fill in gaps of unknown locations. The previous two seasons (2013/2014) had been relatively wet (higher than 30 year mean precipitation) with high water tables (shallow, within -10 cm of surface) across the FEN and strong vertical hydraulic gradients through-out the FEN peat profile. The first half of 2015 (May-June) was a much drier season (low precipitation), resulting in large decreases in the water table of up to 20-30 cm and 5-15 cm within the UPLAND aquifer (southern East-West transect) and FEN peat, respectively. The surface standing water (ponds) within the FEN decreased in size and many dried completely as water tables dropped. There was little outflow (<0.1L/s) through the spillbox and no surface runoff from surrounding slopes during periods of low precipitation. Like UPLAND water tables, FEN water tables readily dropped without repeated rainfall and ceased outflow. This signifies a large storage potential in the system that has not yet been satisfied by incoming precipitation.

The FEN peat was planted according to a prescribed treatment plan (see previous years reports) with different surface vegetation treatments in a grid system of ‘plots’ to rigorously test vegetation treatments validity. These treatments included 5 planting types (bare control, moss, seedlings, moss & seedlings, seeds) and 4 treatment types (mulch, no mulch, weeding, no weeding).

Cumulative evapotranspiration (*ET*) increased steadily over the 2015 study season and, following June 12 exceeded precipitation (*P*) for all vegetation treatment cover types. *ET* rates were found to be significantly different between vegetation types ($p < 0.001$), with the greatest difference between moss and seedling rates. The highest *ET* rates were from open water, averaging 4.4 mm/day with peak rates of 7.3 mm/day and were greater than all other plot rates except seedlings. Seedling plots had the second highest rates, averaging 3.9 mm/day and peaking at 6.4 mm/day, and were consistently higher than control or moss plots. Moss plots had the lowest *ET* rates at 2.8 mm/day, reaching a maximum of 4.9 mm/day, followed by control plots with average rates of 3.2 mm/day and peak rates of 5.5 mm/day. All plots exhibited similar daily *ET* trends, generally increasing, over the study season, with maximum *ET* rates in early July.

ET rates differed significantly in mulched plots. Although, moss-mulch rates were the lowest and significantly different from all cover types, they did not significantly differ from unmulched moss plots. Similarly, seedling-mulch plots showed lower rates than unmulched seedling plots, however, did not differ significantly from seedling or control plots. Mulch increased relative humidity at the peat surface, reducing near-surface temperatures and

vapour pressure deficit. Vegetation type was significant in controlling *ET* from the FEN, where all plot types showed lower *ET* rates than open water. Seedling plots showed the greatest *ET* rates compared to moss and control plots due to the connectivity of vascular plants to the water table and their ability to transpire. However, available energy alone did not provide an accurate estimate of *ET.* Alpha-values show that actual *ET* was greater than equilibrium *ET* in all plot types, except moss plots. Mulch reduced *ET* in moss plots, but had less of an impact on seedling plots, as it had no noticeable effect on transpiration. Mulch dampened temperature fluctuations, keeping the surface and upper peat profile cooler during the day and warmer at night. Mulch also created a near-surface microclimate that increased relative humidity and lowered the vapour pressure deficit in the mulch layer, further mitigating *ET* losses.

Distribution and movement of solutes in and between UPLAND & FEN.

The pH values in 2015, as compared to prior year's values, remain between 6-8 across the FEN (moderate-extreme rich fen). However the pH of peat increased during dry periods, yet remaining under 8. UPLAND tailing sands electrical conductivity (EC) remains roughly between 1500-3500 µS/cm, slightly higher on the lower range than previous years however not significantly different. UPLAND tailing sands EC values at depth (-275 cm) were higher than values from wells (4000 µS/cm compared to 2000-3000 µS/cm) indicating upper layers within the aquifer are more active as a result of recharge and dilution. Transition EC was 1200-3100 µS/cm. FEN EC was 1700-4000 µS/cm, higher than previous years which can be attributed to concentrations increasing due to evaporation at the FEN surface and overall low precipitation. Higher EC values were recorded 50-90 cm below ground surface (bgs) than with depth, 225-275 cm bgs within the FEN. FEN peat EC values are greater than in the sand aquifer, 2000-4000 µS/cm vs 1500-3000 µS/cm. This elevated EC in the peat can likely be attributed to the high sulphate concentration of the peat, which has the unfortunate effect of masking sodium dynamics (through EC measurements) in the system, meaning costly off-site analysis is required to gauge the sodium transport dynamics of the FEN/UPLAND system. Water samples taken from UPLAND recharge basins appear diluted (<1500 µS/cm), as they store precipitation (including snow) and runoff. The isotope data taken from these recharge basin piezometers indicates that freshwater from snow is flushing sodium through the aquifer towards the FEN underdrain as designed.

Hydrologic change over time.

During the snow-free period, infiltration-excess surface runoff from slopes reclaimed within the previous 2-3 years supplemented precipitation inputs to depressional features during intense rainfall events. This contributed to a flashy response in discharge from the watershed, which was otherwise low due to high soil water storage capacity and sustained evapotranspiration rates from reclamation soils. In the FEN peatland, high water table levels were sustained throughout the snow-free period in 2013 and 2014, with persistent ponded water in some areas. Upward hydraulic gradients measured in the FEN suggest strong connectivity with the sand UPLAND aquifer; however low surface infiltration rates on the capping UPLAND reclamation soil layer constrained recharge to the underlying aquifer, which remained below designed water contents in much of the UPLAND.

Actual evapotranspiration (*AET*) and *P* dominated the water fluxes during the snow-free period. Relatively stable shallow water table levels and surface ponding throughout the FEN, combined with extensive vascular vegetation establishment, resulted in *AET* exceeding potential evapotranspiration (*PET*) in 2014 & 2015. Recharge to the UPLAND aquifer was constrained by the low and variable flow of the LFH soil cap (3-200 mm h^{-1}). Groundwater recharge was hindered by high soil water storage capacity of these materials, which were 50 to 125% thicker than the 20 cm targeted thickness. Considerable variability in the depth to water table was observed throughout the UPLAND, e.g. the water table in the southernmost end of the aquifer (farthest from the FEN) was ~150 cm below ground surface (bgs) in August 2013, whereas it was greater than 260 cm bgs in the middle section of the UPLAND

(where LFH cover thickness was greatest) at the same time. Deeper wells installed in this section of the UPLAND in 2014 indicated that the water table remained ~300 cm bgs and that the saturated zone was likely thin.

The water table responded to seasonal *P* influx at several locations throughout the UPLAND aquifer, indicating some groundwater recharge despite the low flow and high water storage capacity of the LFH soil cover. The UPLAND-FEN system received occasional water inputs from the recently reclaimed 2011 slopes via infiltration-excess overland flow generated during intense *P* events. Discharge at the outflow of the system responded rapidly to large, infrequent *P* events. Predominantly small *P* events temporarily recharged near-surface soil water storage and helped to sustain *AET* rates that were comparable to *P* inputs in the UPLAND. Isotope analysis suggests snowmelt is a larger contributor to groundwater recharge in the upland than previously thought, it suggests that depressional features within the upland, such as the "perched fen" and constructed recharge basins, are effective recharge windows, during the snowmelt period.

Saturated hydraulic conductivity (K_{sat}) of all construction materials (2013 values) was lower than targeted in the original design. K_{sat} of the peat and uplands tailings sand were approximately one order of magnitude lower than targeted and K_{sat} of the petroleum coke underdrain layer was over three orders of magnitude below design specifications. Inter-year comparisons of materials placed in 2013 revealed that K_{sat} within the peat increased at all depths in 2014 compared to 2013; whereas the placed tailings sand showed negligible change. 2015 data show K_{sat} slightly lower than 2014 values, but still higher than those measured in 2013. Estimates of K_{sat} at 64 locations throughout the fen in 2014 indicated that the K_{sat} of the shallow (50 cm) placed peat varied by over an order of magnitude spatially within FEN. Remediation efforts (surface tillage in August 2013) resulted in a twofold increase in surface infiltration capacity in the LFH. (Freeze/thaw and vegetation establishment likely contributed to this increase as well.) Groundwater discharge from the UPLAND aquifer is helping to sustain high water table levels within FEN. Despite the lower than targeted K_{sat} values for construction materials, relative to one another, they appear to be functioning similarly to the original hydrogeological model.

Modelling the transport and fate of Sodium (Na) and Napthenic Acids (NA) in the constructed system.

Analysis of data from the material digestions and leaching batch experiment indicates a large pool of available Na (estimated at ~24 T) in the FEN. Most of the available Na is located in the UPLAND. This implies potential for salt accumulation in the rooting zone of the FEN which may stress moss/vascular physiology. Results from the unsaturated column experiment suggested that Na is moving through the unsaturated peat column faster than expected, in a manner that fits a conservative solute rather than non-conservative solute. This might be due to relatively high content of divalent cations in peat such as calcium (Ca) and magnesium (Mg), these cations have a stronger affinity to the bonding sites than Na, limiting attenuation. If this trend continues, it would indicate that upon Na reaching the water table it would move faster than expected to the root zone and surface. These saturated and unsaturated datasets are informing the Hydrus 2D/3D/COMSOL modelling efforts to quantify the time scales for such an accumulation. Transport and fate modelling of Na and NA at the constructed FEN is underway using a three-dimensional groundwater flow model. Steady-state and transient simulations are being conducted to assess contaminant accumulation in the shallow subsurface, and whether Na and NA reach critical toxicity thresholds for mosses and vascular plants.

Controls on carbon fluxes in the constructed FEN and UPLAND.

Fluxes are being measured using greenhouse gas (GHG) chambers atop 0.6x0.6 m^2 soil collars inserted into the peat substrate. Collars have targeted specific vegetation assemblies; comparisons such as the presence of sedges or other graminoids, or the abundance of mosses in a plot. Average growing season CH_4 flux to the atmosphere was

generally lower than literature values at both the FEN and the saline REF site, while the rich fen REF site had high CH_4 flux. This was possibly associated with high sulfate (SO_4^-) content observed from water chemistry data at the FEN and saline REF fen, as there was the potential for SO_4^- reduction to inhibit methanogenesis. Water table, pore water CH_4 concentration, gross ecosystem productivity, and soil temperature were all found to be controls on CH_4 flux across the study sites, as expected.

Despite differing hydrology and vegetation density gradients captured in the study design, CH_4 fluxes in FEN plots did not differ significantly. This is possibly associated with peat quality and the short time since reclamation which was not sufficient for the CH_4 pool to build up after the peat was placed. Evidence of radial oxygen loss (ROL) from *J. balticus* plots at the FEN and saline REF fen site indicates that rhizosphere CH_4 oxidation could be contributing to low CH_4 flux at these sites. This was supported by a decrease in CH_4 flux with increasing plant productivity (which would contribute to ROL).

An assessment of the UPLAND and its nutrient status is underway, it is theorized that nutrients are washing down from the UPLAND to the FEN, rendering the UPLAND nutrient poor and lowering vegetation survival rates. Plant root simulator (PRS) probes are being incubated throughout the UPLAND to determine early/mid/late growing season nutrient availability. Runoff collectors (x6) were built at key locations in the UPLAND in an attempt to understand where the majority of the nutrients were being washed out of the UPLAND and which areas were most affected by this limited nutrient availability. Infiltration capture devices have been placed throughout the UPLAND, to investigate if nutrients are being lost to deep seepage into the underlying aquifer below the LFH cap. Litterbags are installed in those same plots to pair with PRS mineralisation data, allowing for the determination of locations of nutrient losses or accumulation. Soil water access tubes (1m) are measured several times weekly, with sub-surface temperature logged at 2.5, 5, 10, 20 and 30 cm. Soil moisture and EC readings were also taken at both the access tubes and the incubation plots.

Hydrologic carbon stock and export from the constructed FEN.

Runoff collectors have been installed in the UPLAND (for a controlled area) to determine potential runoff and dissolved organic carbon (DOC) production. Water samples were taken following precipitation events from the piezometer network. Infiltration collectors were installed in the UPLAND adjacent to runoff collectors and in each recharge basin landform, helping partition the watershed contribution. Early results suggest that locations adjacent to constructed hillslopes receive more DOC. This is based on DOC concentrations monitored at the head of the UPLAND and immediately up-gradient to the transition zone. Flumes within the UPLAND which are open to collect water from UPLAND runoff also show significantly higher concentrations than samples taken from flumes collecting from an enclosed area within the UPLAND. Both locations presented higher DOC concentrations along hillslope edges than within the middle of the UPLAND. Two hillslope flumes (west, south-east corner) confirm this, showing comparable DOC concentrations, however the flume on the east hillslope shows distinctly lower DOC concentrations relative to those seen within flumes at its base. More investigation is needed to determine the source of this DOC and the mechanisms which transport the DOC.

Within the FEN, vegetation treatment is the likely control on DOC production from the peat substrate. To identify how much DOC at the FEN was sourced from the UPLAND, we installed 30 cm piezometers at previously established piezometer nests to assess DOC contribution closer to the FEN surface. This also allows for measurement of variance in DOC transport from differing vertical hydraulic gradients. Rain gauge samples were taken following precipitation events for isotopic signature and background DOC. These values are being compared against the REF sites, to gauge the DOC production and export functioning. Water sampling at the FEN was timed to coincide with CH_4/CO_2 sampling to show a more complete picture of the carbon dynamics. DOC porewater sampling was coupled with CH_4 porewater sampling to identify how carbon was being transformed/produced within vegetation plots. DOC

samples have been paired with a spectrofluorescence sample to determine more specifically the molecules present at various positions through the FEN and UPLAND.

Field measurements ascertaining the contribution of *Carex* and *Juncus* to the DOC budget have also shown that more DOC is produced at 20 cm than 70 cm within the constructed fen. This contrasts with what is seen in reference sites, which show greater DOC concentrations at depth than near the surface. While further investigation is needed to determine the processes at work, initial inferences may be made that productivity from establishing vascular vegetation is resulting in high levels of root exudates at the constructed fen. These may be dominating the DOC production as it is not expected that the placed peat (which is highly recalcitrant) will contribute greatly to DOC production.

Evaluating carbon accumulation potential of constructed FEN.

While a carbon source in 2013, in 2014 the FEN was a small net C sink, sequestering a total of 69.39g C m^{-2}, an average of 0.45g C m^{-2} day^{-1} and 1.13g C m^{-2} day^{-1} in 2015 (which is within the range of the REF poor fen daily average). The UPLAND has remained a source of C, emitting 4.57 g C m^{-2} day^{-1} in 2013, decreasing to 2.17 g C m^{-2} day^{-1} in 2014, increasing slightly in 2015 to 2.5 g C m^{-2} day^{-1}. While a source, this trajectory suggests that with increased vegetation growth in the UPLAND, it may move towards a carbon sequestering system.

Over the first two growing seasons, revegetation facilitated both above-ground productivity and the cycling of below-ground nutrients, especially in plots where the transferred moss layer was combined with seedlings. The supply of labile substrates in the re-vegetated plots could have increased microbial potential activity, which was reflected in higher rates of respiration, nutrient acquisition and productivity. The fragmentation of donor-peat during relocation to the constructed fen exacerbated degradation of the peat hydro-physical and chemical characteristics, which was initiated by the accelerated decomposition associated with donor-fen dewatering. Nutrient dynamics within the constructed fen suggest that phosphorus (P) limitation could hamper the establishment of a diverse plant community, (and thus carbon accumulation potential), whereas the build-up of microbial biomass appears to be NO_3- limited. Relative to the REF fen sites, significantly lower fluxes of CH_4 ($p < 0.001$) were measured in the FEN. Low fluxes correlated with higher bulk density, lower organic matter, and higher pH and SO_4^{2-} concentration. Hence, more research is required to ascertain whether the low CH_4 flux is peat substrate or water chemistry-induced. Although revegetation did not stimulate CH_4 production, it increased CO_2 uptake and reducing the global warming potential of N_2O emissions by 63 CO_2-e m^{-2} yr^{-1} relative to the non-vegetated control.

Surface and atmospheric controls on water use efficiency.

Overall daily average water use efficiency (*WUE*) of the UPLAND has been measured using the eddy covariance systems as being 0.08 (g C per kg H_2O) in 2013, -0.26 in 2014, and for the FEN, 0.67 in 2013, 0.38 in 2014. FEN *WUE* exceeded UPLAND *WUE* in both 2013 and 2014. Fen *WUE* decreased in 2014 despite becoming a net sink for CO_2 due to drier conditions and increased transpiration. A modelling simulation is underway using the McGill Wetland Model (MWM) for different substrate configurations to see if industry could construct peatlands in terms of their net hydrological functioning at the surface without significant peat deposits as has been required at the FEN. Given that *WUE* is the metric for success in these, where [*GEP* +*ET* = *WUE*], we are interested in simulating gross ecosystem production (*GEP*) and evapotranspiration (*ET*). While the MWM was developed to simulate the CO_2 exchange between peatlands and the atmosphere. A student is developing a hydrological aspect (*ET*) to the MWM, using Penmen-Monteith in order to derive *WUE*, for the FEN. By simulating the three years (2013-2015) of known evapotranspiration (*ET*) fluxes from the FEN with MWM we are evaluating the strength of long-term models to following the trajectory of ecosystem functioning.

Vascular plant establishment, controls on above and below ground growth and production, photosynthesis and plant level transpiration, clone formation, long-term survival.

Freshwater species *C. aquatilis* has become more prevalent on the FEN site than the initial planted design, with halophytic species, *J. balticus* being pushed out of plots. Given this development amid a background of elevated salinity, a competition experiment is being installed in the presence of varying salinity concentrations to aid in tracking the long-term survival trajectory. An unused NW portion of the FEN (previously flooded before additional reclaimed peat substrate was added), has been planted with *C. aquatilis* and *J. balticus* cuttings in isolated containers. Three EC ranges (2500-3500; 5500-6500 and 8500-9500µS/cm²) of FEN water are being used to gauge long-term survival. 20 cm continuous/non-continuous rhizomes of *C. aquatilis* and *J. balticus* are planted in the pots, and total plant producing nodes recorded differences in node density can be determined. Survival of the pots will be monitored throughout year 5 of the project as an analogue for long-term vascular survival vs measured plots planted at the FEN.

Biomass observations show *C. aquatilis* is dominant, having been introduced with both the donor-moss, and seedling treatments. The donor-moss treatment has introduced considerable diversity. Several *Carex* species, shrubs and forbs, found in natural moderate-rich fens, have established successfully on the constructed site. Biomass and species composition in the control and seed plots were variable, but overall, *Triglochin maritima* and *Triglochin palustris* have grown best from seed, versus *Carex* and *Juncus*. Control plots not dominated by *Typha latifolia*, appear similar to moss-donor plots and seed plots, indicating viable seed dispersal from planted seedlings. It also indicates that seedlings can be planted at lower densities, and still establish across a system, when ponding is not present. Weeding treatment applied in 2013 and 2014, was continued in 2015. *T. latifolia* has monopolized unplanted, ponded areas. Within weeded plots, the success of clipping is dependent on the hydrologic conditions, and the initial planting plan. In seedling plots, and moss-donor plots, *J. balticus* and *Carex* species have prevented *T. latifolia* (cattail) establishment, but in control and seed plots, wet conditions promote the weed's growth, and fen species cannot establish quicker than the clipped *Typha* can re-sprout.

OUTCOMES AND LESSONS LEARNED

Depression features are operating as recharge basins for snow water, as evidenced by isotope flushing signatures. Therefore they are providing a larger contribution to groundwater recharge than first thought. While construction materials have increased in saturated hydraulic conductivity since placement, they are still far below target values. However the construction materials hydraulic conductivities, relative to one another, are different enough such to allow the system to function as designed, despite being well below target K_{sat} values.

Lower peat substrate quality (compared to REF sites) and elevated sulphate content means that methane production potential is below that of REF sites given the OSPW and contaminant feedstock (based on laboratory results). Similarly, *Juncus rhizosphere* CH_4 oxidation is helping keep CH_4 production low.

High prevalence of Ca & Mg ions in placed peat substrate may be inhibiting Na bonding sites, leading to quicker than expected accumulation of Na in the vascular rooting zone.

The older previously reclaimed east slope appears to be contributing lower DOC concentrations despite larger vegetation and leaf litter, likely because the mature vegetation retains slope substrate, slowing substrate erosion and runoff. Root exudate from vegetation is believed to be behind increased DOC in FEN peat below surface.

Two post-doctoral fellows, two PhD, seven M.Sc, four B.Sc students, and nine research assistants have now completed work on the project.

PRESENTATIONS AND PUBLICATIONS

Bocking, E. (2015) *Analyzing the impacts of road construction on the development of a poor fen in northeastern Alberta, Canada*. MSc Thesis. University of Waterloo, Waterloo, ON. May 2015. (Thesis)

Bocking, E., Price, J.S. and Cooper, D.J. (2015) *Analyzing the growth response of black spruce to road construction in a boreal fen using tree-ring analysis*. Canada's Oil Sands Innovation Alliance (COSIA) Water Conference, Calgary, AB, Canada; Jan, 2015. (Poster)

Bocking, E., Price, J.S. and Cooper, D.J. (2015) *Analyzing the impacts of road construction on the hydrology and development of a poor fen*. Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Oral presentation)

Bocking, E., Price, J.S. and Cooper, D.J. (2015) *Road impacts on the vegetation and development of a poor fen in Northeastern Alberta*. Canadian Geophysical Union, Montreal, QC, May 4-7, 2015. (Oral presentation)

Borkenhagen, A. and Cooper D.J. *Vegetation establishment on a reclaimed fen in Alberta's oil sands region.* Society for Ecological Restoration 7th World Conference: Reflections on the Past, Directions for the Future. Manchester, UK; August 23-27, 2015. (Oral presentation)

Borkenhagen, A. and Cooper, D.J. (2015) *Peatland Reclamation in the Oil Sands Region of Alberta*. Botany 2015 - Science and Plants for People. Edmonton, Alberta; July 24-27, 2015. (Oral presentation)

Borkenhagen, A. and Cooper, D.J. *Nikanotee Fen: Vegetation Establishment Update.* Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Oral presentation)

Borkenhagen, A. and Cooper, D.J. *Peatland Reclamation in the Oil Sands Region of Alberta*. Restoration Case Studies Seminar. Colorado State University, Fort Collins, CO; Sept.3, 2015. (Oral presentation)

Borkenhagen, A. and D.J. Cooper. (2015) *Vegetation establishment on a reclaimed fen in Alberta's oil sands region*. Invited presenter. Botany 2015 - Science and Plants for People. Edmonton, Alberta; July 24-27, 2015 (Oral presentation)

Borkenhagen, A. and D.J. Cooper. (2015) *Vegetation establishment on a reclaimed fen in Alberta's oil sands region*. Society for Ecological Restoration 6th World Conference. Manchester, UK. (Oral presentation)

Borkenhagen, A. and D.J. Cooper. (2015) *Creating Fen Initiation Conditions: A New Approach for Reclamation in the Oil Sands Region of Alberta.* Journal of Applied Ecology. DOI: 10.1111/1365-2664.12555

Borkenhagen, A., D.J. Cooper and K. Kaczynski. (2015) *Nikanotee Fen: Vegetation Establishment Update*. Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Oral presentation)

Cooper, D.J. and A. Borkenhagen. (2014) *Establishing peatland vegetation on reclaimed wetlands in the Oil Sands Region of Alberta*. Plenary Talk at NAIT Boreal Research Institute Workshop, Peace River, AB. (Oral presentation)

Cooper, D.J., A. Borkenhagen and K. Kaczynski. (2015) *Nikanotee fen wetland watershed: Ecological Research update*. Invited presenter. 2015 Canada's Oil sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA) workshop. Calgary, AB, Canada. (Oral presentation)

Gabrielli, E. and Petrone, R.M. (2015) *Characterizing Conifer Evapotranspiration in two Natural Boreal Fens, Fort McMurray, Alberta, Canada.* Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015 (Oral presentation)

Gabrielli, E. and Petrone, R.M. (2015) *Quantifying and Characterizing Conifer Evapotranspiration in two Natural Boreal Fens, Fort McMurray, Alberta, Canada.* Canadian Geophysical Union Eastern Students Conference. Wilfrid Laurier University, Waterloo ON, Canada. Feb 7, 2015. (Oral presentation)

Ketcheson, S.J. and Price, J.S. (2015) *Hydrophysical variability of reclamation materials in a constructed fen watershed*. Canadian Geophysical Union Eastern Students Conference. Wilfrid Laurier University, Waterloo ON, Canada. Feb 7, 2015 (Oral presentation)

Ketcheson, S.J. and Price, J.S. (2015) *Spatial and temporal variations in reclamation material properties in a constructed watershed*. Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Oral presentation)

Ketcheson, S.J. and Price, J.S. (2015) *The initial hydrology of the Suncor Constructed (Nikanotee) Fen.* Canada's Oil Sands Innovation Alliance (COSIA) Water Conference, Calgary, AB, Canada; Jan, 2015. (Poster)

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Ketcheson, S.J. and Price, J.S. (2015) Snow hydrology of a constructed watershed in the Athabasca Oil Sands Area, Alberta, Canada. *Hydrological Processes.* Submitted

Ketcheson, S.J., Price, J.S., Carey, S.K., Petrone, R.M., Mendoza, C.A. and Devito, K.J. (2015) Can fen peatlands be successfully constructed in post-mining oil sands landscapes? *Earth-Science Reviews*. Submitted

Ketcheson, S.J., Price, J.S., Sutherland, G. and Petrone, R.M. (2015) *Hydrological functioning of a constructed watershed*. Canadian Geophysical Union, Montreal, QC, May 4-7, 2015 (Oral presentation)

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Khadka, B, Munir, T.M. and Strack, M. (2015) Effect of environmental factors on production and bioavailability of dissolved organic carbon from substrates available in a constructed and reference fens in the Athabasca Oil Sands Development Region. *Ecological Engineering*. 84: 596-606. DOI: 10.1016/j.ecoleng.2015.09.061

Murray, K., and Strack, M. (2015). *Recovery of Alberta peatlands used as a source of vegetation donor material for restoration: greenhouse gas exchange and ecohydrology evaluation*. Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Poster)

Murray, K., Borkenhagen, A., Cooper, D., and Strack, M. (2015*). Greenhouse gas exchange from sites used as a source of vegetation donor material for peatland restoration*. Poster presentation at American Geophysical Union (AGU) Joint Assembly conference. Montreal, QC. (Poster)

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Scarlett, S. and Price, J.S. (2015) *Plot-scale hydrodynamic variability of a constructed fen in a post-mined oil sands landscape, Fort McMurray, Alberta*. Peatland Ecology Research Group 21st Symposium. Waterloo, Ontario, Feb, 2015. (Oral presentation)

Scarlett, S. and Price, J.S. (2015) *Plot-scale hydrodynamic variability of a constructed fen in a post-mined oil sands landscape, Fort McMurray, Alberta.* Canadian Geophysical Union Eastern Students Conference. Wilfrid Laurier University, Waterloo ON, Canada. February 7, 2015. (Oral Presentation)

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Simhayov, R., Price J.S. (2015). *Assessment the pools and potential redistribution of sodium in a constructed fen peatland system*. Canadian Geophysical Union, Montreal, QC, May 7, 2015 (Poster)

Volik, O., Petrone, R.M. (2015). *Evolution of a saline fen near Fort McMurray, Alberta: applications from paleoecology to wetland reclamation*. Canadian Geophysical Union Eastern Students Conference. Wilfrid Laurier University, Waterloo ON, Canada. February 7, 2015. (Poster)

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RESEARCH TEAM AND COLLABORATORS

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Principal Investigators: Dr. Jonathan S. Price[1], Dr. Maria Strack[1], Dr. Richard Petrone[1], Dr. David Cooper[2]

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FORWARD III: Modelling to Contribute to Cumulative Effects Management in the Canadian Boreal Forest

COSIA Project Number: LI0009

Research Provider: Lakehead University

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Syncrude Canada Ltd., Total E&P Canada Ltd., Alberta-Pacific Forest Industries, Alberta Newsprint Company, Hinton Pulp, Millar Western Forest Products Ltd., Slave Lake Pulp

Status: Year 4 of 5

PROJECT SUMMARY

The Forest Watershed and Riparian Disturbance Project (FORWARD) is a consortium of university, government, and industry partners with the overarching goal of better understanding how natural and anthropogenic disturbances influence the dynamics of forest watersheds. It will ultimately lead to the development of soil and watershed assessment tools and appropriate bioindicators that will support reclamation efforts within energy and mining sectors. It will also assist in shaping evolving regulatory approaches to reclamation and water management and support components of progressive reclamation.

The objectives of FORWARD III are organized in a framework consisting of four components:

Component 1. Watershed load and contaminant fate modelling will distil the current knowledge base of process-specific data into a watershed modelling framework. The models developed in this component will allow industry and regulators to manipulate the landform designs of proposed mine closure plans [redacted] While this has been presented with varying degrees of success in every environmental impact assessment, recent public critiques have clearly indicated a lack of validation and trust in these approaches that must be addressed using transparent and regulator supported models.

Component 2. Benchmarks for reclaimed and engineered soils will characterize physical, biogeochemical and microbial features of oil sands sites and their changes through time and compare these states and changes to those in reference, burned and forest/ reforested soils.

Component 3. Acceptable vegetation complexes: impacts and recovery after disturbance will compare vegetation recovery trajectories after oil sands activity to trajectories after reforestation treatments for wildfire and harvest activities, as a means to predict mid- to late stage vegetation recovery trajectories for oil sands sites.

Component 4. Risk of toxicity to bio-indicators from anthropogenic load and impacts of organic and inorganic contaminants associated with oil sands extraction will characterize acute and chronic toxicity to amphibians, macroinvertebrates and fish.

PROGRESS AND ACHIEVEMENTS

In this fourth year of the Project considerable progress has been made toward fully calibrating and validating the Environmental Fluid Dynamics Code (EFDC) model. Progress has also been made on further developing the Soil

Water Assessment Tool for Boreal Forests (SWATBF) to incorporate it with the 3-PG forest growth model. As well, two student programs in the toxicology component were completed, and results from many of our student studies were presented at national and international conferences and/or published in peer-reviewed journals.

Component 1: Development of watershed load and contaminant fate models

- Calibration and validation of the hydrodynamics and water quality of the numerical EFDC model, selected to simulate the performance of hydrodynamic, water quality and sediment transport for the lower Athabasca River (LAR), is complete. The final step of sediment calibration is underway. Once the sediment calibration is complete and validation tests are done the modified EFDC-LAR will become openly available. We anticipate early 2016 for completion.
- The numerical surface water model $SWAT_{BF}$ is currently being modified to better represent boreal forest growth and hydrological processes to simulate water export from boreal forest watersheds during recovery. This is being done by incorporating $SWAT_{BF}$ with the 3-PG model (adapted for boreal forest conditions). In addition, we are working on the validation of the $SWAT_{BF}$ using historic data of one of our industry partners to ensure suitability for the oil sands industry. This work and the model integration is expected to be completed in 2016.
- PhD Parratt began a study to determine if black spruce in peat bogs are biologically active in the winter and to investigate their impact on snowpack thawing. Data collected during the winter of 2014/15 and 2015/16 will be used to develop solar radiation and infiltration algorithms for Boreal forest black spruce bogs and fens that better represents the effect of trees on the hydrological cycle. The developed algorithms could be used in combination with $SWAT_{BF}$ or other hydrological models to strengthen their ability to balance the water budget.
- Extensive data collection has taken place on two reclaimed watersheds in the Fort McMurray oils sands region and seven reference sites near Whitecourt, AB. In 2015 over 200 samples (snow and water combined) were received and analyzed for various water quality parameters. Water flow gauging and staff gauging was conducted at biweekly intervals by field staff, and water level and temperature readings were taken by automated loggers. Piezometers, which were installed last year at a reclaimed overburden site, were monitored to allow for the assessment of water quality and quantity within the coversoil and subsoil layers. Meteorological data were also collected from four stations (1 oil sands site, 3 reference sites). Data collection will continue in 2016 to provide a multi-year dataset for use in validation of the $SWAT_{BF}$ model.
- Additional piezometers were installed at the same oil sands site (as above) in June and July 2015, along with 10 new soil probes.

Component 2: Benchmarks for reclaimed and engineered soils.

This component is twofold in order to give a complete assessment of the physical, biogeochemical and microbial elements of soils. In 2015, MSc students Novak and Blain completed the laboratory analysis of samples collected as part of their studies and will conclude their programs in early 2016. As well, MSc Pum, visiting from Vienna for a six month period, concluded her laboratory-based study. Other student projects (PhD Mitter, PhD Bendszak, MSc Templeton) are ongoing. Postdoctoral Fellow S. Chhabra also contributed his expertise to this research component.

- MSc Novak measured and compared the soil physical, chemical and moisture properties from three reclaimed oil sands sites and two natural sites (undisturbed and fire-burned). During this reporting period he completed his laboratory analysis on moisture retention curves, which consisted of subjecting intact soil cores to escalating atmospheric pressure to simulate matric (drying) gradients. This analysis combined with particle size analysis, soil nutrients and soils chemistry analyses concludes his study. His results are being used by one of our industry partners in model validation and will be available to the public in 2016.

- MSc Blain surveyed diversity of endophytic bacteria associated with the natural vegetation growing at the Bitumount Provincial Historic Site. A total of 6 different plant species were identified and sampled based on their abundance at each sampling location. Soil samples were analyzed for hydrocarbon content and culture dependent and independent methods were used to characterize bacterial root endophytes. Analyses revealed diverse communities associated with different plant types. Endophytic profiles differed between plant species and locations suggesting that there are several factors that may be influencing the diversity of endophytic communities. The function of these endophytes is currently under investigation.
- MSc Pum examined potential methane (CH_4) production and oxidation in reclamation covers to find out whether oil sands mining activities create greenhouse gases and if so, which soil cover has the highest CH_4 oxidation potential. She conducted laboratory experiments using soil samples collected from different substrates and fertilization regimes. Her work was presented at an international conference in April 2015.
- Ongoing student projects: PhD Mitter is investigating the diversity of bacterial endophytes associated with plants growing on reclaimed landscapes along different slope positions and under different covers (e.g., engineered, standard) and the potential use of endophytes to degrade hydrocarbons and assist plant growth in reclamation areas. Postdoctoral Fellow Chhabra is in the final phase of his examination of microbial community dynamics and nitrogen cycling in fertilized and unfertilized management areas. MSc Templeton began a laboratory-based investigation into seed tolerance to metal and salt to assess the viability of native plant species in reclaimed soils. PhD Bendszak began a field-based study at oil sands sites to determine available nutrients and pH in soils; the decomposition rate and nutrient release in the litter layer; and tree ring growth and nutrient concentration in tree and herbaceous vegetation.

Component 3: Determination of vegetation complexes

Data collected in previous years is being disseminated by recently recruited Postdoctoral Fellow Shekhar Biswas. Data are also being used in $SWAT_{BF}$ model verification.

Component 4: Characterization of toxicity to macroinvertebrates, fish and amphibians

- Two students, PhD Gauthier and MSc Beery, completed their programs this reporting period and a third, PhD Klemish, is in the final stages of her program and expected to complete in April 2016. Two other student projects (PhD Lari and MSc Chow) are underway.
- PhD Gauthier's laboratory based experiments using the freshwater amphipod *Hyalella azteca* gave insight into the toxicological effects of metal-polycyclic aromatic hydrocarbon (PAH) mixtures on the mortality and behavior, and cellular/molecular activity of this organism. This study will assist in assessing the ecological risk and underlying interactive co-toxic mechanisms of metal-PAH mixtures in aquatic environments and organisms.
- MSc Beery's 14-day reciprocal cross-transplant study also used *Hyalella azteca*. Data collected were analyzed to determine whether *H. azteca* from habitats with naturally occurring bitumen showed increased tolerance to contaminants associated with industrial bitumen extraction compared to those from habitats with no naturally occurring bitumen; and whether any observed tolerance was attributable to local adaptation.
- PhD Klemish conducted a laboratory-based experiment this reporting period to augment her 2013 and 2014 field studies. Mesh exclusions were used to control access of tadpoles (Wood Frogs (*Lithobates sylvaticus*) and Boreal Chorus Frogs (*Pseudacris maculata*) to sediment and compare the toxicity of water and sediment (collected from the same field sites used in the previous two years) to determine if any effects observed were due to direct or indirect sediment exposure. Her program will conclude in 2016.
- PhD Lari has done extensive laboratory-based experiments on the effects of oil sands process-affected water (OSPW) on the feeding, growth and reproduction of *Daphnia magna*. This phase of his program will conclude

this year and he will move into the next phase of his program, in which he will conduct laboratory experiments to establish metal tolerance of fish.
- MSc Chow completed a field-based study to assess the presence and adaptive changes in fish in different parts of the lower Athabasca River basin; identify and distinguish ecological impacts of exposure to natural and industrial sources of bituminous toxicants; and determine risk to aquatic ecology resulting from oil sands operations in comparison to erosion of natural bitumen deposits. Her program will conclude in 2016.

OUTCOMES AND LESSONS LEARNED

Work on the EFDC model led by Dr. Preston McEachern has shown that:

- Previous modelling efforts by Alberta Environment and others were not able to accurately predict flow in the Athabasca River because they did not account for ungauged contributions. Errors were largely restricted to base flow and falling limb sections of the annual hydrography. A new model was created that used flow data to estimate contributions from smaller tributaries and groundwater. The new EFDC model can now accurately predict flows in the Athabasca River.
- With the improved flow prediction, aquatic chemistry predictions for conservative ions and dissolved oxygen are accurate for the limited locations and times where validation data are available.
- Sediment transport dynamics in the Lower Athabasca River (LAR) are very different from other rivers that have been used to represent sediment erosion and deposition default values. In the LAR, many of these controlling factors such as surface erosion rate and settling velocity for cohesive sediments had to be increased by two orders of magnitude. This was found in other studies and is supported in the literature for sand bed rivers like the LAR.
- There is a distinct shortage of data for important compounds of concern. These include polycyclic aromatic hydrocarbons (PAHs) and metals. The model can predict metal concentration data in the sediment and water column but more work is required to both calibrate and validate this essential component of the model. The continued lack of data despite increased funding for monitoring in the LAR must be addressed.

The application of the $SWAT_{BF}$ model to regional watersheds and one reconstructed watershed led by Drs. Brett Watson and Gordon Putz and published in Oil Sands Research Information Network (OSRIN) technical report http://hdl.handle.net/10402/era.34250 concluded that:

- The overall performance of $SWAT_{BF}$ for predicting runoff from the five regional watersheds studied was deemed to be satisfactory.
- Few reconstructed watersheds have long-term data sets that would be considered adequate for stringently testing the performance of hydrological models.
- The collection of high quality long-term meteorological and hydrological data from reconstructed watersheds is important to better understand and support scientific and engineering studies.
- The results of this study warrant that further research be conducted to further test and develop the model.

Based on molecular analysis of functional genes from plant and soil samples collected from natural and constructed reclaimed sites, the soil microbiology group, led by Dr. Jim Germida, now knows that:

- A higher level of alkane degrading gene copy numbers were identified and may be associated with higher abundances of *Pantoea*, *Pedobacter*, *Pseudomonas*, *Stenotrophomonas* and *Sphingomonas* populations within endophytic profiles.
- 16s-RNA, alkB, CYP153 varied by different community profiles; however, all genes analyzed including NAH (Napthene Degradative) genes also varied by slope positions (i.e. communities thus varied by slope).

- Only 5% of 316 endophytic bacterial isolates assessed for hydrocarbon degrading genes tested positive for the presence of alkB genes.

The results of the laboratory-based investigation of CH_4 production and oxidation showed:

- CH_4 production and CH_4 oxidation occurred in reclaimed soil covers
- Differences in CH_4 production and oxidation occurred at different soil depths with the highest activity occurring in the upper layers (0-10 cm).

The results of the study of microbial community dynamics and nitrogen (N) cycling in fertilized and unfertilized management areas of oil sands reclamation soils shows:

- An associated link between ammonia oxidizing activity and diversity of ammonia oxidizing bacteria (AOB) and ammonia oxidizing archaea (AOA) present in soils.
- Forest floor mineral soil had higher activity, abundance and diversity than peat soils.
- Fertilization management supports higher activity and abundance and diversity in these soils.

Results from the study of physical, chemical and moisture properties of soils, led by Dr. Ken Van Rees show that:

- Soil physical and chemical properties (bulk density, soil strength, pH, salinity, texture) measured at the reclaimed sites show no significant barriers to vegetation growth.
- Soil infiltration rates and bulk densities appears to suggest that peat-mineral mixes used in reclamation can efficiently mimic soil structure development in the short-term.
- Soil moisture retention curves were developed to investigate soil-water relationships. Five soil hydraulic models were fitted using these data to confirm trends and allow insertion into more complex soil modelling tools.
- All reclaimed and natural reference soils exhibited bimodal moisture retention properties, while the fire-burned soil showed unimodal trends.
- Site-specific hydraulic properties are costly and time consuming to measure; as such many soil hydraulic tools use literature values. Results of soil infiltration models using either literature or lab-derived hydraulic variables were compared. Despite the unique hydraulic properties of peat-mineral mixes, no significant differences were found between models. These results suggest that literature hydraulic values can be dependably utilized in place of measured values within certain contexts.

As published in peer-reviewed journals Aquatic Toxicology, Environmental Science & Technology and Chemosphere the toxicology group led by Dr. Gregory Pyle have learned that:

- Metals and PAH mixtures examined in this study, which occur ubiquitously in aquatic environments, produced higher mortality in the aquatic amphipod *Hyallela azteca* compared to the effect of each element on its own. More-than-additive lethality was observed for all Copper (Cu) –phenanthrene (PHE), Cu-phenanthrenequinone (PHQ) and several Cadmium (Cd) –PHE, Cd-PHQ and Nickel-PHE mixtures. Canadian Water Quality Guidelines currently do not consider the effect of mixture toxicity (Gauthier et al., 2015a).
- Mixtures of PHE and Cu, two contaminants commonly co-occurring in marine and freshwater environments, induce more-than-additive lethality in the amphipod *Hyalella azteca*. Understanding the interactive toxic mechanisms that mediate more-than-additive toxicity will allow for better predictive power in assessing the ecological risks of Cu-PHE mixtures in aquatic environments. There was no evidence that interactive aspects of oxidative stress were responsible for more-than-additive mortality in *H. azteca* exposed to metal-PAH mixtures. There was evidence that increased Cu accumulation may contribute to more-than-additive lethality in *H. azteca* exposed to Cu-PHQ mixtures (Gauthier et al., 2015b).
- PHE acts as a potent neurotoxicant in *H. azteca* with a similar mechanism of action as Malathion. The PHE-induced neurotoxic effects amounted to severe behavioural impairment and co-exposure to Cu attenuated

several of the pesticide-like effects of PHE (e.g., increased respiration and hyperstimulation). (Gauthier et al., In press).

- Results of behavioural assays of *Daphnia magna* exposed to sub-lethal concentrations of OSPW (1%) showed that OSPW significantly inhibits feeding behaviour, suppresses growth, and reduces reproductive output of *D. magna*. *D. magna* are an important zooplankton in freshwater environments and changes in their population may result in shifts in the food web structure (Lari et al., In press).

The amphibian study led by Collaborator Dr. Michael Lannoo has shown that:

- Wood Frog and Boreal Chorus Frog tadpole survival was high when exposed to water in reclaimed wetlands.
- Wood Frog survival was lower when exposed to sediment than water from reclaimed wetlands.

PRESENTATIONS AND PUBLICATIONS

Publications in peer-reviewed journals:

Gauthier, P.T., W.P. Norwood, E.E. Prepas and G.G. Pyle. In Press. Behavioural alterations from exposure to Cu, phenanthrene, and Cu-phenanthrene mixtures: linking behavior to acute toxic mechanisms in the aquatic amphipod, *Hyalella azteca. Aquatic Toxicology (Special edition on behavioural aquatic toxicology)*.http://dx.doi.org/10.1016/j.aquatox.2015.10.019:

Lari, E., S. Wiseman, E. Mohaddes, G. Morandi, H. Alharbi and G. Pyle. In Press. Determining the effect of oil sands process-affected water on grazing behavior of *Daphnia magna*, long-term consequences, and mechanism. *Chemosphere*.

Gauthier, P.T., W.P. Norwood, E.E. Prepas and G.G. Pyle. 2015a. Metal-polycyclic hydrocarbon mixture toxicity in *Hyalella azteca*. I. Using response surfaces and isoboles to measure non-additive mixture toxicity and ecological risk. *Environmental Science & Technology*. 49: 11772-11779 doi: 10.1021/acs.est.5b03231.

Gauthier, P.T., W.P. Norwood, E.E. Prepas and G.G. Pyle. 2015b. Metal-polycyclic aromatic hydrocarbon mixture toxicity in *Hyalella azteca*. II. Exploring metal accumulation and oxidative stress as interactive co-toxic mechanisms. *Environmental Science & Technology*. 49: 11780-11788 doi: 10.1021/acs.est.5b03233.

MacDonald, R.L., H.Y.H. Chen, S.F. Bartels, B.J. Palik, E.E. Prepas. 2015. Compositional stability of boreal understory vegetation after overstory harvesting across a riparian ecotone. *Journal of Vegetation Science.* Doi: 10.1111/jvs.12272.

Conference presentations (presenter bolded):

S.S. Chow and G.G. Pyle. Poster. Effect on olfactory and behavioural antipredator responses in fish exposed to natural and anthropogenic sources of oil sands related toxicants within the lower Athabasca River. SETAC North America 35th Annual Meeting, Salt Lake City, Utah, 1 - 5 Nov 2015.

J.L. Klemish, S.J. Bogart and G.G. Pyle. Oral. Effects of oil sands reclaimed wetlands on native amphibians. SETAC North America 35th Annual Meeting, Salt Lake City, Utah, 1 - 5 Nov 2015.

E. Lari, E. Mohaddes and G. Pyle. Poster. Determining the effect of oil sands process-affected water on grazing behaviour of *Daphnia magna*. SETAC North America 35th Annual Meeting, Salt Lake City, Utah, 1 - 5 Nov 2015

S.S. Chow and G.G. Pyle. Oral. Local adaptation of Finescale Dace (*Phoxinus neogaeus*) olfaction, behaviour, and swim physiology post-exposure to natural and anthropogenic sources of bituminous toxicants. 42nd Canadian Ecotoxicity Workshop, Saskatoon, SK, 4-7 Oct 2015.

J.L. Klemish, S.J. Bogart, G.G. Pyle and M.J. Lannoo. Oral. Response of native amphibians to reclaimed wetlands in the Athabasca Oil Sands. 42nd Canadian Ecotoxicity Workshop, Saskatoon, SK, 4 -7 October 2015.

E. Lari, E. Mohaddes and G.G. Pyle. Oral. The role of suspended particulate matter on the toxicity of oil sands process-affected water on feeding behaviour of *Daphnia magna*. 42nd Canadian Ecotoxicity Workshop, Saskatoon, SK, 4 - 7 October 2015.

Blain, N.P., B.L. Helgason and J.J. Germida. Poster. A survey of bacterial root endophytes associated with vegetation at a bitumen impacted site. Rhizosphere4 "Stretching the interface of life" Maastricht, the Netherlands, 21 - 25 June 2015.

Mitter, E.K., R. deFreitas and J.J. Germida. Oral. Bacterial root endophytes of plants growing on oil sands reclamation covers in Alberta, Canada. Rhizosphere4 "Stretching the interface of life" Maastricht, the Netherlands, 21 - 25 June 2015.

Blain, N.P., B.L. Helgason and J.J. Germida. Invited Oral. A survey of bacterial root endophytes associated with vegetation at the Bitumount Provincial Historic Site. Canadian Society of Microbiologists, Regina, SK, 15 - 18 June 2015.

Blain, N.P., B.L. Helgason and J.J. Germida. Poster. A survey of bacterial root endophytes associated with vegetation at the Bitumount Provincial Historic Site in Alberta Canada. Canadian Society of Microbiologists, Regina, SK, 15 - 18 June 2015.

Chhabra, S. and J.J. Germida. Poster. Abundance and diversity of ammonia-oxidizing bacteria and achaebacteria and their ammonia oxidation potential in land reclamation covers. Canadian Society of Microbiologists, Regina, SK. 15 - 18 Jun 2015.

Mitter, E.K., R. deFreitas and J.J. Germida. Poster. Bacterial endophyte communities associated with plants growing on Alberta's oil sands reclamation covers. Canadian Society of Microbiologists, Regina, SK, 15 - 18 June 2015.

Chow, S. and G. Pyle. Poster. Effects of fish populations exposed to bituminous toxicants. Canadian Society of Zoologists Annual Meeting, Calgary, AB, 25 - 29 May 2015.

Gauthier, P., W. Norwood, E. Prepas and G. Pyle. Oral. Behavioural alterations following exposure to copper, phenanthrene, and copper-phenanthrene mixtures: linking behavior to acute toxic mechanisms in *Hyalella azteca*. Canadian Society of Zoologist Annual Meeting, Calgary, AB, 25 - 29 May 2015.

Gauthier, P., W. Norwood, E. Prepas and G. Pyle. Poster. Behavioural alterations following exposure to copper, phenanthrene, and copper-phenanthrene mixtures: linking behavior to acute toxic mechanisms in *Hyalella azteca.* SETAC Europe 25th Annual Meeting, Barcelona, Spain, 3 -7 May 2015.

Lari, E., E. Mohaddes and G. Pyle. Poster. Effect of oil sands process-affected water on *Daphnia magna* feeding, growth, and reproduction. SETAC Europe 25th Annual Meeting, Barcelona, Spain, 3 -7 May 2015.

Pum, L., T. Reichenauer and J. Germida. Oral. Potential methane production and oxidation in soil reclamation covers of an oil sands mining site in Alberta, Canada. European Geosciences Union General Assembly, Vienna, Austria, 12 - 17 Apr 2015.

Chen, H., J. Germida, **P. McEachern**, E. Prepas, G. Putz, G. Pyle, D.W. Smith and K. Van Rees. Oral. Watershed research and modelling to contribute to cumulative effects management in the Canadian Boreal Forest (FORWARD III). COSIA Innovation Summit, Banff, AB, 31 Mar - 2 Apr 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Lakehead University

Principal Investigator: Dr. Ellie E. Prepas

Co-investigators: Dr. Han Chen, Lakehead University; Dr. Jim Germida, University of Saskatchewan; Dr. Preston McEachern, Lakehead University/University of Alberta; Dr. Gordon Putz, University of Saskatchewan; Dr. Greg Pyle, University of Lethbridge; Dr. Daniel W. Smith, University of Alberta; Dr. Ken Van Rees, University of Saskatchewan.

Collaborators: Dr. Renato deFreitas, University of Saskatchewan; Dr. John Headley, Environment Canada; Dr. Bobbi Helgason, University of Saskatchewan; Dr. Michael Lannoo, Indiana University School of Medicine; Mr. Jonathan Russell, R.P.F.; Dr. Brett Watson, Saskatchewan Polytechnic/University of Saskatchewan.

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Virginia Antoniak	Lakehead University	Project Administrator	N/A	N/A
Samuel Bartels	Lakehead University	Postdoctoral Fellow	Sep 2015	COMPLETED 2015
Michael Bendzsak	University of Saskatchewan	Doctoral	May 2014	May 2017
Steven Beery	Lakehead University	Masters	May 2012	COMPLETED 2015
Shekhar Biswas	Lakehead University	Postdoctoral Fellow	Sep 2015	Jun 2016
Natalie Blain	University of Saskatchewan	Masters	May 2013	Aug 2016
Sarah Bogart	University of Lethbridge	Research Technician	N/A	N/A
Sylvia Chow	University of Lethbridge	Masters	May 2014	May 2016
Xue (Emily) Chen	University of Alberta	Research Associate	N/A	N/A
Sagar Chhabra	University of Saskatchewan	Postdoctoral Fellow	Jun 2013	COMPLETED 2015
Yin Chu	University of Saskatchewan	Visiting Scholar	N/A	N/A
Patrick Gauthier	Lakehead University	Doctoral	Jan 2012	COMPLETED 2015
Jaimie Klemish	Indiana State University	Doctoral	May 2012	May 2016
Tanai Gregson	Lakehead University	Field Technician	N/A	N/A
Ebrahim Lari	University of Lethbridge	Doctoral	Feb 2014	Sep 2017
Rebecca MacDonald	Lakehead University	Postdoctoral Fellow	Apr 2013	COMPLETED 2013
Nancy Martin	University of Alberta	Doctoral	Jan 2012	COMPLETED 2013
Eduardo Mitter	University of Saskatchewan	Doctoral	May 2012	May 2016
Kristopher Novak	University of Saskatchewan	Masters	May 2012	Jan 2016
Kristopher Novak	Lakehead University	Project Coordinator	N/A	N/A
Toomas Parratt	University of Saskatchewan	Doctoral	Sep 2012	Sep 2016
Lisa Pum	University of Saskatchewan	Masters	Jun 2014	Dec 2014
Timothy Sobey	Lakehead University	Masters	Sep 2012	COMPLETED 2014
Bethany Templeton	University of Saskatchewan	Masters	Sep 2014	Sep 2016
Maarit Wolfe	Lakehead University	Laboratory Manager	N/A	N/A

Long-Term Watershed Response to Climate: Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms

COSIA Project Number: LJ0210

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

The overarching goal of the research is to develop methods of characterizing, monitoring, and simulating water movement through reconstructed oil sands landscapes. The development of the investigative and interpretative tools are focused on the evolving hydrogeology of two of the largest oil sands landscapes: overburden shale and tailings sands. Two relatively large (100–1,000 ha) closure landscapes – South West 30 Dump (SWD, overburden shale) and South West Sand Storage (SWSS, tailings sand) – are the primary study sites supplemented by two smaller landforms comprised of the same materials but with less complexity (W2, a shale overburden dump, and Sandhill Fen Tailings Sand Hummocks, TSH).

The overall objectives are as follows:

1) Develop conceptual and numerical models of reconstructed oil sands landforms (shale overburden and sand tailings) as Hydrologic Landscape Units HLUs.
2) Define the magnitude and spatial variability of current rates of recharge into shale overburden and tailings sand landforms.
3) Develop a set of new monitoring tools to track the hydrological evolution of oil sands mine closure landforms over the next 100 years.
4) Develop a model of the transient hydrogeology of large-scale shale overburden and tailings sand landforms.

PROGRESS AND ACHIEVEMENTS

The major activities over the past year are summarized by individual research projects, generally linked to a particular graduate student or research staff member.

Fatemeh Madaeni (PhD – discontinued)
Integrated modelling of surface water and groundwater flow and contaminant transport within the Southwest Sand Storage facility
A Hydrogeosphere (HGS) model along two transects of Syncrude's South West Sand Storage (SWSS) has been developed. This model incorporates the evolution of the dyke structure since construction of the SWSS began in 1991. Modelling was undertaken to evaluate if modelling of the evolution of the dump over time (dump chronology) was required to represent the water flow and contaminant transport processes currently observed in the dyke. It was shown that although the incorporation of dump chronology is not required to understand the water migration through the dump it is required to accurately represent the evolution of the pore-fluid chemistry and mass release from the dump over time.

James Tipman (MSc)

Calibration and use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms

It has been shown that purpose installed, high sensitivity, vibrating wire piezometers in aquitards or confined aquifers can be calibrated to detect small surface loads (e.g. soil moisture loading) by using barometric pressure cycles. In this past year, 7 purpose installed piezometers, 4 existing geotechnical piezometers, and 3 barometric pressure transducers have been monitored at high frequency (15-30 minutes). The loading efficiency of the formations have been measured and used to develop an initial evaluation of the potential to measure soil moisture loading. At Syncrude's South West Sand Storage (SWSS) the geolysimeters will be compared to soil moisture loading obtained from conventional monitoring (O'Kane soil cover monitoring and rain gauge) as well as a specially installed Eddy Co-variance system. The results to date show that the geolysimeters provide good estimates of large rainfall events (>5mm) but that further refinement will be required to detect smaller soil moisture loads.

Saidur Chowdhury and Willemijn Appels (PDF)

Characterizing the oxidation and salt generation within reclaimed shale overburden

The rate of salt flushing from saline-sodic overburden dumps will need to be characterized in order to evaluate the potential impact on surface and groundwater quality post-closure. In this project, a previous study on the oxidation of the Cretaceous shale at the South Bison Hill dump at Syncrude's Mildred Lake mine site is being re-interpreted to characterize the distribution of salts within this deposit and the generation of salts associated with ongoing oxidation processes. The work is also characterizing the distribution and source of gases within the dump, particularly oxygen and carbon dioxide associated with pyrite oxidation and methane release from the shale.

Matthew Buchynski (MSc)

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils

The project involves a column test in which an isotopically enriched water is infiltrated into a column of unsaturated sand and is then allowed to redistribute as a result of diffusion of the isotopes through both the liquid and vapour phases of the column. Repeated sampling of the profile following infiltration is used to measure the movement of the isotope over time. A numerical model of water migration and isotope redistribution has been developed and is being used to interpret the data. Two column tests have been complete with final data analyses and thesis writing underway.

Shahabul Alam (PhD)

Spatial and Temporal Variability in Net Percolation into Reclaimed Oilsands Mine Waste

Shahab is in the first year of his program but has experience with downscaling global climate models for evaluating the potential impact of climate change on hydrology. His PhD will eventually deal with spatial variability in reclamation water balances and net percolation; however, in the first year of his study he has advanced a study on evaluating the potential impact of climate change on reclamation cover water balance for the oil sands region. This work is nearing completion and will be prepared in paper form over the next few months.

Spencer Chuhaniuk (Research Engineer/MSc)

A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste

His primary activity has been to redesign and test the CTP/TDR unit previously developed by Amos (2015) for application to full scale field testing. The new CPT/TDR has also been combined with vapour sampling to measure stable isotopic composition of pore water using real-time vapour sampling. Field trials of this newly developed tool was undertaken at 2 field sites, one outside of Saskatoon, and one at Syncrude's Southwest Sand Storage (SWSS) facility. Following further refinement of the method over the winter a full scale field trial is planned for SWSS in the summer of 2016.

Dyan Pratt and Stephanie Villeneuve (Research Engineer and Research Scientist)

Vapour measurement of the isotopic composition of pore water in deep, unsaturated zones

The previous work undertaken by MSc student Thomas Baer (Baer 2014, Baer et al. 2016) demonstrated the value of characterizing the isotopic composition of all site wide waters including precipitation (snow, rain and snow melt), oil sands process water, fresh water inputs from the Athabasca River, and overburden pore-water. Thomas' work has been synthesized into a journal publication (Baer et al. 2016). A regular program of sampling of the stable isotope composition of mine site waters has continued at Syncrude's Mildred Lake mine site and has been expanded to the Aurora mine site. In addition, a protocol for field sampling of soil vapour to characterize the stable isotope of water composition of pore water has been developed and tested at the two sites noted above. In addition, existing gas monitoring sites at SWSS and at Teck Coal's operation in the Elk Valley, BC have been undertaken and this work has been summarized by Pratt et al. (2015, 2016). New protocols for the measurement of stable isotope of water signatures from in situ vapour samples, and soil samples (including the effects of drying) are being developed (Hendry et al. 2015; Lu 2014; Pratt et al. 2015, 2016).

Mingin Huang (Research Scientist)

Transport of stable isotopes of water and sulphate within reclaimed oil sands saline-sodic mine overburden

The utility of using high resolution profiles of the stable isotopes of water to characterize net percolation rates was demonstrated by an MSc Student (Hilderman 2011). In this past year we used a coupled soil-vegetation-atmosphere-transfer (SVAT) model (Huang et al. 2015a) with isotope transport to demonstrate the utility of these detailed stable isotope profiles to characterize net percolation. This work was published as Huang et al. (2015b). Mingbin also published a valuable paper on the use of air permeability to characterize the hydraulic conductivity of mine waste and reclamation soils (Huang et al. 2016).

OUTCOMES AND LESSONS LEARNED

- Integrated modelling of surface water and groundwater flow and contaminant transport within the Southwest Sand Storage facility
  - Modelling of the dump chronology of a large sand tailings dyke is required to represent the evolution of pore chemistry over time.
- Calibration and use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms
  - Preliminary results highlight that soil moisture loading (e.g. rainfall) can be measured accurately using the geolysimeters
- Characterizing the oxidation and salt generation within reclaimed shale overburden
- Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils
  - Rates of dual phase transport of the stable isotopes of water in unsaturated sand as a result of advection and diffusion processes characterized.
- Spatial and Temporal Variability in Net Percolation into Reclaimed Oilsands Mine Waste
- A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste
  - The CPT/TDR probe provides direct measurements of the stored water volume in sand tailings to depths of 7-10 m.
- Mapping of Site-wide Water using Stable Isotopes of Water
  - The local meteoric water line (LMWL) developed by Baer (MSc) has now been strengthened and the mechanisms controlling the isotopic composition and evolution of oil sands process water has been identified (Baer et al 2016)
- Transport of stable isotopes of water and sulphate within reclaimed oil sands saline-sodic mine overburden

- SVAT models incorporating stable isotope of water transport can be used to interpret high resolution profiles of the stable isotopes of water to obtain estimates of net percolation.

PRESENTATIONS AND PUBLICATIONS

Published Thesis:

Amos, Michael, M.Sc., 2015. "Development of a TDR In-Situ Probe & Gas Sampler Compatible w CPTu", (jointly with Bing Si), January.

Baer, Thomas, M.Sc., 2014. "Isotopic Tracking of Water Migration through Oil Sands Mine", April 17.

Lu M. Development of Methodology for In-situ Vapour Sampling for Stable Isotopes of Water [M.Eng.]. Saskatoon, SK: University of Saskatchewan; 2014.

Conference Presentations:

Appels, WM, Ireson, AMI, McDonnell, J., Barbour, SL. (2015). "Evolution of hydrological pathways in engineered hillslopes due to soil and vegetation development", HS 2.3.1, Abstract EGU2015-9528 (http://meetingorganizer.copernicus.org/EGU2015/EGU2015-9528.pdf), Poster in: 'Understanding catchment and hillslope responses: from changing states and non-linearities to emergent behaviours', EGU General Assembly 2015, Vienna, Austria, April 12-17.

Appels, WM, Ireson, AMI, McDonnell, J., Barbour, SL. (2015). "Soil and vegetation development affect the evolution of hydrological pathways in engineered hillslopes", H13A-01 - Abstract 35736 in: http://www.gac.ca/wp/wp-content/uploads/2011/09/2015_Joint_Assembly_Abstract_Proceedings.pdf, Joint Assembly (AGU-GAC-MAC-CGU), Montreal Cda, May 3-7.

Buchynski, M., Barbour, S.L., Hendry, M.J. (2015). "Characterizing the transport of the stable isotopes of Water in unsaturated mining waste". In: 'Mining Waste Management and Environmental Geotechnology: Mine Waste Disposal', GeoQuebec 2015, 68th Canadian Geotechnical Conference, Quebec City, Sept. 20-23.

Pratt, D.L., Lu, M., Barbour, S.L., Hendry, M.J. (2015). "Development of in-situ vapour sampling for stable isotopes of water within unsaturated mine waste". Poster 098p, Internat. Symp. On Isotope Hydrology (IAEA), Vienna, Austria, May 13.

Journal Publications:

Barbour, S.L., Hendry, M.J., Carey, S.K. (2016). High-Resolution Profiling of the Stable Isotopes of Water in Unsaturated Coal Waste Rock. Accepted with revisions by Journal of Hydrology.

Hendry, M.J., Schmeling, E.E., Wassenaar, L.I., Barbour, S.L., Pratt, D.L. (2015). "Determining the stable isotope composition of pore water from saturated and unsaturated zone core: Improvements to the direct vapor equilibration laser spectroscopy method", Hydrol. Earth Syst. Sci. (HESS), 19(11): 4427-4440, 2015, www.hydrol-earth-syst-sci.net/19/4427/2015/doi:10.5194/hess-19-4427-2015;

Huang, M., Barbour, S.L., Carey, S. (2015). "The impact of reclamation cover depth on the performance of reclaimed shale overburden at an oil sands mine in Northern Alberta, Canada", Hydrological Processes, doi: 10.1002/hyp.10229, (published online Jan. 6); 29(12): 2840-2854, June 15.

Huang, M., Hilderman, J.N., Barbour, S.L. (2015). "Transport of stable isotopes of water and sulphate within reclaimed oil sands saline-sodic mine overburden", Journal of Hydrology, August, doi: 10.1016/j.jhydrol.2015.08.028

Huang, M., Rodger, H., Barbour, S.L. (2015). "An Evaluation of Air Permeability Measurements to Characterize the Hydraulic Conductivity of Soil Reclamation Covers", Canadian Journal of Soil Science, published online Dec.19/14, doi: 10.4141/CJSS-2014-072, 95(1): 15-26.

Huang, M., Zettl, J., Barbour, S.L., Pratt, D. (2016). "Characterizing the spatial variability of the hydraulic conductivity of reclamation soils using air permeability", Geoderma, doi: 10.1016/j.geoderma.2015.08.014, 262: 285-293, January 15.

Pratt, D., Lu, M. Barbour, S.L., Hendry, J.M. 2016. An evaluation of materials and methods for vapour measurement of the isotopic composition of pore water in deep, unsaturated zones. Accepted for publication Isotopes in Environmental & Health Studies.

Zettl, J.D., Huang, M., Barbour, S.L., Si, B.C. (2015). "Density Dependent Calibration of Multisensor Capacitance Probes in Coarse Soil", Canadian Journal of Soil Science, published on the web Sep.21/15, (doi: 10.4141/CJSS-2015-021).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Lee Barbour

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Dr. Jim Hendry	University of Saskatchewan	Collaborator	-	-
Dr. Bing Si	University of Saskatchewan	Collaborator	-	-
Dr. Garth van der Kamp	Environment Canada	Collaborator	-	-
Dr. Carl Mendoza	University of Alberta	Collaborator	-	-
Dr. Sean Carey	McMaster University	Collaborator	-	-
Dyan Pratt	University of Saskatchewan	Res. Engineer	-	-
Brenda Bews	University of Saskatchewan	Res. Engineer	-	-
Mingbin Huang	University of Saskatchewan	Res. Scientist	-	-
Spencer Chuhaniuk	University of Saskatchewan	Res. Engineer	-	-
Stephanie Villeneuve	University of Saskatchewan	Res. Scientist		
Thomas Baer	University of Saskatchewan	M.Sc.	January 2012	March 2014
Mengna Lu	University of Saskatchewan	M.Eng.	February 2014	June 2014
Mike Amos	University of Saskatchewan	M.Sc.	September 2012	January 2015
James Tipman	University of Saskatchewan	M.Sc.	September 2013	In Progress
Matthew Buchynski	University of Saskatchewan	M.Sc.	September 2013	In Progress
Arash Janfada	University of Saskatchewan	Ph.D.	January 2012	Withdrew Aug 2014
Fatemeh Madaeni	University of Saskatchewan	Ph.D.	August 2013	Withdrew Dec 2015
Shahabul Alam	University of Saskatchewan	Ph.D.	March 2015	In Progress
Willemijn Appels	University of Saskatchewan	PDF	Jan 2015	Dec 2015
Saidur Chowdhury	University of Saskatchewan	P.D.F.	February 2015	July 2015

Long Term Watershed Response to Climate: Industrial Research Chair in Mine Closure Geochemistry

COSIA Project Number: LJ0210

Research Provider: University Of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 2 of 5

PROJECT SUMMARY

Dr. Lindsay's Associate NSERC/Syncrude Industrial Research Chair (IRC) in Mine Closure Geochemistry was established on April 1, 2014 with support from NSERC, Syncrude Canada Limited (Syncrude), and the University of Saskatchewan (U of S). The overall goal of this IRC program is to develop geochemical and conceptual models to inform oil sands mine closure planning. Achieving this goal requires that a comprehensive understanding be developed of the geochemical characteristics and evolution of oil sands mine wastes within mine closure landscapes. The specific research objectives and activities defined for this IRC therefore focus on developing this geochemical understanding.

Interdisciplinary field and laboratory studies of chemical, biological, and physical processes are being conducted to elucidate controls on the release, transport, and attenuation of contaminants in oil sands mine closure landscapes. This research examines relationships between geochemical and hydrogeological processes, and assesses the influence of geochemical variability on contaminant mobility across a range of measurement scales. Particular emphasis is being placed on processes occurring at environmental interfaces, including grain margins and material boundaries. This research addresses four principal objectives:

Objective 1: Define the geochemical characteristics of existing waste deposits.

Objective 2: Identify processes and conditions controlling water quality.

Objective 3: Constrain geochemical implications of potential closure scenarios.

Objective 4: Develop conceptual models of the geochemical evolution of closure landscapes.

These research objectives and associated activities were initially focused on centrifuged fine tailings (CFT), (referred to as cake in IRC proposal) and petroleum coke. Selection of these wastes as principal research foci was based upon three considerations: (i) information on their geochemical characteristics and evolution are limited; (ii) large volumes of these materials will be stored in the closure landscape; and (iii) geochemical research can be immediately applied to ongoing closure planning. Subsequent inclusion of additional mine wastes – fluid fine tailings (FFT) and composite tailings (CT) – has ensured that potential reclamation scenarios proposed since initiation of this IRC are also considered in the research program.

PROGRESS AND ACHIEVEMENTS

The principal activities carried out in this IRC program have followed two key themes: (1) recruiting and training an initial team of Highly Qualified Personnel (HQP); and (2) planning and executing initial field studies and associated laboratory analyses. Although the original start date proposed for this IRC program was September 2013, the actual start date was offset by seven months to April 1, 2014. Consequently, some milestones described in the Activity

Schedule of the original IRC proposal have become misaligned with actual timing of individual research activities. Nevertheless, progress toward meeting the research objectives has been very strong with excellent progress being made on several objectives during 2015. Details of progress related to the research objectives are described below, in relation to specific research activities outlined in the original IRC proposal.

Objective 1: Define the geochemical characteristics of existing waste deposits.

Substantial progress toward meeting research Objective 1 was made in 2015. This objective is focused on CFT and petroleum coke deposits and has involved several field-sampling campaigns. Detailed analysis of these samples has been performed to constrain their geochemical, mineralogical, microbiological, and physical characteristics. Overall, these research activities are progressing well and should be completed on originally proposed timelines.

Activity 1.1 – Characterization of existing centrifuge cake deposits

The objective of this research activity is to identify principal controls on water chemistry in existing CFT deposits. This research has examined biogeochemical conditions and processes within several CFT deposits. Sample collection and analysis focused on two experimental deposits (GD, TD) constructed in 2010 and two production-scale deposits (EV-1, EV-2) constructed in 2014. A total of 60 core samples were obtained at 15 discrete locations within these deposits during field campaigns in Dec. 2013 and Jun. 2014. Core samples were sealed, frozen and shipped to the U of S for analysis. Sub-samples were collected in an anaerobic chamber and pore-water geochemistry, solid-phase geochemistry, mineralogy, molecular geomicrobiology, and petroleum hydrocarbon contents were analyzed.

Kaitlyn Heaton (MSc Student) completed this research between September 2013 and December 2015. Heaton successfully defended her MSc thesis on Sep. 15, 2015 and recently completed required thesis revisions. Results from this MSc thesis have provided insight into spatial and temporal trends in CFT geochemistry, and into processes and conditions influencing CFT pore-water chemistry. These data have provided the foundation for development of initial geochemical and conceptual models of CFT deposits. These results have also proven critical to the development of complementary laboratory and field experiments. Mattea Cowell (BSc Student) contributed to this research as an Undergraduate Research Assistant during the summer of 2015. Cowell is currently conducting a BSc research project to further examine how chemical treatments influence terminal electron accepting processes and water chemistry within CFT deposits.

Activity 1.2 – Characterization of existing petroleum coke deposits

The objective of this research activity is to characterize spatial and temporal variability in coke geochemistry, and to examine biogeochemical and physical processes controlling pore-water chemistry within coke deposits. The solid-phase comportment of V and Ni and the geochemical behaviour of S and Fe during weathering are also important components of this research activity. A total of 132 samples were obtained from various depths at 12 locations within three coke deposits. This core-sampling program was completed during four field campaigns conducted between June and September 2014. These deposits included coke beach (6 locations), coke watershed (3 locations), and coke cell 5 (3 locations). Multi-level monitoring wells were installed at coke beach (5 locations) and coke watershed (3 locations) immediately following core sample collection. Detailed geochemical sampling of these wells was completed in August 2014. Characterization of pore-water geochemistry included field measurements (pH, Eh, EC, alkalinity, H_2S, NH_3) and laboratory analyses (inorganic anions, major cations, trace elements, δ^2H and $\delta^{18}O$ of water, and naphthenic acids).

Jake Nesbitt (MSc Student) began this research in May 2014 and has made excellent progress. He has completed all field and laboratory aspects of this research and is currently preparing his thesis for defence, which is scheduled for April 2016. During 2015, Jake conducted a large number of synchrotron-based measurements at both the Canadian

Light Source (Saskatoon, Canada) and the Advanced Photon Source (Chicago, USA). Results from this research activity have provided new information on the geochemical characteristics of oil sands petroleum coke, the environmental geochemistry of vanadium, and the conditions under which vanadium and other elements (e.g., nickel) may be released to groundwater within coke deposits.

Objective 2: Identify processes and conditions controlling water quality

Research aimed at realizing this research objective has not yet been initiated. This objective includes two principal activities, which aim to improve understanding of relationships between biogeochemical and physical processes influencing water quality in CFT and coke deposits. This objective is, therefore, dependent upon findings of initial field studies (Objective 1) and this research will be initiated in 2016.

Activity 2.1 – Laboratory investigation of controls on cake pore-water chemistry

This research activity examines interactions among the chemical, biological, and physical processes that influence the geochemical evolution of CFT. Field studies by Heaton (MSc student; *Activity 1.1*) have demonstrated that evaporation and freeze-thaw cycling are important controls on pore-water chemistry in CFT deposits. This activity was initially planned to start in 2015; however, in retrospect it made more sense to initiate this research once results from *Activity 1.1* were available. Consequently, this activity will now be initiated in 2016.

Laboratory column experiments will examine the influence of successive freeze-thaw and evaporation cycles on CFT pore-water and drainage chemistry. This research will focus on understanding ion exchange dynamics and biogeochemical sulfur and carbon cycling within CFT. These experiments will utilize CFT produced using different chemical (i.e., gypsum, polyacrylamide) amendment rates and will provide additional information on the influence of chemical treatments on water chemistry.

Activity 2.2 – Laboratory investigation of controls on coke pore-water chemistry

The objective of this activity is to further constrain controls on pore-water chemistry – specifically metal release and attenuation – within coke deposits. Field studies by Nesbitt (MSc student; *Activity 1.2*) have demonstrated that vanadium and nickel release result from leaching during infiltration of meteoric water into the vadose zone of coke deposits. Pore-water concentrations of these metals decrease rapidly with depth below the water where distinct changes in pore-water pH and redox conditions were observed.

Laboratory column experiments will be conducted to examine the influence of these and other factors on pore-water concentrations of vanadium, nickel, and other contaminants (e.g., naphthenic acids). These experiments examine relationships between biogeochemical processes and contaminant mobility within coke. This research activity was originally planned to start in 2015; however, a suitable student was not identified and the start date has been shifted to 2016.

Objective 3: Constrain geochemical implications of potential closure scenarios

Research focused on this objective was initiated during Year 2 and will continue through 2018. This objective involves interdisciplinary field-scale lysimeter experiments designed to improve understanding of the geochemical implications of proposed closure scenarios for water quality. More specifically, this research examines chemical, biological, and physical processes controlling the evolution of water chemistry under of relevant closure scenarios. Results of these experiments will also support development of geochemical and conceptual models of contaminant transport within these closure landscapes.

Activity 3.1 – Field experiments on the geochemical implications of potential closure scenarios

The lysimeter experiments were initiated as planned in 2015. Specific progress to date has included: (1) acquisition, programming, calibration, and testing of data logger systems; (2) design, construction, and instrumentation of lysimeter experiments; and (3) water and solid-phase sampling to constrain initial biogeochemical conditions. The lysimeters were constructed and instrumented in October 2015 using mine wastes and reclamation cover materials to emulate three potential closure scenarios: (1) reclamation cover (0.5 m) overlying coke (1.0 m) overlying CFT (1.5 m); (2) coke (1.0 m) overlying CFT (2.0 m); and (3) CFT (2.0 m) overlying tailings sand (1.0 m). These three scenarios have been replicated under water saturated and unsaturated conditions to mimic in-pit and out-of-pit closure landscapes. The scenarios have been modified somewhat from the original IRC proposal to reflect continuing development of mine closure plans.

The lysimeters (~23 m^3) were engineered and constructed by Syncrude at the Mildred Lake mine. The lysimeters have each been instrumented with a series of thermistors, electrical conductivity (EC) sensors, time-domain reflectometry (TDR) probes, and matric potential sensors. Pore-water samples will be obtained from continuous core samples and drive-point piezometers. Core samples will also be used to facilitate solid-phase geochemical analyses and gas-phase samples will be obtained from unsaturated lysimeters using drive-point samplers. This research is currently being conducted by Carlo Cilia (MSc student) and Lawrence Swerhone (MSc student), but will benefit from collaboration with a PhD student or Postdoctoral fellow beginning in 2016.

Objective 4: Develop conceptual models of the geochemical evolution of closure landscapes

This objective is focused on data synthesis and the development of conceptual models of the geochemical evolution of closure landscapes. Integration of data derived from complementary research activities being conducted under Objectives 1 through 3 is critical for effective knowledge transfer and, therefore, informing long-term closure planning.

Activity 4.1 – Synthesis of data from field and laboratory research activities

This final research activity has not yet been initiated; however, research that will support this activity including development of geochemical and conceptual models of CFT deposits (*Activity 1.1*), coke deposits (*Activity 1.2*), and potential closure landscapes (*Activity 3.1*) is underway. This study will integrate the field measurements, laboratory observations, and modelling by PhD, MSc, and BSc students into a guidance document that will support ongoing mine closure planning. Lindsay (NSERC IRC) will lead this research activity from 2016 through 2018.

OUTCOMES AND LESSONS LEARNED

Research conducted over the past year has provided valuable insight into the biogeochemical characteristics of centrifuged fine tailings and coke deposits. In particular, this research has shed some light on the biogeochemical processes controlling water chemistry within these deposits.

Centrifuge Cake: The electrical conductivity (EC) of pore-water in production-scale centrifuge cake deposits exceeded 7 mS/cm. Average EC values within these deposits were two-to-three times higher than those observed in the test deposits. These values are very similar to EC typically observed for pore-water in saline-sodic overburden dumps. These high EC values are attributed to gypsum addition to promote coagulation during the centrifugation process. Calculations suggest that gypsum amendment rates vary, often substantially, from the target rate of 1.5 kg t^{-1} dry FFT. The gypsum amendment rate has important implications for cake pore-water chemistry and for biogeochemical processes that influence pore-water chemistry. Specific implications include: (1) higher EC values; (2) higher sodium concentrations; (3) increased potential for sulfate reduction and hydrogen sulfide production; and (4) suppression of methanogenesis and associated hydrocarbon degradation.

Petroleum Coke: Elevated vanadium (V) and nickel (Ni) concentrations were observed in some groundwater samples obtained from coke beach. The highest concentrations in the saturated zone were generally observed within 2 m of the water table, where mixing of oxic infiltration and anoxic process water occurs. Further evaluation of field data suggests that redox conditions are an important control on V concentrations, whereas pH is an important control on Ni concentrations. Mass balance calculations suggest that release of less than 0.1 % of total V and Ni present in coke could produce observed concentrations of these metals in pore-water. Ongoing laboratory analyses are focused on constraining what proportion of total V and Ni has potential to be released to pore-water under different geochemical conditions. Nevertheless, results demonstrate that V concentrations are lowest under anoxic conditions, while Ni concentrations decrease with increasing pH with the lowest values observed at pH values greater than 6.5.

PRESENTATIONS AND PUBLICATIONS

Presentations (Presenting Author)

Heaton, K.K., Vyskocil, J., McBeth, J.M., Lindsay, M.B.J., 2015. Biogeochemical characteristics of centrifuged fine tailings at an oil sands mine in northern Alberta, Canada. Saskatchewan Geological Open House, November 30–December 2, Saskatoon, Canada. [Poster]

Nesbitt, J.A., Lindsay, M.B.J., 2015. Geochemical characteristics of petroleum coke deposits at an oil sands mine, Alberta, Canada. Proceedings of the 25th V.M. Goldschmidt Conference, August 16–21, Prague, Czech Republic. [Oral, Invited]

Nesbitt, J.A., Lindsay, M.B.J., 2015. Vanadium geochemistry of petroleum coke at an oil sands mine in northern Alberta, Canada. Canadian Light Source Annual Users' Meeting, May 4–6, Saskatoon, Canada. [Poster; Student Poster Award]

Publications

Heaton, K.K., 2015. Biogeochemical investigation of centrifuged fine tailings deposits at an oil sands mine in northern Alberta, Canada. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Canada, 149 pp.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Department: Geological Sciences

Principal Investigator: Dr. Matthew Lindsay

Research Team:

Name	Institution	Degree	Start Date	Completion Date
Kaitlyn (Scott) Heaton	University of Saskatchewan	M.Sc.	Sept. 2013	Dec. 2015
Jake Nesbitt	University of Saskatchewan	M.Sc.	May 2014	In progress
Carlo Cilia	University of Saskatchewan	M.Sc.	Sept. 2015	In progress
Mattea Cowell	University of Saskatchewan	B.Sc.	Sept. 2015	In progress

Collaborators:

Name	Institution	Department	Position
Dr. Lee Barbour	University of Saskatchewan	Civil and Geological Engineering	Professor and NSERC IRC
Dr. Joyce McBeth	University of Saskatchewan	Geological Sciences	Assistant Professor
Dr. Ning Chen	Canadian Light Source	Operations - Science	Staff Scientist

Industry Lead: Dallas Heisler, Syncrude Canada Limited

Sandhill Fen: Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

The Sandhill Fen Research Watershed (SFRW) is a large scale pilot fen wetland research program designed to address two challenges in oil sands reclamation and closure: 1) the ability to re-establish fen wetlands and 2) technology and practices for reclamation of 'soft tailings'. Syncrude Canada Ltd (SCL) has undertaken over 30 years of research and monitoring efforts on understanding and developing best practices for out of pit landforms and structures (i.e., upland landscapes conducive to the development predominantly of upland forests) such as overburden disposal areas and dyke beaches and slopes of tailings storage areas. In pit hydraulic placement of sand and composite tailings (CT) presents both a new challenge and a new opportunity for oil sands mine reclamation and closure. The challenge is developing technologies suitable for this landform strategy; the opportunity is to advance wetland reclamation because these facilities are more conducive to supporting the development of persistent wetland complexes. This challenge and opportunity were combined in the SFRW.

The Sandhill Fen research watershed is located in the North West corner of Syncrude's East in Pit (EIP). EIP is the former east mine, which was actively mined between 1978 and 2000. After completion of mining, EIP has been back filled hydraulically with composite tailings. The SFRW area is 57 hectares. It contains 7 upland hummocks ranging in height, shape and orientation. These hummocks were constructed from tailings sand and mechanically placed in 2010. Various soil prescriptions have been applied to the hummocks utilizing course sand, surface soil salvaged from either an A/B or D ecosite and standard peat mineral mix. Course woody debris has been applied to all the hummocks. All hummocks were planted with conventional mix and density of trees (2,000 stems per hectare: aspen, white spruce and jack pine) as well as some shrub species. In experimental plots on each hummock, densities were adjusted. These plots were planted with 0, 5,000, and 10,000 stems per hectare. Simon Landhäusser's group from the University of Alberta lead the revegetation research program on the upland hummocks. They are working collaboratively with Carl Mendoza and Kevin Devito's program looking at hummock hydrology and the movement, availability, and interaction of water between the hummocks and the wetland.

The SFRW also contains a 17 hectare wetland. The wetland is surrounded by the upland hummocks. The soil prescription for the wetland is 50 cm of clay till, overlaid with 50 cm of peat mineral mix. The peat material was salvaged on lease and stockpiled for less than 1 year before being placed in 2011. The wetland area was seeded in the winter of 2011 with a wetland seed mix collected from reference wetlands in the region. Planting of several native boreal wetland species took place in the summer of 2012. Dale Vitt is the lead for the wetland revegetation program, looking at suitable native boreal wetland plants and their ability to survive and reproduce across a range of expected conditions. Lee Foote from the University of Alberta is also working in the wetland portion of the study, assessing optimum peat depths and the use of rhizomes for revegetation. Jan Ciborowski from the University of Windsor is executing an invertebrate monitoring research program in the wetland as well. There are two eddy covariance monitoring stations located on the SFRW. One is in the centre of the wetland and the other is in the southern portion of the uplands, these stations, combined with meteorological data being collected across the site, inform Sean Carey's program (McMaster University) looking at the water, salt and carbon balances.

An online metadata and mapping tool system, developed by the University of Windsor, has been piloted as part of the SFRW as a tool for supporting multidisciplinary research. The tool allows researchers access to information about the type and location (metadata) of data being collected by others as part of the program. This tool is assisting in collaboration and aids in the ability to cohesively interpret data within the context of the entire project and not just each program component. The specific objectives of the SFRW research program are to gain knowledge and provide guidance for future lease development and reclamation. Three key study areas are:

- Understanding the nutrient, carbon and water balances;
- Landform design guidance, especially hummock landform technology; and
- Wetland reclamation guidance.

PROGRESS AND ACHIEVEMENTS

The SFRW has recognized a number of research disciplines for research study. The research programs are discrete projects integrated under the larger SFRW Single Industry Projects (SIPs). A list of these research projects, including the primary investigator and their classification within COSIA are provided in the table below. A more detailed description of the individual projects and their results to date can be found in the accompanying project updates in this document.

Project Type	COSIA Project Number	Project Title	Program Length	Principal Investigators
Single Industry	LJ 0204	Water and Carbon Balance in the Constructed Fen	5 years 2012-2016	McMaster University and Carleton University Dr. Sean Carey Dr. Elyn Humphreys
Single Industry	LJ 0204	Forest reconstruction on upland sites in the Sandhill Fen Watershed	5 Years 2012-2016	University of Alberta Dr. Simon Landhäusser Dr. Brad Pinno
Single Industry	LJ 0122	The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development	4 Years 2012-2016	Southern Illinois University and Villanova University Dr. Dale Vitt Dr. Stephen Ebbs Dr. Kelman Wieder
Single Industry	LJ 0204	Hydrogeologic Investigation of Sandhill Fen and Perched Analogues	4 Years 2012-2018 (end date extended from 2015)	University of Alberta Dr. Carl Mendoza Dr. Kevin Devito
Single Industry	LJ 0204	Biogeochemical investigation in Sandhill Fen	3 years 2011-2013	McMaster University Dr. Lesley Warren
Single Industry	LJ 0204	Influence of peat depth, hydrology and planting material on reclamation success within a created fen-like setting	3 years 2013-2016 (end date extended from 2015)	University of Alberta Dr. Lee Foote

Project Type	COSIA Project Number	Project Title	Program Length	Principal Investigators
Single Industry	LJ 0204	Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality	2 years 2014-2016 (end date extended from 2015)	University of Windsor Dr.Jan Ciborowski

OUTCOMES AND LESSONS LEARNED

See individual SFRW COSIA project updates for more details

PRESENTATIONS AND PUBLICATIONS

See individual SFRW COSIA project updates for more details.

RESEARCH TEAM AND COLLABORATORS

See table above and individual SFRW COSIA project updates for more details.

Industry Lead: Carla Wytrykush and Jessica Piercey; Syncrude Canada Ltd

Sandhill Fen: Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality

COSIA Project Number: LJ0204

Research Provider: University of Windsor

Industry Champion: Syncrude Canada Ltd.

Status: Year 2 of 3

PROJECT SUMMARY

Zoobenthic community composition and production are affected by diverse but often correlated environmental factors. Previous research conducted by the Carbon Dynamics, Foodweb Structure, and Reclamation Strategies in the Athabasca Oilsands Wetlands (CFRAW) program has documented that the most important determinants of zoobenthic community composition in young marsh-like wetlands of the oil sands region are water quality (dissolved oxygen concentration, pH, salts and naphthenic acids), substrate characteristics (mineral vs. organic sediments – these have strong direct effects on zoobenthos and indirect effects through the macrophytes they support), and the density and type of aquatic vegetation.

This research will document the continued development of the aquatic fauna of the Sandhill Fen community and its relationship with the evolution of water quality characteristics and plant development across the fen and at reference fen locations. Complementary work will assess the distribution and composition of semiaquatic fauna associated with areas of the fen that are intermittently inundated.

PROGRESS AND ACHIEVEMENTS

Sampling entailed assessing zoobenthic community composition/early-stage development and associated covariate information at 72 aquatic locations in the Sandhill Fen following the study design developed in 2013. Additionally, the invertebrate community of semi-aquatic and drier fen locations was sampled to better delineate associations with the developing aquatic plant community. These data document the development of a fundamental component of the wetland food web that will be responsible for sustaining higher trophic levels as the Sandhill Fen ages. As in 2013, a stratified-random sampling design was employed across submerged locations on the fen landscape and georeferenced.

The zoobenthic vegetation/substrate/water quality association information will be integrated with complementary remote sensing and in situ survey data on vegetation across the wetland. The combined data will be used to estimate fen-wide distribution, abundance and emergence potential of particular invertebrate assemblages for comparison with natural systems and for time trend analyses.

OUTCOMES AND LESSONS LEARNED

This project has no outcomes or lessons learned that are ready for release to the public.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Windsor

Principal Investigator: Jan Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Jan Ciborowski	University of Windsor	Professor		
Kathryn Williams	University of Windsor	M.Sc. Student	September 2011	2014
Kellie Menard	University of Windsor	M. Sc. Student	September 2014	2016

Sandhill Fen: The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development

COSIA Project Number: LJ0204

Research Provider: Southern Illinois University

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

This project addresses questions centered on plant establishment and development of critical ecosystem functions on a soft tailings deposit that has been reclaimed to a 57-hectare wetland complex at Syncrude East in Pit (EIP). This research is a field scale follow-up to the research performed at Syncrude's U-shaped cell study site. From that research it was learned which species might be select for wetland and specifically fen species establishment on tailings substrates. In addition, it was learned that invasive species may be a real concern and that several species tolerate the salinity predicted for tailings closure features. Despite these advances in our knowledge, we still know little about how plants will respond to reclamation conditions. It is also important to understand how critical ecosystem functions will return on the reclaimed landscape. The specific research being addressed in this program will be:

1. Chemical gradients within Sandhill fen:
   - Vertical and horizontal gradients in base cations, pH, and alkalinity
   - Wetness

2. Species establishment responses:
   - Vascular plant establishment and growth
   - Moss establishment and growth
   - Invasive species
   - Changes in resource allocation (light, nutrients)

3. Community development:
   - Development of community complexity and species richness
   - Effects of density and competition

4. Nitrogen mineralization, nitrification, and utilization:
   - Atmospheric inputs
   - Dissolved inorganic nitrogen (DIN)/ dissolved organic nitrogen (DON) pools
   - Development of microbial communities

5. Reference sites:
   - Naturally occurring young fens (5-10 years old) as benchmarks
   - Old fens

PROGRESS AND ACHIEVEMENTS

Bulk density soil samples were collected from the plots 3 times from May to September 2015. Nitrogen mineralization was studied during June-July. Water samples were collected from the sipper peepers three times throughout the field season. In the lab, base cation (Na^{+}, Mg^{+2}, Ca^{+2}) concentrations were analysed. Winter 2014 resin tubes were removed and summer resin tubes were installed and removed. Winter 2015 resin tubes are installed and will be removed in May 2016. The resin tubes are currently being extracted for nitrogen and sulphur deposition. Physiological performance of the plants introduced in the plots was tracked, through monitoring photosynthetic and transpiration rates. Soil samples were collected from the 20 plots for soil microbial analysis. Lab procedures for analysing the soil microbe community are being conducted. Plots planted with different plant communities were assessed. A vegetation survey was carried out to determine the species living in Sandhill Fen; community analysis and weed cover have been completed. Benchmark sites used as natural reference points for Sandhill Fen were sampled again this year. Work continued on determining what wetland species are best for establishing a carbon sink; this study focuses on carbon dioxide flux and plant above and below ground biomass.

OUTCOMES AND LESSONS LEARNED

In 2015, a decrease in nitrogen mineralization rates was observed at Sandhill Fen. Comparison to fen sites in the region revealed a similar decrease in rates as compared to 2014. Climate, specifically lower precipitation prior to the incubation period, is the likely factor affecting nitrogen mineralization rates in the region. Data collected from natural benchmark sites was critical to the interpretation of the results from Sandhill Fen.

Carex aquatilis, *Scirpus microcarpus*, and *Triglochin maritima* have photosynthetic rates and water use efficiencies within the range observed at natural sites. Reduced precipitation has a negative effect on *Triglochin maritima*; *Carex aquatilis* and *Scirpus microcarpus* can tolerate variable rates of precipitation.

Four distinct vegetative communities were found in Sandhill Fen, and when spatially mapped 3 vegetative zones within the fen were identified. Zone 1 is characterized by standing water and *Typha latifolia* dominance. *Carex aquatilis* dominates Zone 2, which hosts the largest abundance of desirable fen species. Zone 3 is dominated by *Calamagrostis canadensis*, and is drier than peatlands of the region. 40% of the fen is characterized by peat forming species, 48% is dominated by upland and weedy species, and 12% is dominated by marsh plants.

Decomposition in wet areas is lower than in the dry areas, but higher in 2015 than 2014. Fens of the region are characterized by low decomposition rates.

Net ecosystem exchange rates were lower in 2015 than 2014 for all 4 sedge species studied. The underlying cause, including the possibility of a climate effect, is being investigated.

Carex aquatilis, *Scirpus atrocinctus*, and *Triglochin maritima* had very strong physiological response to soil moisture. Lily Glaeser concluded in her M.Sc. thesis that soil moisture may be the most important factor during the early stages of mine reclamation, particularly when it comes to plant physiological success and survival.

Studying natural analogues is key to understanding and interpreting the ecological processes monitored at Sandhill Fen (and all reclamation).

PRESENTATIONS AND PUBLICATIONS

Ebbs, S., Glaeser, L., House, M., and Vitt, D.H. (2015) A plant ecophysiological approach to assess the performance and potential success of mine revegetation. Proceedings of Mine Closure 2015 conference. Vancouver, BC.

Glaeser, L. (2015) Established plant physiologic responses and species assemblage development during early fen reclamation in the Alberta oil sands. M.Sc. thesis, Southern Illinois University, 135 pp.

Glaeser, L.C., Vitt, D.H., and Ebbs, S.E. (2016) Responses of the wetland grass, *Beckmannia syzigachne*, to salinity and soil wetness: Consequences for wetland reclamation in the oil sands area of Alberta. Ecological Engineering 86: 24-30.

Hartsock, J., Vitt, D.H., Ebbs, S., and House, M. (2015) Net nitrogen mineralization in boreal wetlands: A test of early success for Canadian Oil Sands reclamation. Botany 2015. Edmonton, Alberta, Canada.

Hazen, R., Vitt, D.H., Ebbs, S., Hartsock, J., and House, M. CO_2 assimilation rates associated with four sedge species during reclamation in the Alberta oil sands region. Botany 2015. Edmonton, Alberta, Canada.

House, M., Vitt, D.H., Glaeser, L., Hartsock, J., and Ebbs, S. (2015) The challenge of constructing peatland reclamations: The effect of soil moisture and sodium concentration on plant community assessment. Botany 2015. Edmonton, Alberta, Canada.

Vitt, D.H. and Ebbs, S. (2015) Changes at Sandhill Fen 2014 – Water, Soil, Air, and Plants: Are things as they seem. COSIA Annual Meeting, Edmonton, AB.

Vitt, D.H. and House, M. (2015) Establishment of bryophytes from indigenous sources after disturbance from oil sands mining. The Bryologist 118: 123-129.

Vitt, D.H., House, M. Ebbs, S., Glaeser, L., and Hazen, R. (2015) Reclaiming peatlands after oil sands mining: Plant responses after two years at Sandhill Fen. Botany 2015. Edmonton, Alberta, Canada.

Submitted Papers:

Hartsock, J., House, M., and Vitt, D.H. (2016, In Review) Net nitrogen mineralization in boreal fens: A potential performance indicator for peatland reclamation. Botany.

Vitt, D. H., House, M., and Hartsock, J. (2016, In Review) Sandhill Fen, a first generation trial for wetland species assembly on in-pit substrates: lessons after three years. Botany.

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University

Principal Investigator: Dale Vitt

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Stephen Ebbs	Southern Illinois University	Professor		
Melissa House	Southern Illinois University	Research Scientist		
Jeremy Hartsock	Southern Illinois University	Ph.D. Student	August 2015	ongoing
Rene Hazen	Southern Illinois University	M.Sc. Student	August 2013	May 2016
Lily Glaeser	Southern Illinois University	M.Sc. Student	January 2013	May 2015

Sandhill Fen: Forest Reconstruction on Upland Sites in the Sandhill Fen Watershed

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

The overall goal of this research project is to examine the inter-relationships among tree species, and density, understory development and potential water use on upland coarse-textured (a/b ecosite) and fine-textured (d-ecosite) capping materials in a reclamation area. This work will be completed and presented in the context of water availability for adjacent wetlands.

PROGRESS AND ACHIEVEMENTS

- Soil water matric potential in addition to soil temperature were recorded using Decagon MPS-2 sensors installed in 2012 at 10cm and 20cm depths in each of the revegetation plots. These data have been collected throughout the project beginning in May 2013.
- Stomatal conductance was measured on one aspen and one pine seedling in the buffer of each planted revegetation plot (June 10-12, July 11-13, and August 18-19, 2015), followed by leaf collection of the monitored aspen seedlings to assess leaf area.
- Stand level leaf area was measured using an LAI-2200 (LI-COR Inc., Lincoln, Nebraska, USA) on June 10, July 7-11, and August 17-21, 2015.
- An inventory of all tree seedlings found in the 30 slope and aspect plots was performed August 19-21 as a follow-up to seedling measurement performed August 2012 and August 2014. Root collar diameter and seedling height were recorded on the remaining aspen and pine stocktypes planted on south and north facing slopes and in hydrogel amended plots.
- Ocular cover estimation of understory plant communities was undertaken in each of the vegetation assessment plots July 6th to July 15th, 2015. Shrub, forb, graminoid, and bryophyte vegetation by species was estimated for percent cover and abundance within the 312 1 m^2 plots. This data will be linked in the future to leaf area development. These assessments were the last set of vegetation assessments that will be performed at the fen during this contractual period.
- Using data collected since 2012, multivariate analyses are being conducted to explain tree seedling success at the fen. Structural equation modelling will be the main tool used to perform these analyses.

OUTCOMES AND LESSONS LEARNED

Species richness is driven by source material, but vegetation cover is higher on finer textured materials compared to coarser materials.

Regardless of vegetation type, colonizing communities reached a first plateau after four growing seasons which might indicate that early yearly monitoring of plant communities may not be essential in the first three years

following site construction particularly when surface materials are directly placed. We expect another plateau will be reached when tree and shrub canopy begins to close.

Early annual and some perennial (incl. noxious) species appear to disappear or significantly decline in the first four years on upland sites which might suggest value in adjusting early weed management practices.

In 2015 vegetation communities and tree performance continue to be very different on the coarse and fine capping materials. Tree density still had no significant effect on plant communities; however a trend appears to be emerging. 2015 was also an exceptionally dry year, particularly in the first half of the growing season, therefore we attribute the following observations and findings to this fact:

- a reduction of species richness in both vegetation types compared to 2013
- a reduction of vascular plant cover on fine capping materials compared to 2013.
- a reduction of LAI on both sites with a proportionally greater reduction on the finer capping materials compared to 2013.
- a reduction in soil water potential and stomatal conductance greater in the finer capping materials compared to 2013.

PRESENTATIONS AND PUBLICATIONS

Hoffman, E, Landhäusser, SM, and MacDonald, E. 2015. Vegetation pattern development on reclaimed mine sites using salvaged forest floor material. SER Conference, August 23-27, 2015, Manchester, UK. Poster presentation.

Hoffman, E, Landhäusser, SM, and MacDonald, E. 2015. Temporal and spatial development of vegetation community patterns on reclaimed boreal forest sites using salvaged forest floor material. North American Forest Ecology Workshop, June 15, 2015, Puerto Vallarta, Mexico. Oral presentation.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Simon Landhäusser	University of Alberta	Professor		
Brad Pinno	Canadian Forest Service	Research Scientist		
Fran Leishman	University of Alberta	Research Assistant		
Ruth Errington	Canadian Forest Service	Research Assistant		
Alex Goeppel	University of Alberta	M.Sc. Student	September 2012	May 2014
Shaun Kulbaba	University of Alberta	M.Sc. Student	September 2012	August 2014
Elizabeth Hoffman	University of Alberta	M.Sc. Student	September 2013	2016
Kate Melnik	University of Alberta	B.Sc. Student	May 2012	May 2013

Sandhill Fen: Hydrogeologic Investigation of Sandhill Fen and Perched Analogues

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 6

PROJECT SUMMARY

This program looks at integrated hydrologic studies to quantify and generalize landscape and transition zone hydrologic interactions within the Sandhill watershed at a number of scales. These range from determining the hydrologic role of basin-scale hummocks, to the contributing influence of transition areas and ephemeral draws, to the hydrologic functioning of two isolated, perched fens. The field studies will help develop and refine models that can be used to generalize hydrologic and salt dilution requirements for future landscape reconstruction. This work is tightly integrated with several other programs on the Sandhill Fen, including Simon Landhäusser's work on vegetation succession and very shallow moisture regimes on hummocks and Sean Carey's work on atmospheric interactions. It also links with Lee Barbour's Industrial Chair for defining landscape hydrology through isotope sampling. Additional work within this program looks at monitoring the hydrologic behavior of a perched fen complex at the Utikuma Region Study Area (URSA). This is valuable in providing background conditions for natural peatlands and to assess the relative role of climatic variability on initiation and maintenance of the constructed fen.

PROGRESS AND ACHIEVEMENTS

Most activities in the reporting period involved ongoing collection of data, interpretation of past data, new laboratory measurements and integration of field results with BGC Engineering Inc. modelling efforts. Analysis of field data is ongoing. Saturation mapping was refined and automated this year, and has been highly successful.

OUTCOMES AND LESSONS LEARNED

The following general comments can be made about groundwater flow:

- Some flow reversals appear to occur at the toes of hillslopes.
- Groundwater flows through East-In-Pit, as predicted by conceptual model developed through the HEAD research programs. Water flows towards Kingfisher Fen, as expected, but may be enhanced by water management or construction activities.
- Very little, if any, snowmelt reaches water tables below hummocks.
- Ponded water accumulates at the base of ephemeral draws, coinciding with (a) different reclamation treatments, (b) changes in slope and/or (c) edges of drains.

It is too early to tell which directions water will eventually flow (e.g., forest to wetland vs. wetland to forest, or frequent water reversals).

The electrical conductivity at depth (within 10 m of the ground surface) is 2000 to 3000+ µS/cm, but is lower and highly variable in shallow piezometers and wells.

PRESENTATIONS AND PUBLICATIONS

Benyon, J., 2015. Characterization of Hydraulic Conductivity Profiles for Sandhill Fen Watershed Reclamation Materials. Undergraduate thesis, Earth & Atmospheric Sciences, University of Alberta. April.

Hamilton, A., 2015. Instrumentation and Characterization of Soil Moisture for the Syncrude Sandhill Fen Watershed. Undergraduate project, Earth & Atmospheric Sciences, University of Alberta. December.

Report (omitted last year):

Longval, J.M., and C. Mendoza, 2014. Initial Hydrogeological Instrumentation and Characterization of Sandhill Fen Watershed. Final report, Hydrogeology Group, Earth & Atmospheric Sciences, University of Alberta. December.

Conference presentations:

Biagi, K., S. Carey, E. Nicholls and C. Mendoza, 2015. Understanding flow pathways, major chemical transformations and water sources using hydrochemical and hydrometric data in a constructed fen, Fort McMurray, Alberta. AGU/CGU Joint Assembly, Abstract H14A-0187.

Nicholls, E., S. Carey, G. Drewitt, E. Humphreys, M.G. Clark and C. Mendoza, 2015. Multi-year water balance assessment of a constructed wetland, Fort McMurray, Alberta. AGU/CGU Joint Assembly, Abstract H13A-05. (CGU Best Student Paper Award)

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Carl Mendoza and Kevin Devito

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Carl Mendoza	University of Alberta	Co-Principal Investigator		
Kevin Devito	University of Alberta	Co-Principal Investigator		
Jean-Michel Longval	University of Alberta	BSc	2012	2014
Max Lukenbach	University of Alberta	Post doctoral researcher		
Mika Little-Devito	University of Alberta	Technical assistant		
Jennifer Benyon	University of Alberta	B.Sc.	2014	2015
Trevor Moningka	University of Alberta	M. Eng.	2012	2013

Sandhill Fen: Influence of Peat Depth, Hydrology and Planting Material on Reclamation Success Within a Created Fen-Like Setting

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 3 of 3 (but extended into 2016 to allow time for thesis and publications)

PROJECT SUMMARY

Wetlands are largely defined by three criteria: wetland-adapted plants, wetland-specific soils and hydrologic conditions. All three criteria will be tested as measured, controlled factors in this growth trial. Viable rhizomes and seeds of *Carex aquatilis* will be placed in replicated beds of peat installed at 4 distinct depths across a continuum of water depths along a shoreline moisture gradient. The objective is to test peat minimum requirements, operationally feasible rootstock placement, and hydrologic optima at the Sandhill Fen.

PROGRESS AND ACHIEVEMENTS

Field data for the project were collected again in summer of 2015. This included peat depth measurements on our 72 peat plots located on clay islands. Summer 2015 marked the final round of *Carex aquatilis* survival and spread data. The number of living stems was counted, and a percent cover recorded. A bryophyte survey was also undertaken.

OUTCOMES AND LESSONS LEARNED

This project has no outcomes or lessons that are ready for release to the public.

PRESENTATIONS AND PUBLICATIONS

Nothing external or public

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Lee Foote

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Mallory Hazell	University of Alberta	M.Sc. student	2013	2016

Sandhill Fen: Water and Carbon Balance of the Constructed Fen

COSIA Project Number: LJ0204

Research Provider: McMaster University/Carleton University

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

The objectives of this research program over its entire 5-year period are to:

1) Measure the ecosystem-scale annual water/energy and carbon (C) balance for the reclaimed fen over a 5 year period (2012-2016) based on complete year measurements of all the major inputs and outputs to the system;
2) Establish the intra-fen variability in net ecosystem production (NEP) and methane flux FCH_4 to establish which areas of the fen are more productive (successful) than others and link this to the ecosystem-scale flux (2012-2016);
3) Characterize the quantity and quality of dissolved organic carbon (DOC) and particulate organic carbon (POC) released from Sandhill Fen through surface and subsurface hydrological pathways (2012-2016);
4) Monitor changes in DOC and POC quantity and quality across a range of hydrological conditions (2012-2016); and
5) Establish whether the concentrations, fluxes, and quality of DOC and POC are similar to reference wetlands in the local area and other reclaimed fens.

PROGRESS AND ACHIEVEMENTS

- Installed instruments are measuring water and carbon balances of the fen over the course of the study period.
- A two-year water balance of the fen has been completed and this research is ongoing.
- Greenhouse gas dynamics within the watershed are being observed.
- Water quality issues and aqueous carbon and mercury transport have been examined.
- Dissolved organic quality dynamics are being studied and well data is being used to evaluate the sustainability of the wetland.
- Mercury (Hg) assessment has been completed. A pilot study of Hg output from the fen has been completed and has been compared to reference fens in the area. A manuscript has been submitted to Environmental Pollution.
- Soil nutrient assessment is ongoing. Plant root simulator (PRS) probes and soil chemical analysis are being used to understand the availability and limitations of nutrients for plant growth and assess intra-fen variability in soil quality status.
- Stable isotopes and hydrochemistry are being used to better understand the linkage between runoff flow pathways and sources of water. This work is complete and may be expanded as part of a PhD program.

OUTCOMES AND LESSONS LEARNED

There is preliminary evidence that uplands are supplying water to the wetlands, but as ET increases in the uplands, this may decline.

There is evidence that the system is moving towards become a carbon sink. On an annual basis, the fen is still a small net source of carbon to the atmosphere or neutral in 2015, although it is on track to become a carbon. Gross ecosystem exchange (photosynthesis) is increasing every year whereas respiration only changes subtly. These values of GEE are similar to others reported for boreal wetland systems.

We have made considerable progress towards completing a carbon and water balance of the watershed. In this work, we have provided considerable insight into processes operating within the fen and how they compare with natural systems.

PRESENTATIONS AND PUBLICATIONS

Nichols EM, Carey SK, Humphreys ER, Clarke MG, Drewitt GB. Multi-year water balance assessment of a newly constructed wetland, Fort McMurray, Alberta. Hydrological Processes. Accepted pending minor revisions.

Oswald CJ, Carey SK. Total and methyl mercury concentrations in sediment and water of a constructed wetland in the Athabasca Oil Sands Region. Submitted to Environmental Pollution.

Clark MG, Humphreys ER, Carey SK. Evolution of function in a constructed wetland over the first two years. Presented at CGU Annual General Meeting, May 2015.

Thorne CE, Carey SK, Humphreys EH, Macrae ML, Petrone RM. A Comparison of Soil Nitrogen Availability Between a Post Mined Reclaimed Wetland and Two Natural Wetlands in Fort McMurray, Alberta. Presented at CGU Annual General Meeting, May 2015.

Nichols EN, Carey SK, Drewitt GB, Humphreys EH, Clarke MG, Mendoza CA. Multi-Year Water Balance Assessment of a Constructed Wetland, Fort McMurray, Alberta. Presented at CGU Annual General Meeting, May 2015.

Biagi K, Carey SK, Nicholls EN, Mendoza CA. Understanding Flow Pathways, Major Chemical Transformations and Water Sources Using Hydrochemical and Hydrometric Data in a Constructed Fen, Fort McMurray Alberta. Presented at CGU Annual General Meeting, May 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: McMaster University

Principal Investigator: Sean Carey

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Sean Carey	McMaster University	Professor		
Elyn Humphreys	Carleton University	Professor		
Claire Oswald	McMaster University	Post doctoral researcher		June 2014
Graham Clarke	Carleton University	Ph.D student	Sept 2013	Aug 2017
Chelsea Thorne	McMaster University	M.Sc. student	Sept 2013	Aug 2015
Kelly Biagi	McMaster University	M.Sc. student	Sept 2013	Sept 2015
Jessica Rastelli	McMaster University	M.Sc. student	Sept 2014	Aug 2016
Haley Spennato	McMaster University	M.Sc. student	Sept 2014	Aug 2016
Erin Nicholls	McMaster University	M.Sc. student	Sept 2013	Sept 2015

Soils And Reclamation Materials

Kearl Stockpile Study

COSIA Project Number: LJ0254

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: complete

PROJECT SUMMARY

Due to discrepancies between anticipated volumes (calculated using area and target depth) and realized volumes (using as-built stockpile surveys); a Reclamation Material Stockpile (RMS) density investigation was conducted at the South Reclamation Material Stockpile (SRMS) on the Kearl Oil Sands lease. The primary focus of the investigation was to test the validity of commonly applied "bulking factors" for stockpiles. The results are intended to inform subsequent stockpile design and to improve the ability to audit reclamation material salvage programs.

PROGRESS AND ACHIEVEMENTS

The investigation was conducted on an Other surface soil (OSS) stockpile as well as on a Good/Fair subsoil (GFS) stockpile. The density and settlement investigation methods and subsequent drilling and sampling program was designed and executed by CH2MHILL Canada Limited. Data was collected from four boreholes on the OSS stockpile, five boreholes on the GFS stockpile and one from original ground surface adjacent to the stockpiles in the SRMS. Geotechnical laboratory testing was completed and included moisture content, gradation (sieve/hydrometer), Atterberg limits, specific gravity, wet and dry density, and one dimensional consolidation. Pocket penetrometer, torvane, and shear vane testing were also conducted in the field on cohesive soils. Bulk density samples were also collected from shallow test pits on the surface of the stockpiles. Bulk density results from reclamation monitoring plots on OSS and GFS soil types are compared to the in-situ and stockpiled soil densities of the same material types. The project was started in Oct 2014 and completed in 2015.

OUTCOMES AND LESSONS LEARNED

- The bulk density of both stockpiled material types appeared to increase during storage, suggesting the influence of overbearing pressure. Results show the OSS stockpile has compressed by 19-21% and the GFS stockpile has compressed by approximately 18%
- The estimated primary consolidation of the OSS stockpile is approximately 0.5 m below the original ground surface, without including any potential for long-term thaw consolidation of the frozen zone within the pile. The estimated primary consolidation of the GFS stockpile is approximately 1 m below original ground surface.

It is commonly assumed that stockpiled soils have lower densities than in-situ soil, and that a swell factor of approximately 20% should be applied to estimate available soil volumes. However, the results of this investigation suggest that stockpiled OSS and GFS soil actually have higher densities than in-situ soil, indicating that a compression factor - rather than a swell factor - should be applied to these stockpiled soil types. Shortfalls in anticipated salvage volumes may thus be in part due to stockpile consolidation and increased soil density. These results suggest implications for material balance calculations and stockpile design.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and & Environmental Consulting Inc. and CH2MHILL.

Principal Investigator: Paragon Soil and & Environmental Consulting Inc.

Nutrient Biogeochemistry 2: Tracking Nutrient Fluxes Through Reconstructed Soils

COSIA Project Number: LJ0120

Research Provider: University of Alberta, University of British Columbia

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial, Shell Canada Energy, Suncor Energy Inc., Total E&P Canada Ltd.

Status: Year 5 of 6

PROJECT SUMMARY

Following surface mining, land reclamation of substrates necessitates the reconstruction of soil profiles using salvaged surface mineral materials and organic soils (peat) as the coversoil (topsoil) layer and mineral parent materials as subsoil. Establishment of biogeochemical cycling between these reconstructed soils and plants is required to ensure long-term sustainability in reclaimed landscapes. While vegetation growing on recently reconstructed soils relies primarily on the coversoil for its nutrient needs, over time in situ litterfall and the build-up of a forest floor layer, like undisturbed upland soils in the region, should play a prominent role. This project, which represents a collaborative effort between several oil sands operators and Canadian universities, directly contributes to ongoing research efforts in land reclamation by characterizing forest floor development and associated biogeochemical processes in chronosequences of reclaimed ecosystems. These characteristics are being compared to the forest floor characteristics developing in recently burned ecosystems, another disturbance that is common in northern Alberta.

The following specific objectives were developed to provide discrete thesis topics for individual graduate students while being sufficiently complementary to allow integration into one comprehensive study:

- **Objective 1.** How does the addition of fresh litter and forest floor materials interact with the peat amendment, and does this result in a cumulative or a synergistic effect?
- **Objective 2.** How does forest floor development in reclaimed soils compare to naturally disturbed (fire) soils, and how does this influence nutrient availability?
- **Objective 3.** Does litter decompose via the same pathways in reconstructed soils as it does in natural soils, and are the carbon (C) and nitrogen (N) fluxes from the litter to the soil organic pools comparable?
- **Objective 4.** Does forest floor development and soil organic matter accumulation at the reclaimed sites occur faster under planted aspen than under spruce, and is it related to populations and activities of soil fauna?
- **Objective 5.** How does the spatial variability within reclaimed soils compare to fire-disturbed soils?
- **Objective 6.** Are the nitrifying communities in reclaimed soils similar to those in soils recovering from fire, and how does this influence nitrification rates?
- **Objective 7.** For this last objective, results from the first six projects are combined and further analyzed so that a mechanistic model of C and N fluxes in reclaimed soils can be developed.

PROGRESS AND ACHIEVEMENTS

Objective 1. Carbon release from forest floor and peat amendments

This objective was completed by Mark Béasse (M.Sc). One peer-reviewed article from Mark's work was published in Ecological Engineering in 2015. Mark showed that combining forest floor material and peat created a mixture with a soil microbial community more similar to that of forest floor material than to peat. Given operation considerations and the shortage of forest floor material available for soil reclamation, a forest floor:peat mixture has the potential to increase the volume of material available while increasing water-holding capacity and producing a microbial community more analogous to an upland forest community than peat alone.

Objective 2. Key characteristics of fire-disturbed soils and comparison to reconstructed soils

Jill Martin defended her M.Sc. thesis in 2015. She compared a chronosequence of aspen-white spruce stands recovering from wildfire, with stand ages ranging from 2 to 125 years, to a chronosequence of five reclaimed sites aged 4 to 27 years since reclamation. She established sampling transects at each site for routine soil characterization, nutrient availability, plant community composition and microbial analyses. Results indicated significant differences immediately following disturbance in all parameters measured. However, with increasing time since disturbance (>20 years), there was some convergence in community composition (both plant and microbial) between natural and reclaimed sites. This was mostly attributed to the formation of natural forest floor on the reclaimed sites.

Objective 3. Organic carbon and nitrogen cycling in boreal forest soils

Charlotte Norris (Ph.D.) utilized stable isotopes (^{13}C and ^{15}N) to trace C and N fluxes from new litter to various soil organic matter pools. She generated double labelled (^{13}C and ^{15}N) aspen litter and applied the labelled leaves as an amendment to the forest floor of aspen and spruce stands in a 16 month field experiment. Results were submitted in 2015 to a refereed journal for publication.

As part of this third objective, an ongoing experiment is characterizing carbon chemistry and substrate utilization pathways of microbial communities at a range of natural aspen and spruce sites and a chronosequence of reclaimed sites (8-31 years). A M.Sc. student (Cassandra McKenzie) sampled soils from all sites during summer 2015 to investigate how tree cover (aspen vs. spruce) and time since disturbance (8 to 31 years) influences soil microbial structure and function. The current hypothesis is that the microbial community should adapt to their new surroundings and evolve towards the undisturbed communities with time. We also hypothesize that microbial communities in aspen stands will start to exhibit traits similar to undisturbed site much more rapidly than communities in spruce stand due to the rapid rate of aspen recolonization of reclaimed sites. Data interpretation and analysis is currently underway.

Objective 4. Effects of faunal communities on forest floor and soil organic matter accumulation

Meghan Laidlaw (M.Sc.) compared total soil carbon and the distribution of carbon in chemically and physically protected pools between three reclaimed vegetation treatments, and naturally fire-disturbed boreal forest sites. She described and sampled 20 to 35 year-old reclaimed sites, which included 4 areas planted to grassland, 5 stands planted to spruce and 4 stands planted to aspen. In addition, 4 fire-disturbed sites, of similar age since fire, were sampled in the Fort McMurray area. The soil organic matter content of all reclaimed soils was significantly higher than the natural analogues due in part to the presence of residual peat from the originally added peat mix surface soil horizon. Within reclaimed vegetation types, grassland sites had the greatest physically and chemically protected carbon, while deciduous sites had the greatest unprotected carbon, despite both vegetation types having similar total soil organic

matter content. Coniferous sites had the lowest total soil organic matter content, but tended to have more physically and chemically protected carbon than deciduous sites, Meghan defended her M.Sc. in April 2015.

A last part of Objective 4 is to assess mesofaunal diversity at a chronosequence of 20 reclaimed and natural sites. In particular, oribatid mites may prove to be useful in monitoring the development of the forest floor and associated ecological functions due to their high abundances in the humus layer and their key role in nutrient cycling processes. Brittany McAdams (M.Sc. student) sampled all sites in 2015. The objective of her study is to investigate the use of oribatid mites as an index of soil health and development in reclaimed forests from the Alberta Oil Sands Region. Laboratory analysis is currently underway.

Objective 5. Spatial variability in fire- disturbed and reconstructed soils

Sanatan Das Gupta, who was conducting this work, defended his Ph.D. in April 2015. For his Ph.D. research, Sanatan focused on the dynamics of spatial variability in aboveground (canopy, understory vegetation and forest floor) and belowground (nutrient availability, microbial biomass, respiration and enzyme activities) processes in wildfire disturbed upland boreal forests to create a benchmark condition for measuring reclamation success. He also characterized the spatial variability in oil sands reclaimed sites to see if any heterogeneity in ecosystem properties was created a decade after reclamation.

Sanatan published one peer-reviewed article in 2015, where he used spatial analysis to tease apart scale dependent relationships between nutrient availability, microbial properties and above-ground attributes within a reclaimed 14 year-old aspen stand. His results showed a fine scale spatial association for stand attributes, but a weak control of these attributes on essential macronutrients (N, P and S), which were dominated by microbial processes. These results suggest that belowground processes are still the main regulators of soil nutrient availability in reclaimed environments less than 20 years old.

Objective 6. Microbial communities in reconstructed soils

Jacynthe Masse (on going PhD student) measured the gross rates of nitrogen transformations under different vegetation treatments in both reclaimed and naturally-disturbed (fire) sites, which ranged in age between 20 and 30 years post disturbance. The ^{15}N tracing approach allowed her to separate the contribution of the labile and the recalcitrant organic nitrogen pool, which highlighted key distinctions in nitrogen cycling processes between reconstructed and natural soils that have undergone wildfire disturbance. Reclaimed sites nitrified and produced more NO_3- than they immobilized, which likely accounts for the significantly higher NO_3- concentrations noted in reclaimed soils. Vegetation type did not appear to influence nitrogen transformation rates in reconstructed soils, indicating that the characteristics of the soil material used during soil reconstruction still dominates nitrogen dynamics.

In 2015 Jacynthe presented results of her research at two International conferences, the Canadian Society of Soil Science conference in Montreal and the Wageningen Soil conference in the Netherlands. She is planning to defend her Ph.D in 2016.

Objective 7. Development of a mechanistic model for C and N fluxes within reclaimed sites

Nilusha Welegedara (on going PhD student) is using the ecosys model to analyse and model the basic processes in the cycling of water, nutrients and carbon in reclaimed oil sand areas and thereby to predict the time period required to restore natural ecosystem productivity. She is studying the South Bison Hills experimental site to better understand regeneration of ecosystem productivity in reclamation landscapes with different reclamation capping depth thicknesses (35, 50, and 100 cm). This understanding is being tested with detailed site measurements of

soil water content, salinity, soil and plant nutrient status and plant biomass accumulation from 1998-2015. Plant samples collected during summer 2015 were analyzed for foliar nutrient status (total carbon, nitrogen and phosphorous). Collected soil samples were analyzed for nutrient status and other biochemical properties, including pH, anion and cation concentrations, cation exchange capacity, and electrical conductivity. At the same time, model values are being analyzed to determine root penetration in different soil profiles and to predict the effect of the reclamation material depth on canopy conductance and plant water stress during wet and dry years. Data analysis and interpretation is currently underway.

OUTCOMES AND LESSONS LEARNED

Below are some key outcomes derived from the work conducted under Objectives 2, 4, and 5. Please note that outcomes for Objective 1 and some outcomes for Objective 4 were described in the 2014 report, and that the other objectives (Objectives 3, 6 and 7) are part of ongoing student graduate work, hence outcomes for these objectives are not included in the current annual report.

Objective 2:

- Post-fire and post reclamation sites have different plant and microbially community structure.
- Reclaimed sites function more similarly to natural sites when the forest floor begins to develop.

Objective 4:

- Reclaimed 20- to 25-year old sites had more total soil organic carbon than natural sites. Almost one third of reclaimed soil carbon was biochemically resistant carbon, compared to only 10% at natural sites, and is probably residual peat from the added peat mix surface soil horizon. Within reclamation treatments, grassland and deciduous soils had greater total soil organic carbon than coniferous soils.

Objective 5:

- Examining the spatial interactions between above and belowground components of terrestrial ecosystems gives insight into key ecological processes, which may be used to evaluate reclamation success. Results from a reclaimed 14-year old aspen stand showed that spatial heterogeneity had begun to develop for available soil nutrients, and that there was a link between stand characteristics and some below-ground properties (base cations and micronutrient availability).

PRESENTATIONS AND PUBLICATIONS

Conference presentations/posters:

Quideau*, S.A. Restoring organic matter processes in reconstructed soils. Canadian Soil Science Meetings, Montreal, Quebec. July 5-10, 2015. Invited oral presentation (keynote).

Laidlaw*, M., C. Prescott, and S. Grayston. Soil carbon stabilization under deciduous, coniferous, and grassland reclamation treatments in the Alberta oil sands. SER World Conference on Ecological Restoration, Manchester, UK. Aug 23-27, 2015. Poster.

Masse*, J., S. Grayston, C. Prescott, and S.A. Quideau. Microbial communities and nitrogen cycle in reclaimed oil-sand soils. Canadian Soil Science Meetings, Montreal, Quebec. July 5-10, 2015. Poster.

Lloret*, E., and S.A. Quideau. Microbial processing of leaf- and root-derived organic matter in the boreal forest. European Geosciences Union General Assembly, Vienna, Austria. April 12-17, 2015. Poster.

Masse*, J., S. Grayston, C. Prescott , and S.A. Quideau. Microbial communities and nitrogen cycle in reclaimed oil-sand soils. Wageningen Soil Conference, Aug 23-27, 2015. Poster.

Publications:

Beasse, M., S.A. Quideau*, and S.-W. Oh. 2015. Soil microbial communities identify organic amendments for use during oil sands reclamation. Ecological Engineering 75: 199-207.

Das Gupta*, S., M.D. Mackenzie, and S.A. Quideau. 2015. Using spatial ecology to examine above and belowground interactions on a reclaimed aspen stand in Northern Alberta. Geoderma 259-260: 12-22.

Other publications:

Laidlaw, M.2015. Soil carbon stabilization under three reclaimed vegetation types in the Alberta oil sands. M.Sc. Dissertation. University of British Columbia, Forest Sciences, 106 pages.

Das Gupta, S. 2015. Spatial variability in disturbed boreal ecosystems: An aboveground-belowground approach. Ph.D. Thesis. Department of Renewable Resources, University of Alberta. Edmonton, AB. 226 pages.

Martin, J. 2015. M.Sc. Nitrogen, plant and microbial community dynamics in sites recovering from wildfire and surface mining in the Athabasca Oil Sands Region M.Sc. Dissertation. Department of Renewable Resources, University of Alberta. Edmonton, AB. 68 pages.

RESEARCH TEAM AND COLLABORATORS

Institutions: University of Alberta and University of British Columbia

Principal Investigators: S.A. Quideau, M.D. MacKenzie, S.M. Landhäusser, C. Prescott, S. Grayston, R.F. Grant, R.E. Wasylishen.

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Preston Sorenson	University of Alberta	M.Sc.	September 2008	January 2011
Tyrel Hemsley	University of Alberta	M.Sc.	September 2009	January 2012
Aria Hahn	University of Alberta	M.Sc.	September 2009	January 2012
Mark Beasse	University of Alberta	M.Sc.	September 2009	September 2012
Charlotte Norris	University of Alberta	PhD	January 2009	September 2013
Jill Martin	University of Alberta	M.Sc.	September 2010	September 2015
Emily Lloret	University of Alberta	PDF	April 2011	August 2013
Sanatan Das Gupta	University of Alberta	PhD	June 2011	April 2015
Jeff Anderson	University of British Columbia	M.Sc.	September 2011	April 2014
Meghan Laidlaw	University of British Columbia	M.Sc.	September 2012	April 2015

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Mathew Swallow	University of Alberta	PDF	September 2012	August 2014
Jacynthe Masse	University of British Columbia	PhD	September 2011	Ongoing
Nilusha Welegedara	University of Alberta	PhD	January 2013	Ongoing
Brittany McAdams	University of Alberta	M.Sc.	May 2015	Ongoing
Cassandra McKenzie	University of Alberta	M.Sc.	May 2015	Ongoing

Revegetation

Industrial Research Chair in Forest Land Reclamation

COSIA Project Number: LE0012

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Transalta Corporation, Suncor Energy Inc., Imperial, Shell Canada Energy, Canadian Natural Resources Limited, Devon Energy

Status: Year 2 of 5

PROJECT SUMMARY

Oil sands extraction is a major component of the Albertan and Canadian economy but the associated surface mining completely disrupts forest ecosystems. A pressing objective of land reclamation in the boreal forest region is to return disturbed sites to fully functioning and self-sustaining ecosystems. Early in the recovery of forests, the main challenge is rapid re-development of a tree canopy to create conditions that initiate and sustain abiotic and biotic processes characteristic of functioning forest ecosystems. The first Industrial Research Chair (IRC) program dealt with the use of trembling aspen, a tree species native to the boreal forest, to quickly develop a forest canopy. Great progress has been made in developing better aspen planting stock, and increasing the establishment success of aspen on stressed sites that hastened the development of a closed tree canopy. Building on this, the renewal of the IRC program is examining critical issues related to growth constraints, such as limited soil nutrients and high competition, during stand initiation and development. In addition, it is exploring the use of different topographical features to promote more spatially diverse site conditions resulting in more diverse plant communities.

To provide Canadian resource industries with a clear path to reconstruct boreal forests, the specific deliverables from the project include:

- further development of new techniques to manage the establishment and growth of trees on reclamation sites;
- development of indicators for site conditions suitable for the natural establishment of understory species;
- assessment of risks associated with forest development, in particular ones related to water use and availability in reclaimed forest landscapes; and
- the development and testing of planning tools.

PROGRESS AND ACHIEVEMENTS

Accelerating forest establishment:

To expedite initial forest establishment (stand initiation and early growth), the IRC program is investigating the use of various soil amendments and techniques to ameliorate limiting site conditions, enhance meso- and micro-topography, and explore the use of less dominant tree species for reclamation purposes.

To explore the use of tall aspen stocktypes for planting on competitive grassy sites Kyle Le (M.Sc. candidate) re-measured the performance of aspen stock on sites that had been established in 2014. Overall seedling performance was poor due to the very dry conditions in 2015 and Kyle is currently in the process to summarize his data. Re-measurements will take place in 2016 to evaluate mortality that might have occurred as a result of the dry conditions. The project should be completed by mid-2016. An operational scale field study at Highvale (TransAlta) was set up

in the fall of 2015 to test the arrangement and usage of different amendments for successful tree establishment on nutrient limited sites. Erika Valek (M.Sc. candidate) started in the fall and will be leading this study. The project is in early development and results will not be available until 2017 at the earliest. Another study was set up at Shell's oil sands mine in 2014. This operational study tests questions related to the feasibility of enhanced meso-topography for natural establishment of vegetation and trees. Kate Melnik (M.Sc. candidate) has taken a lead to explore the effects and is in the process of summarizing her initial results. Seedlings were also planted on this site and a second M.Sc. student will be recruited to explore seedling performance in relation to topographical position on these sites. This study is just starting and initial results can be expected in 2017.

Preliminary work to determine if a study to test the effectiveness of specific fertilizer formulations for the three surface soils at Aurora is feasible has been completed (Jana Bockstette M.Sc. candidate). It appears that while some nutrients limitations (in particular phosphorous and potassium) may be present, they are not sufficiently severe to be of great concern at this time. We will monitor leaf nutrients at this site in 2016 and reevaluate the feasibility once the new data are available.

Influencing forest stand trajectories:

Following initial stand establishment many reclamation sites take more than 10 to 15 years to reach canopy closure. In this time, understories are developing that can be dominated by undesirable species, with potentially undesirable effects on stand development. The IRC program is exploring stand management strategies (e.g., intervention practices) that could facilitate and improve forest canopy and understory development on older reclamation sites with sparse canopies.

In 2015 we explored the feasibility of cutting juvenile (8-12 years) aspen of seedling origin to increase stem density through root suckering. The measurements are currently being summarized and results can be expected in the next report. Carolyn King (M.Sc. candidate) is taking the lead in this study. Under the same topic Caren Jones (M.Sc. candidate) is exploring the influence of planted tree selection on understory plant community development. This study is closely linked to the Aurora soil capping study. Early results suggest that in the first three years planted tree seedlings had little effect on the plant community development and richness but after the last measurement (2015) some difference in community development appeared. In addition, Caren's project explores the impact of long distance seed dispersal on understory vegetation dynamics on reclamation sites.

Assessing trajectories of forest reclamation:

There has been over 30 years of forest land reclamation in the oil sands area. Assessment of stand trajectories as a result of past reclamation strategies will provide insights into tree growth, leaf area development, forest structure, soil development and soil-water availability of these reclaimed forests. Soil water availability and water-use as main drivers of forest stand performance on reclamation sites are being explored.

In a study that was established in the summer of 2014 on Syncrude's South Bison Hills. Dr. Jeff Kelly (PDF) lead this study in which the relationships between climate driven water use (sapflow) of aspen and spruce canopy trees were explored and investigated how it is influenced by capping material thickness and rooting depth. This was repeated in 2015 in order to get a more complete data set. Morgane Merlin (Ph.D. student) took over the project in 2015. In addition to the sapflow measurements a number of soil cores were collected to explore rooting depth and root mass distribution on this site. No firm results are yet available but everything is set to correlate sapflow data with other climatic and edaphic data collected by Syncrude, other colleagues and their research groups on the same site. This study is ongoing and first results should be available in the next report.

OUTCOMES AND LESSONS LEARNED

This project is not yet at the stage to report on outcomes and lessons learned.

PRESENTATIONS AND PUBLICATIONS

There are not yet any publications resulting from work under the current IRC. However, there are publications that continue to be generated from the original chair as listed below. Also listed below in a separate category are publications that were closely associated with or influenced by the chair.

Refereed publications related to chair program:

Landhäusser SM, Wachowski J & Lieffers VJ 2015. Transfer of live aspen root fragments, an effective tool for large scale boreal forest reclamation. Canadian Journal of Forest Research 45: 1056-1064.

Macdonald SE, Snively AEK, Fair JM & Landhäusser SM 2015. Early trajectories of forest understory development on reclamation sites: influence of forest floor placement and a cover crop. Restoration Ecology 23: 698-706.

Kelly JWG, Landhäusser SM, & Chow PS 2015. The impact of light quality and quantity on root-to-shoot ratio and root carbon reserves in aspen seedling stock. New Forests 46: 527-545.

Other refereed publications:

Macdonald, S.E., S. Landhäusser, J. Skousen, J. Frouz, S. Quideau, S. Hall, J. Franklin, D. Jacobs. 2015. Forest restoration following surface mining disturbance: Challenges and solutions. New Forests 46: 703-732.

Karst J, Chow PS & Landhäusser SM 2015. Biases underlying species detection using fluorescent amplified-fragment length polymorphisms yielded from roots. Plant Methods 11: Article Number: 36.

Hankin SL, Karst J & Landhäusser SM 2015. Influence of tree species and salvaged soils on the recovery of ectomycorrhizal fungi in upland boreal forest restoration after surface mining. Botany 93: 267-277.

Bachmann S, Lieffers VJ & Landhäusser SM 2015. Forest floor protection during drilling pad construction promotes resprouting of aspen. Ecological Engineering 75: 9-15.

Petrone RM, Chasmer L, Hopkinson C, Silins U, Landhäusser SM, Kljun N, & Devito KJ 2015. Effects of harvesting and drought on CO2 and H2O fluxes in an aspen-dominated western boreal plain forest: early chronosequence recovery. Canadian Journal of Forest Research 45: 87-100.

Quentin AG, Pinkard EA, Ryan MG, Tissue DT, Baggett LS, Adams HD, Maillard P, Marchand J, Landhäusser SM et al. 2015. Non-structural carbohydrates in woody plants compared among laboratories. Tree physiology 35: 1146-1165.

Jacobs DF, Oliet JA, Aronson J, Bolte A, Bullock JM, Donoso PJ, Landhäusser SM, Madsen P, Peng SL, Rey-Benayas JM & Weber JC 2015. Restoring forests: What constitutes success in the twenty-first century? New Forests 46: 601-614.

Gaster J, Karst J & Landhäusser SM 2015. The role of seedling nutrient status on development of ectomycorrhizal fungal communities in two soil types following surface mining disturbance. Pediobiologia 58: 129-135.

Completed theses associated with the original chair:

Gaster J.R. 2015.The role of nutrient and carbon reserve status of aspen seedlings in root-soil interactions. M.Sc. Thesis, University of Alberta, 84 pages.

Hankin S.L. 2015 Native tree seedling interactions with variations in edaphic properties in upland boreal forest restoration. M.Sc. Thesis, University of Alberta, 142 pages.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Jana Bockstette	University of Alberta	M.Sc.	2013	ongoing
Caren Jones	University of Alberta	M.Sc.	2013	ongoing
Kyle Le	University of Alberta	M.Sc.	2014	ongoing
Katherine Melnik	University of Alberta	M.Sc.	2014	ongoing
Simon Bockstette	University of Alberta	Ph.D.	2011	ongoing
Morgane Merlin	University of Alberta	Ph.D.	2015	ongoing
Carolyn King	University of Alberta	M.Sc.	2015	ongoing
Erika Valek	University of Alberta	M.Sc.	2015	ongoing
Robert Hetmanski	University of Alberta	Research Assistant		
Angeline Letourneau	University of Alberta	Research Assistant		
Mika Little-Devito	University of Alberta	Research Assistant		
Jeff Kelly	University of Alberta	Postdoctoral Fellow		
Fran Leishman	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

Industry Funders (through Land EPA): Syncrude Canada Ltd., BP Canada; Canadian Natural Resources Limited; Cenovus Energy Inc.; ConocoPhillips Canada Resources Corp.; Devon Canada Corporation; Imperial; Nexen; Shell Canada Energy; Statoil Canada Ltd.; Suncor Energy Inc.; Teck Resources Limited; Total E&P Canada Ltd.; and TransAlta.

Developing a Functional Approach to Assessment of Equivalent Capability: Utilizing Ecosystem Water, Carbon and Nutrient Fluxes as Integrated Measures of Reclamation Performance

COSIA Project Number: LJ0127

Research Provider: McMaster University, University of Waterloo and Integral Ecology Group

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Suncor Energy Inc.

Status: Year 3 of 5

PROJECT SUMMARY

This project seeks to develop an alternate approach to the assessment of equivalent capability and reclamation performance directly based on, and linked to, ecosystem function, by leveraging long-term eco-hydrological research that measures growing-season water and carbon balances across a range of reclaimed land and recovering boreal forest ecosystems. This alternative function-based approach is based on the following premises:

- that long-term and intensive research on water, carbon and nutrient fluxes on a small number of instrumented reclamation sites can provide in-depth mechanistic understanding of ecosystem function and trajectories on these sites and provide detailed records of performance over time;
- that identified relationships between flux measurements and a select number of more easily assessed biometrics (e.g., vegetation characteristics) will permit this mechanistic understanding to be extended to non-instrumented sites, thereby allowing a spatially extensive, low-intensity application of findings across reclaimed landscapes, for internal and external (certification) evaluation of equivalent capability and reclamation performance; and
- that conducting similar research in juvenile ecosystems on non-mine sites disturbed through fire or forest harvest can provide ranges of natural variation for key parameters, and thus the performance “envelopes” for definition and evaluation of equivalent capability.

Through this approach, alternate metrics for reclaimed land assessment that are directly linked to the fundamental processes of ecosystem function may be discovered. This will allow more relevant and realistic evaluation of equivalent capability, as well as defining time frames for this evaluation.

This project is divided into three work packages (components): WP1, WP2 and WP3. WP1 is being undertaken by McMaster and Waterloo universities, WP2 is being completed by Integral Ecology Group, while WP3 is a cooperative effort between all three entities.

PROGRESS AND ACHIEVEMENTS

For WP1: WP1 (Process Ecohydrology) focuses on understanding and quantifying the linkages between hydroclimatic (water table, soil moisture and tension distributions, evapotranspiration) properties, soil physical properties and nutrient (nitrogen N, phosphorus P, potassium K) availability and pathways and carbon exchange (net ecosystem exchange, NEE) at the ecosystem scale for existing installations. For WP1, activity is underway and there are a number of students/post-doctoral fellows engaged in this project. Bio-meteorological stations are running on each of the identified sites to continue long-term data collection.

Key Findings from this research to date include:

1) We now have over fifty-three location-years of total growing season water and carbon flux data over reclamation and regenerated sites using the eddy covariance technique, along with extensive hydrologic, climatic and biometric data. In terms of hydrological fluxes, evapotranspiration (ET) dominates water loss from reclaimed, regenerating and undisturbed upland and wetland systems. The processes that drive ET are largely driven by climate (radiation, temperature, precipitation), yet as stands mature, a greater influence is exerted by the vegetation in regulating water loss. At most sites and in most years, water does not appear to be a limiting factor in establishing upland forest ecosystems. Data suggests that water in reclaimed soils is sufficient to support upland vegetation establishment. While there are some temporal delays in cases with reduced moisture availability, over time, forest establishment does occur. There is a robust relationship between leaf area index (LAI) and ET, highlighting it as a first-order metric of ecosystem water use.

2) ET among sites is variable, yet largely explainable by annual climate variations and vegetation age/type. There is little difference in ET among reclaimed, regenerating and natural systems with similar stand properties, although different sites may have different trajectories, and thus take different lengths of time to reach similar stand conditions. ET fluxes observed at regenerating reclaimed sites are similar to those observed in mature and harvested boreal stands. For the growing season, aspen forests lose more water than their coniferous counterparts. Forests regenerating after harvest recover faster than reclaimed sites, particularly with regards to aspen and their clonal rooting system. While we do not yet have a definitive timeline, maximum water use among reclaimed sites appears to be achieved by approximately 10-years post stand establishment. Long-term mine management must consider temporal evolution of vegetation along with forest type, but the meaningful trajectory of this evolution appears to be shorter than previously believed.

3) Carbon fluxes (particularly gross ecosystem photosynthesis) at reclaimed sites are similar to those reported at regenerating sites and mature sites in the published literature, with some exceptions. Following disturbance, ecosystems typically lose carbon (C) due to the presence of labile material at the surface, which enhances respiration. At reclaimed sites, recalcitrant C of the placement material appears to limit respiration, allowing the system to accumulate C more quickly than naturally disturbed regimes. Water Use Efficiency (WUE), which links photosynthesis with water use, provides a useful metric to compare ecosystems and evaluate their utilization of resources. WUE defines how productive a site is in a given moisture regime, which will establish the successional pathway of the system as climatic and hydrologic conditions change and evolve, and shows a clear discrimination among ecosystem types. Aspen stands assimilate more carbon per unit weight of water than conifers. WUE also changes with time as ecosystems become more effective at transpiring water through plant pathways compared with bare-soil evaporation.

4) The concept of developing a functional-based approach for evaluating reclaimed peatlands requires quantifying the primary interactions and feedback processes that underlie various peatland ecosystem functions. Results thus far highlight the sensitivity of microbial-mediated biogeochemical processes to a range of variability in other ecosystem processes. While WUE and moisture regimes seem to be the dominant controls on successional pathways of forested systems (and therefore the assessment), peatlands appear to be more influenced by the establishment of biogeochemical processes, and are ultimately more controlled by relative nutrient states. Thus, in the assessment of the functional capacity and successional pathways of peatland systems, microbial-mediated biogeochemical processes present potential functional indicators of ecosystem function. Work so far on the evolution of above and below-ground nutrient transformation processes in reclaimed and natural peatlands illustrate that revegetation facilitates both above-ground productivity and the cycling of below-ground nutrients. Supply of labile substrates with re-vegetation increased microbial potential activity, which was reflected in higher rates of nutrient acquisition and productivity. Nutrient dynamics within reclaimed systems suggest that phosphorus limitation could hamper

the establishment of a diverse plant community, whereas the build-up of microbial biomass appears to be nitrate limited. Ammonification, nitrogen mineralization and phosphorus availability were identified as potential functional indicators of the fen's recovery.

For WP2: WP2 is scheduled for 2013-2016, making 2015 the 3rd of the 4-year program. The purpose of this work is to characterize vegetation and soil conditions and trends over time on the instrumented research sites in order to link eco-hydrologic measures with vegetation-based measures of reclamation development and success. During the 2015 field season, work focused on characterizing upland sites co-located with active eddy-covariance-towers (four reclaimed, two reference). One new site was added on the side slopes surrounding the Suncor Nikanotee constructed fen to ensure that soil and vegetation were characterized for the larger research catchment. Sites that were co-located with inactive towers and wetland sites (four reclaimed, six reference) were visited for site maintenance but not measured. Measurements were conducted in 89 permanent sample plots (64 reclaimed, 25 reference). At each site, data was collected on forest-stand characteristics (tree densities, heights, diameters, and ages); foliar nutrition (chemistry) of dominant tree species; and vegetation-community characteristics (prominent species presence and cover, LAI). In addition, soil characterization and sampling was conducted at the new Suncor Nikanotee constructed fen site to describe cover materials and substrate, and to collect samples for analysis of particle-size distribution. The 2015 dataset has been compiled and is ready for synthesis with the WP1 data from co-located flux towers. At this time, the planned field component of the program has been completed, with 194 permanent sampling plots installed on 17 sites.

As noted above, this vegetation characterization and examination of relationships with measured fluxes has demonstrated a robust relationship between LAI and ET – this relationship and others such as those between fluxes and site index will continue to be explored as the project moves forward.

For WP3: This work package consists of synthetic interpretations of data collected in WP1 and WP2, and previous related work. It is scheduled to run from 2014-2017, making 2015 the 2nd year of a 4-year program, with the majority of effort devoted to interpretations and reporting in 2017. At this time synthesis discussions are ongoing, and research meetings were held with industry funders in March 2015, and with non-industry research partners in November 2015. A timeline for future research meetings and knowledge synthesis activities has been established.

OUTCOMES AND LESSONS LEARNED

For all work packages (WPs), emerging outcomes are discussed above. As the knowledge-synthesis component of this project (WP3) is still in its early phases, it is too early to speculate on outcomes and lessons learned, other than to observe that progress is being made on stated objectives and that potential vegetation-flux relationships and expected developmental trajectories – including "envelopes" of performance for evaluating equivalent capability – are beginning to be identified for studied stand types.

PRESENTATIONS AND PUBLICATIONS

Theses:

Elise Gabrielli (MSc In Progress) "Partitioning Canopy and Surface Contributions to Peatland ET" Contributions to this project: Information on what scale gives the most efficient idea of water loss from a peatland.

Midori Depante (MSc In Progress) "Moisture and Nutrient Sources for Regenerating Aspen WUE" Contributions to this project: Quantifying thresholds in moisture and nutrient status, as well as sources for Aspen regeneration.

Tristan Gingras-Hill (MSc In Progress) “Biogeochemical Controls on Upland Reclamation Success” Contributions to this project: Determining foliar nutrient levels as an indication of upland nutrient use efficiency.

Nichols, Erin (MSc, Completed) “Multi-year water balance of a newly constructed wetland-upland watershed, Fort McMurray, Alberta”.

Thorne, Chelsesa (MSc, Completed) “A comparison of soil nitrogen availability along hillslopes for a previously mined reclaimed wetland and two natural wetlands in Fort McMurray, Alberta”

Related Presentations:

Chasmer LE, Hopkinson C, Devito KJ, Petrone RM 2015. Quantifying ecosystem resilience to climate change in the Western Boreal Plains. 26th International Union of Geodesy and Geophysics General Assembly, Prague, Czech Republic, June 22 – July 2, 2015.

Gabrielli E, Petrone RM 2015. Quantifying and characterizing conifer evapotranspiration in two natural Boreal fens, Fort McMurray. 21st Symposium Peatland Ecology Research Group, Waterloo, Ontario, February 18, 2015.

Nicholls EM, Carey SK, Drewitt GB, Humpreys EM, Mendoza C 2015. Multi-year water balance dynamics of a newly constructed watershed, Fort McMurray, Alberta. American Geophysical Union – Canadian Geophysical Union Joint Assembly, Montreal, Quebec, May 3 – 7, 2015

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Nwaishi F, Petrone RM, Andersen R, Price, J 2015. Towards developing a functional-based approach for constructed peatlands evaluation in the Alberta Oil Sands Region, Canada. Canadian Oil Sands Innovation Alliance Land EPA 2015 Land Workshop, Calgary, Alberta, January 29 – 30, 2015.

Petrone RM 2015. Productivity and Water Availability: Balancing the Role and Needs of Peatlands in Landscape Reclamation. University of Waterloo Water Institute Symposium, Waterloo, Ontario, April, 2015.

Petrone RM, Carey SK, Straker J 2015. Water, Energy and Carbon Balance Research: Recovery Trajectories for Oilsands Reclamation and Disturbed Watersheds in the Western Boreal Forest. Canadian Oil Sands Innovation Alliance Land EPA 2015 Land Workshop, Calgary, Alberta, January 29 – 30, 2015.

Petrone RM, Carey SK, Straker J 2015. Water, Energy and Carbon Balance Research: Recovery Trajectories for Oil Sands Reclamation and Disturbed Watersheds in the Western Boreal Forest, 26th International Union of Geodesy and Geophysics General Assembly, Prague, Czech Republic, June 22 – July 2, 2015.

Petrone RM, Sutherland G, Wells C, Nwaishi F, Price JS 2015. Water Use Efficiency at the Community to Ecosystem Scales of a Newly Reclaimed Fen. Canadian Oil Sands Innovation Alliance Land EPA 2015 Land Workshop, Calgary, Alberta, January 29 – 30, 2015.

Thorne C, Carey SK, Humphreys E, Macrae ML, Petrone RM 2015. A Comparison of Soil Nitrogen Availability Between a Post Mined Reclaimed Wetland and Two Natural Wetlands in Fort McMurray, Alberta, American Geophysical Union – Canadian Geophysical Union Joint Assembly, Montreal, Quebec, May 3 – 7, 2015.

Related publications:

Huang M, Barbour SL, Carey SK 2015. The impact of reclamation cover depth on the performance of reclaimed shale overburden at an oil sands mine in Northern Alberta, Canada. Hydrological Processes 29:2840-2854, doi:10.1002/hyp.10229.

Nicholls EM, Carey SK, Humphreys EH, Clarke MG, Drewitt GB 2015. Multi-year water balance assessment of a newly constructed wetland, Fort McMurray, AB. Hydrological Processes, - accepted with revisions.

Nwaishi F, Petrone RM, Macrae ML, Price JS, Strack M, Slawson R, Andersen R. In Press. Above and Below-ground Nutrient Cycling: A Criteria for Assessing the Biogeochemical Functioning of a Constructed Fen. Applied Soil Ecology – 10/15; doi:10.1016/j.apsoil.2015.10.015.

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Rooney R, Robinson D, Petrone RM 2015. Megaproject reclamation and climate change. Nature Climate Change, 2015, 5: 963-966.

RESEARCH TEAM AND COLLABORATORS

Institutions: McMaster University / University of Waterloo / Integral Ecology Group

Principal Investigators: Sean Carey / Richard Petrone / Justin Straker

Name	Institution	Degree	Start Date	Completion Date
Stacey Strilesky	McMaster / Carleton	PhD	Sept 2014	August 2018
Gordon Drewitt	McMaster University	Research Associate	January 2015	December 2017
Erin Nicholls	McMaster University	MSc	Sept 2013	Sept 2015
Chelsea Thorne	McMaster University	MSc	Sept 2013	August 2015
Felix Nwaishi	University of Waterloo	Post Doctoral Fellow	December 2015	December 2018
George Sutherland	University of Waterloo	Research Associate	January 2015	December 2018
Elise Gabrielli	University of Waterloo	MSc	September 2013	February 2016
Tristan Gingras-Hill	University of Waterloo	MSc	September 2014	December 2016
Midori Depante	University of Waterloo	MSc	September 2013	February 2016
Janina Plach	University of Waterloo	Post Doctoral Fellow	September 2014	May 2016
Jeff Anderson	Integral Ecology			
Trevor Baker	Integral Ecology			
Meghan Laidlaw	Integral Ecology			

Industry Lead: Craig Farnden, Syncrude Canada Ltd.

Native Balsam Poplar Clones for Use in Reclamation of Salt-Impacted Sites

COSIA Project Number: LJ0202

Research Provider: Alberta-Pacific Forest Industries Inc.

Industry Champion: Syncrude Canada Ltd.

Status: Year 2 of 5

PROJECT SUMMARY

The main objective of this research is to identify and select balsam poplar clones from the Alberta-Pacific (Al-Pac) Controlled Parentage Program Plan (PB1 – CPP) for balsam poplar (*Populus balsamifera*) (2011) (CPP) that are well adapted to, and are appropriate for planting on growing sites challenged with elevated dissolved salt concentrations on reclaimed oil sands mine sites.

It is hypothesized that balsam poplar clones exhibiting tolerance to salts in greenhouse trials (identified by exposure to varying concentrations of oil sands process-affected water (OSPW)) will have higher survival and increased growth (e.g., height and diameter) on reclamation sites than either: i) poplar clones tested with OSPW that did not exhibit tolerance to elevated salt concentrations, or ii) a local Stream I Syncrude balsam poplar cutting collection (Syncrude control). The null hypothesis is that no such differences exist.

A total of 35 clones selected from Al-Pac's PB1 - CPP registered clonal population were included in this field study based on the results from previously completed salt screening. Twenty-five of these clones were the top performing clones in the 50% OSPW treatment (high salt treatment) and were chosen as the 'salt tolerant treatment group' (Treatment 1) and 10 of the remaining clones that did not exhibit salt tolerance in the 50% process affected water treatment were chosen as a control group (Treatment 2). The Syncrude Stream I cuttings (Treatment 3) were included as a second control to compare the Al-Pac CPP clones to a local unscreened population.

Three discrete trials were established in fall 2014: trial one was established on the south shore of Base Mine Lake, trial two was established in the southeast corner of Sandhill Fen and trial three was established on Sand Islands "A" and "B" within the Sandhill Fen. All three trials were laid out as a randomized block design with single tree plots. Trials one and two were established with four ramets of each of 35 Al-Pac clones and 60 Syncrude control trees planted in three blocks (for a total of 200 trees in each block).

On the sand islands, there was one tree of each of the 35 Al-Pac clones and 25 Syncrude control trees planted in each of six blocks. Each block had a total of 60 trees (10 trees x 6 trees) with three blocks planted on each of the two sand islands (180 trees per island).

A further operational trial is intended for establishment at a larger scale in current reclamation on Kingfisher Fen when the site becomes available for planting.

PROGRESS AND ACHIEVEMENTS

During the summer of 2015 the trial sites were visited to conduct a preliminary qualitative assessment of survival, and growth. At this time naturally regenerated balsam poplar seedlings/suckers were removed in trial two located

within the Sandhill Fen to eliminate potential confusion between ingress versus planted experiment trees. Flagging and tagging was redone in all trials where flags or tags had fallen off to maintain tree visibility and identity.

On October 22-23, 2015, following the first complete year of growth, all of the trees were assessed for survival, and measured for height and basal diameter. Growth increments were calculated from the difference between year 1 measurements and initial measurements (trees were measured prior to planting).

Growth increments were small but consistent across all treatments in both the Sandhill Fen trial two and on Sand Island A of trial three. Mean growth across all treatments was 8.3cm for height and 0.7mm for basal diameter for Sandhill Fen and 6.6cm for height and 0.9mm in basal diameter for Sand Island A. Survival was high ranging from 94-100% for individual treatments in trial two and on Sand Island A. Sand Island B was flooded for an extended period of time in the spring of 2015, and as a result the majority of the trees died, irrespective of source and, therefore, it is suggested that further monitoring of this site not be continued.

Growth increments in trial one, planted along Base Mine Lake showed some individual trees grew as much as one meter in height and up to 14 mm in basal diameter. Mean survival across treatments at Base Mine Lake was 89%. Detailed analysis of treatment and clone effects has not been completed to this point for any of the trials included in this experiment.

Sampling and measurements will continue until the fall of 2018.

OUTCOMES AND LESSONS LEARNED

This project is not yet at the stage to report on outcomes and lessons learned.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta-Pacific Forest Industries Inc.

Principal Investigator: Barb Thomas; University of Alberta and Dave Kamelchuk; Little Creek Agroforestry

Selected Willow Clones for Use in Reclaimed Ecosystems Impacted by Elevated Salt Levels

COSIA Project Number: LJ0203

Research Provider: Natural Resources Canada

Industry Champion: Syncrude Canada Ltd.

Status: Year 2 of 3

PROJECT SUMMARY

In Alberta oil sands reclamation, oil sands process-affected water (OSPW) is expected at varying concentrations in the closure landscape. OSPW contains various constituents including naphthenic acids and elevated levels of salts which may adversely affect plant growth when concentrations of these compounds reach unacceptable levels. Potentially impacted ecosystems include water bodies and their shorelines, peatlands, lowland forests and seepage sites.

Many species of willow commonly occur in the environments most at risk from exposure to OSPW, and are frequently a major structural component of lowland and riparian ecosystems. Willows are often deployed early in the reclamation of these areas based on their value for slope and shoreline stabilization. As such, they often play an important role in oil sands mine reclamation efforts.

A recent greenhouse study conducted by Natural Resources Canada (NRCan) has identified several clones of various native willow species that appear to have particularly high tolerance to OSPW. The current study is a field deployment of 15 native willow clones previously identified as having the highest tolerance levels.

The objectives of the study are to:

1) Determine if willow clones, previously identified in greenhouse studies as tolerant to OSPW, are also tolerant to in-situ conditions when planted along the shoreline of an end-pit lake containing OSPW by monitoring:
    - survival
    - growth rate
    - foliar chemistry;
2) Monitor the soil moisture and soil chemistry in the rooting zone of the willows.
3) Assess the potential of willows to stabilize the shorelines of end-pit lakes by evaluating the root growth of selected willow clones.

Approximately 1000 willow container seedlings (6 native species with a variable number of genotypes per species) were grown from cuttings during the summer of 2013, hardened off and cold stored for planting in spring of 2014. Seedlings were planted at the water's edge, and 30, 60, 120 and 240 centimeters up the slope. Monitoring of growth is being accompanied by environmental assessments including soil pore water chemistry, soil texture, bulk density, soil water content, photosynthetically active radiation, temperature, root development and foliar chemistry.

PROGRESS AND ACHIEVEMENTS

Seedling survival was assessed one week after planting, at the end of the first growing season (2014), and in the spring and fall of 2015. Stem length and stem diameter at soil level was measured in the fall of 2014 and 2015. All leaves from the top 30 cm of the tallest shoot of 4 seedlings at each of the four replications of one clone were

collected at the planting position at the water's edge and 240 cm up slope. The samples were sent to a commercial lab for tissue analysis.

Twenty-eight lysimeters were installed at the time of planting, and an additional 21 mini lysimeters were installed in the fall of 2015. Soil pore water was collected from 15 of the older units in the fall of 2015 and is being analyzed. The additional units were installed to increase the probability of collecting soil pore water from a well at each planting position up the slope and each sampling depth (15 and 30 cm).

Soil samples (0-15, 15-30cm) were collected in the same planting row as the older soil lysimeters and are being analyzed. Soil water content is being continuously monitored 15 cm below the soil surface at two locations at the shoreline and 60, 120 and 240 cm planting positions along the slope.

The project began in the winter of 2013 with the collection of willow cuttings for stock production. We have completed two growing seasons of the three planned for the project. The last growth measurement is planned for the fall of 2016 with a final report delivered by the spring of 2017.

OUTCOMES AND LESSONS LEARNED

One week after planting, one percent of the seedlings planted were dead or missing. The predominat source of mortality was damage by rodents. Survival at the end of the first growing season was 94%. Of the seedlings that died, only one was located at the water's edge. At the end of the second growing season, survival was 93%. The additional mortality occurred at the 30 and 120 cm planting location.

There was a significant difference in stem length increment between clones at the end of the first growing season. The differences between clones are more a function of the inherent growth form differences between the six species than to treatment effects. Some species have a prostrate growth form while others have a columnar growth form. Stem length increment in the first growing season ranged from an average of 20 to 140 centimeters depending on the clone. Stem length increment in the second growing season ranged from 6 to 90 cm depending on clone.

All of the willow clones in the trial grew well regardless of slope position as represented by stem length increment in the first and second years. Stem length increment was generally numerically less for the 0 slope position compared to the higher slope positions; however, the difference was only statistically different from the 60 cm mid-slope position.

Soil pore water, soil and leaf chemistry data are being compiled and will be assessed over the winter of 2015-16.

PRESENTATIONS AND PUBLICATIONS

Krygier, R. 2015. Using willows for shoreline stabilization of end-pit lakes containing oil sands process-affected water. Poster given at the 12th International Conference, International Phytotechnology Society- Phytotechnologies for Sustainable Development. 2015 September 27-30, Manhattan, Kansas.

RESEARCH TEAM AND COLLABORATORS

Institution: Natural Resources Canada, Canadian Forest Service, Edmonton

Principal Investigator: Richard Krygier

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Martin Blank	Natural Resources Canada	Land Reclamation Technician		

A Forest Fertilization Trial in a Mildred Lake Jack Pine Stand

COSIA Project Number: LJ0209

Research Provider: University of British Columbia

Industry Champion: Syncrude Canada Ltd.

Status: Year 5 of 5

PROJECT SUMMARY

This study investigates application of fertilizers in a controlled experiment on a reclaimed 19-year old (at start of study) jack pine stand that has reached canopy closure. The soil cover design is a direct placement of peat-mineral mix to target depth of 50 cm directly over tailings sand. The hypothesis is that fertilizer blends identified during an initial screening trial would result in increases in tree growth. The initial screening trial employed 16 exploratory fertilizer treatments applied to 80 two-tree plots (five replicates per treatment). Vector analysis of changes in needle mass and foliar nutrient content after the first growing season was used to recommend fertilizer rates and formulations for the main trial. Final treatments included nitrogen (N), phosphorus (P), sulfur (S), potassium (K), and the micronutrients copper (Cu) and magnesium (Mg) formulated as NPS and NPKS + Cu and Mg. An original option to also thin the stand as part of the suite of treatments is not being pursued.

The trial is set up as a randomized block design, with blocking by initial mean tree height. Twenty plots were established with four replicates of (originally) five treatments: control, NPS fertilizer, NPKS + micronutrient fertilizer, thin, and thin + NPS fertilizer. Given that the thinning will not be undertaken, the control and NPS treatments have effectively been duplicated with eight replicates each.

Each fertilizer plot is 35 m square, including a 5 m treated buffer. The measurement area of each plot is divided into three sections, with half the plot in each case being evaluated for tree growth. One quarter of each plot is available for evaluations of understory vegetation response, and one quarter for the addition of supplementary studies. As of autumn 2014, the plots have been measured three times (with the first occurring prior to treatment).

An additional post-hoc study, initiated following early observations in the stand, has been completed. The objective of this study was to identify correlations between observed variations in pre-treatment tree growth and measurable soil parameters. A journal article highlighting correlations between soil properties and tree growth has been produced (Farnden et al. 2013).

PROGRESS AND ACHIEVEMENTS

In the current reporting period, a re-measurement of the trial was undertaken to detect growth variations during the third growing season after treatment.

OUTCOMES AND LESSONS LEARNED

The screening trial indicated a likely growth response to a combination of N, P and S nutrients based on first year foliar mass increases.

Overall, three-year growth response (2012 – 2015) to both treatments was small and highly variable. Applications of NPS and NPS + Cu and Mg resulted in a 1.0 % (0.3% standard error) and 1.5% (0.5% SE) increase in three-year basal

area increment, respectively. Both treatments were statistically different from the control but only at the $\alpha < 0.1$ level. No blocking effect was found. Growth response in this study is lower than similar studies of natural jack pine treated with urea based fertilizers in the same time period (Weetman and Algar, 1974). High variability between individuals likely contributes to the low statistical power and may mask treatment effects if present.

The additional trial that was conducted on this site indicated a statistically significant correlation between soil organic matter content and tree height (Farnden et al. 2013). It was hypothesized that this relationship was strongly influenced by the contributions of N to the soil by the peat.

LITERATURE CITED

Farnden, C., R.J. Vassov, M. Yarmuch and B.C. Larson. 2013. Soil reclamation amendments affect long term growth of jack pine following oil sands mining. New Forests 33:799-810.

Weetman, G. F., & Algar, D. (1974). Jack pine nitrogen fertilization and nutrition studies: three year results. Canadian Journal of Forest Research, 4(3), 381-398.

PRESENTATIONS AND PUBLICATIONS

There were no publications or presentations in 2015

RESEARCH TEAM AND COLLABORATORS

Institution: University of British Columbia

Principal Investigator: Dr. Bruce Larson

Name	Institution or Company	Degree or Job Title	Degree Start Date	Completion Date
Adam Polinko	University of British Columbia	Ph.D	September 2014	In progress

Fertilizer Dose Response Studies

COSIA Project Number: LJ0141

Research Provider: University of Alberta

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Shell Canada Energy, Imperial, Total E&P Canada Ltd.

Status: Year 3 of 4

PROJECT SUMMARY

Reclamation of disturbed sites linked with resource extraction in oil sands is often challenged by slow revegetation success. One of the major constraints to enhanced revegetation success is the higher mortality and slow growth of planted seedlings caused by limited soil nutrients and high competition during the early establishment of seedlings. Although field fertilization has been a common practice to alleviate nutrient deficiency of the reclaimed soil, it subsequently increases competition for nutrients.

The Fertilization Dose Response project aims to examine potential application of the nutrient- loading technique in oil sands mine reclamation, as an alternative approach to field fertilization. The objective is to enhance the early establishment success of planted seedlings of trembling aspen, white spruce and jack pine.

The project consists of two phases. In the first phase of the project, a greenhouse experiment was conducted to optimize nutrient-loading of the seedlings in the nursery. In the second phase, the nutrient-loaded seedlings are being tested in the field for their growth performance. Once loaded with nutrients in the nursery, seedlings have greater nutrient reserves that they can use for early establishment after outplanting in the field. Nutrient-loaded seedlings are expected to have higher nutrient retranslocation from old tissues (potentially increasing new tissue growth), as compared to conventionally produced seedlings. Improved new tissue growth favours the early establishment of roots and their contact with the soil. The roots can then exploit nutrients and moisture more effectively from the soils. This can enhance survival and early growth of seedlings. Because of the greater nutrient reserves in nutrient-loaded seedlings, they are expected to have better abilities to compete with understory vegetation for nutrients and moisture. The benefits of the nutrient-loading technique may be higher in reclaimed soils that have inherent adverse characteristics such as nutrient deficiency, drought and weed competition that limit plant growth.

The objectives of the present study are to examine the efficiency of nutrient-loaded seedlings to retranslocate nutrients from storage tissues to new growth and to evaluate the survival and growth performance of these seedlings in nutrient poor and weedy environments found in oil sands mine reclamation.

PROGRESS AND ACHIEVEMENTS

To examine nitrogen (N) retranslocation and field growth performance of nutrient-loaded seedlings, field experiments were established in 2014 in a reclaimed site.

In the first experiment, nutrient-loaded and conventionally produced seedlings of aspen were planted on sites with peat-mineral mix (PMM) and LFH-mineral soil mix (LFH) as cover soils. Seedlings were labelled with ^{15}N during nursery production to quantify N retranslocation into new tissues. Field and laboratory data were collected and analyzed for two growing seasons. The data include morphological parameters, nutritional status and survival of seedlings,

physical and chemical properties of soil and understory vegetation competition assessment. A draft manuscript for this experiment has been completed.

In the second experiment, nutrient-loaded and conventionally produced seedlings of white spruce and jack pine were planted on a site with PMM as the cover soil. A dataset similar to the first experiment has been collected and data analysis is in progress and a draft manuscript/thesis chapter will be completed in April 2016.

OUTCOMES AND LESSONS LEARNED

With the aspen experiment, overall survival was not affected by the treatments. However, height and root collar diameter (RCD), were increased by nutrient-loading and weed removal over two growing seasons. Nutrient-loaded seedlings yielded more new stem and leaf biomass than conventionally produced ones but the percentage allocation of biomass to roots was greater in conventionally produced seedlings. Nutrient-loading increased the N content (product of N concentration and biomass) of the seedlings. About 73 to 80% of total N demand of new tissues was met by internal N retranslocation. The N content in new tissues derived from old tissues was increased by nutrient-loading while N uptake from the soil was not changed by the treatment. Weed competition reduced N retranslocation in both PMM and LFH sites but the N uptake from the soil was reduced only in the LFH site. The increased growth and N retranslocation in nutrient-loaded seedlings can be attributed to greater nutrient reserves built up in these seedlings.

With the jack pine seedlings, nursery nutrient-loading exhibited a significant effect on growth parameters such as height, RCD and component dry mass. The effect of weed competition on growth of these seedlings was not significant. Despite a significant difference in N concentration of component parts of nutrient-loaded and conventionally produced seedlings before outplanting, the N concentration of new tissues (current needles and stems) was not different at the end of first growing season. However, N content of component parts of seedlings in the field experiment was significantly increased by nutrient-loading in the nursery. The N retranslocation into new needles of jack pine seedlings accounted for 66 to 71% of total N demand in the first year of outplanting. Nutrient-loaded seedlings were more efficient than conventionally produced seedlings to retranslocate N into new tissues.

The data for white spruce seedlings are still being analyzed.

The improved N retranslocation and growth of nutrient-loaded seedlings of aspen and jack pine in the field experiments indicate that using nutrient-loading to enhance land reclamation success was effective.

PRESENTATIONS AND PUBLICATIONS

Pokharel, P., S. Ibsen, J.H. Kwak, G.M. Jamro, K. Lou and S.X. Chang. 2015. *Nursery nutrient loading promotes growth of jack pine seedlings planted on reclaimed soils.* Canadian Land Reclamation Association and Manitoba Soil Science Society Joint Conference. Winnipeg, Manitoba, Canada, June 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott Chang

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Prem Pokharel	University of Alberta	M.Sc.	January 2014	August 2016
Stephanie Ibsen	University of Alberta	Research Assistant		
Kangyi Lou	University of Alberta	Research Assistant		
Jin-hyeob Kwak	University of Alberta	Research Assistant		

Plant Community Succession of Oil Sands Reclamation

COSIA Project Number: LJ0129

Research Provider: University of Alberta, Dept. of Renewable Resources

Industry Champion: Shell Canada Energy

Status: Year 1 of 2

PROJECT SUMMARY

An understanding of effects of reclamation treatments on plant community assembly and succession would assist in developing realistic indicators and targets for reclamation of upland oil sands sites to forest ecosystems. This should include a better understanding of the effects of topography, subsoil and substrate, cover/donor soil, soil moisture regime, coarse woody material, surface characteristics, fertilization, agronomic cover crops, planting and seeding of native species, weeds, and other factors on plant community development.

Over the 2 year duration of this project we will assemble information and data to better inform reclamation of upland oil sands sites to sustainable forest communities through a literature review, workshops, and analysis of data from CEMA long-term monitoring plots, and supplemental field data collection.

Deliverables will include:

1) A report describing how successional processes and ideas relating to plant community assembly can be effectively used in oil sands reclamation, including a literature review, analysis of existing monitoring data and collection of personal observations from individual experts and practitioners.
2) A strategy and framework to guide future plant establishment, research and monitoring projects, towards a better understanding of vegetation prescriptions.
3) A peer-reviewed paper submitted for publication in an appropriate peer reviewed journal.
4) Two workshops for exchange of information relating to plant community succession on reclaimed upland oil sands sites.

PROGRESS AND ACHIEVEMENTS

Recruitment of a Post Doctoral Fellow/Research Associate has been initiated.

OUTCOMES AND LESSONS LEARNED

None to report at this time.

PRESENTATIONS AND PUBLICATIONS

None to date.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Phil Comeau

Improving Seed Longevity Of Native Shrubs During Storage For Reclamation Of Oil Sands Mines

COSIA Project Number: LJ0195

Research Provider: University of Saskatchewan

Industry Champion: Shell Canada Energy

Industry Collaborators: Shell Canada Energy, Canadian Natural Resources Limited, Imperial, Suncor Energy Inc., Syncrude Canada Ltd., Total E&P Canada Ltd.

Status: Year 5 of 5

PROJECT SUMMARY

Vegetation of reclaimed land in the oil sands region requires a consistent and adequate supply of seeds of local native shrubs. However, annual seed production is erratic and seeds are usually short lived and insufficient to supply all of the reclamation projects undertaking reclamation. Seeds of eleven native shrub species (*Arctostaphylos uva-ursi, Vaccunium myrtilloides, Vaccinium vitis-idaea, Vaccinium oxycoccos, Shepherdia canadensis, Prunus virginiana, Cornus sericea ssp. sericea, Alnus viridis ssp. crispa, Viburnum edule, Prunus pensylvanica*, and *Amelanchier alnifolia*) were used to analyze physiological changes that happen during storage and artificial aging processes. Shrub seeds were studied for up to four years during storage under eight combinations of temperature (-20, 4, and 22.5 °C), atmosphere (air and N_2) and relative humidity (seed moisture content, 7-8 %, 3-4 %).

PROGRESS AND ACHIEVEMENTS

This COSIA project ended on December 31, 2015 and a final project report is being compiled

Final measurements and analyses were conducted in 2015 towards fulfillment of the objectives which have been met.

OUTCOMES AND LESSONS LEARNED

Storage of seed at room temperature with low seed moisture content and ambient condition was suggested for bearberry (*Arctostaphylos uva-ursi*), bog cranberry (*Vaccinium vitis-idaea*), cowberry (*Vaccinium oxycoccos*), choke cherry (*Prunus virginiana*), low bush cranberry (*Viburnum edule*), and pincherry (*Prunus pensylvanica*), since seed viability, germination, and seedling growth of these species were not affected by different storage conditions during storage. A low storage temperature combined with low seed moisture content was the key factor in maintaining high viability, germination, and seedling vigour of blueberry (*Vaccunium myrtilloides*), buffalo berry (*Shepherdia canadensis*), dogwood (*Cornus sericea* ssp. *sericea*), green alder (*Alnus viridis* ssp. *crispa*), and saskatoon berry (*Amelanchier alnifolia*).

For all tested species, N_2 was not recommended for use due to its high cost and limited effects on keeping seed viability, germination, and seedling vigour.

For most shrub species, the seed viability decreased significantly after 10-15 days (d) of artificial aging and was down to 0 % after 20 d. The germination percentage declined after 5 d; therefore there was a delay in detecting viability loss using the tetrazolium test. Non-aged seeds and aged seeds of most collections showed significantly different seedling lengths, which indicated a negative effect of accelerated aging process on the seedling growth.

The electrolyte conductivity, as well as seed dehydrin protein expression, is strongly correlated with the seed vigour, which can be used as a seed quality assessment method in seed longevity predictions. A loss of membrane integrity occurred during the accelerated seed aging processes, as indicated by an increased electrolyte conductivity that was negatively correlated with the seed viability and germination. During the artificial aging process, heat stress of Prunus virginiana induced expression of dehydrins with a molecular mass of 27 kDa, which reached a detectable level after 5 d.

The storage protocol developed in this study will help to ensure an adequate supply of viable shrub seeds for reclamation. Taking into consideration species-specific parameters, the artificial aging technique to predict seed longevity can be further expanded to other non-crop species used in land reclamation.

PRESENTATIONS AND PUBLICATIONS

M.Sc. Thesis: Y. Wang 2015. Physiological characterization on seed aging of six native shrub species. University of Saskatchewan.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Yuguang Bai, Ph.D., Professor and Head

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Ravi Chivar	University of Saskatchewan	PhD., Professor, CRC		
Christine Walters	USDA-ARS	Ph.D., Research Scientist		
Lei Ren	University of Saskatchewan	Ph.D., PDF		
Yimeng Wang	University of Saskatchewan	M.Sc. student	Sept. 2010	Feb.2015
Yongsheng Wei	University of Saskatchewan	Ph.D., PDF		
Lixue Wang	China Agricultural University	Visiting Ph.D. Student	Nov. 2010	Nov. 2011
Jushan Liu	NE Normal University	Visiting Ph.D. Student	June 2010	July 2011
Maya Zhang	University of Saskatchewan	Research Assistant	Jan. 2011	Aug. 2011
Rashim Bibi	University of Saskatchewan	Research Assistant	Jan. 2012	In progress
Nicolas Poulin	University of Saskatchewan	Summer Student	May 2012	Aug. 2012
Fengqin Jia	Yili Normal University	Visiting Ph.D. Student	Jan. 2013	Dec. 2013
Tao Liu	University of Saskatchewan	Research Assistant	Sept. 2013	Dec. 2013
Marika Cameron	University of Saskatchewan	Summer Student	Sept. 2014	July 2015

Trembling Aspen Seedling Establishment, Survival and Growth Related to Soil Properties on Reclaimed Sites

COSIA Project Number: LJ0007

Research Provider: Canadian Forest Service

Industry Champion: Canadian Natural Resources Limited

Status: Year 3 of 4

PROJECT SUMMARY

The purpose of this project is to investigate the effects of soil types and soil compaction levels typically found in oil sands reclamation surface soils on aspen regeneration from seed. Both greenhouse and field studies will be conducted with the ultimate goal of making recommendations to improve reclamation practices to optimize natural aspen seedling establishment potential. The greenhouse studies will be used to test the impacts of specific soil and site properties on aspen seedling establishment. The field studies will build upon the greenhouse findings and answer questions related to soil and topographic impacts on seedling establishment and longer term questions related to aspen survival and growth rates.

PROGRESS AND ACHIEVEMENTS

Greenhouse experiments have been completed. Field work in 2015 focused on remeasuring aspen seedling establishment, survival, and growth in permanent monitoring plots on different reclamation soil types. This included sampling for determining site fertility, leaf area development, and foliar nutrient concentrations. Field work will conclude in 2016 with a more extensive study of the ecological drivers controlling tree productivity on reclamation soils.

OUTCOMES AND LESSONS LEARNED

Seedling establishment: Soil type is the major controller of aspen seedling establishment with significantly greater establishment on peat-mineral mix (PMM) soil compared to forest floor-mineral mix (FFMM) soil. Results from 3 separate reclamation sites show initial aspen seedling densities averaging from 6,000 – 17,000 seedlings per hectare on PMM and from 0 – 3,000 on FFMM. Aspen seedling establishment was reduced by early fertilization. It was positively related to increased soil surface roughness and water holding capacity. Findings from our oldest site (5 years) show that aspen seedlings have continued to recruit to the site every year and the rate of establishment was again greater on PMM. We also found the natural establishment of approximately 1,000 seedlings of black spruce in an area that had spruce coarse woody debris containing spruce cones applied.

Seedling growth: Once established, seedling growth rates were similar between soil types. The main difference was in establishment density. Individual tree leaf area development and foliar nutrient concentrations were also similar between reclamation soil types.

Soil properties: The complete soil nutrient profile of both PMM and FFMM was significantly different from nearby natural soils but FFMM was more similar to the natural soil. P and K were significantly lower in reclamation soils compared to natural soils while S, Ca, and Mg were significantly higher in reclamation soils. Inorganic N was not

different between any soil types except when fertilized. Fertilization may align the temporal trajectory of the nutrient profile of PMM to be similar to natural soils. Foliar nutrients were not consistently correlated with soil solution or total soil nutrient pools.

PRESENTATIONS AND PUBLICATIONS

Howell, D.M., Das Gupta, S., Pinno, B.D. and MacKenzie, M.D. Reclaimed soils, fertilizer, and bioavailable nutrients: Determining similarity with natural benchmarks over time. Submitted to Ecological Engineering. In press

Pinno, B.D. and Errington, R.C. 2015. Maximizing natural deciduous tree seedling establishment on a reclaimed oil sands site. Ecological Restoration. 33:43-50.

Startsev, N., Krygier, R. and Pinno, B.D. Aspen seedling establishment on reclamation soils with differing compaction and watering levels. In preparation. In press

Pinno, B.D. 2015. Rebuilding forest ecosystems after oil sands mining. Invited oral presentation at the Athabasca River Basin Research Institute ARBRI Day 2015. November 2015, Edmonton.

Stefani, F.O.P, Morency, M-J., Lachance, D., Isabel, N., Pinno, B., Yergeau, E. and Séguin, A. 2015. Comparative analysis of soil and root microbiomes of aspen trees (*Populus tremuloides*) growing in reclaimed oil sands mine sites. Poster presentation at the Gordon Research Conference: Microbes that influence, sustain and protect our planet. July 2015, South Hadley, MA, USA.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Ruth Errington	CFS	Research technician		
Edith Li	CFS	Research Technician		
Jim Weber	CFS	Research Technician		
Richard Krygier	CFS	Researcher		
Armand Seguin	CFS	Research Scientist		
Nathalie Isabel	CFS	Research Scientist		
Evelyne Thifault	Universite Laval	Professor		
Derek Mackenzie	University of Alberta	Professor		
Stephanie Jean	CFS/ University of Alberta	BSc		
Pamela Freeman	CFS/ University of Alberta	BSc		
Sanatan Das Gupta	CFS	PDF		
Jeff Hogberg	University of Alberta	MSc	Sept 2014	
Pierre-Yves Tremblay	Universite Laval	MSc	Sept 2015	

Understory Plant Community Development on Reclaimed and Natural Sites

COSIA Project Number: LJ0005

Research Provider: Canadian Forest Service

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 3

PROJECT SUMMARY

Establishing functioning upland plant communities on land reclaimed after oil sands mining is an important goal for reclamation practitioners. These plant communities, which include trees, shrubs and understory vegetation, are important for their role in establishing nutrient cycling, providing biodiversity and wildlife habitat, contributing to primary productivity and many other ecological functions. In general, the goal for reclaimed plant communities is that their species composition is similar to that of native stands in the area and that the successional trends are similar between reclaimed and natural sites.

On reclaimed sites, peat - mineral mix (PMM) and upland forest floor – mineral mix (FFMM) are currently being used as surface soils to provide the initial growing medium for plants. However, these organic – mineral soil mixes differ greatly in their resource availability with peat – mineral mix having greater N availability but lower P availability than the forest floor – mineral mix which could have an impact on vegetation development. Initial results from Canadian Natural Horizon Mine Reclamation Area 1 (RA1) and other studies also indicate that forest floor treatments have higher initial species richness than the peat – mineral mix treatments, likely due to the greater propagule bank stored in the forest floor, but the longer term successional trends are not known.

The overall goal of this study is to determine the impacts of these different reclamation options, i.e., soil type, fertilization, coarse woody debris and weed management on vegetation development and then compare vegetation development on the reclaimed sites to nearby natural stands. The results of this study will be to make recommendations to improve reclamation practices that optimize long term vegetation development.

PROGRESS AND ACHIEVEMENTS

Data collection, focusing on plant community composition, continued at the Horizon Mine RA1 and WA2 research sites in 2015. Summer 2016 will be the final field season for this project and will involve extensive plant community sampling.

OUTCOMES AND LESSONS LEARNED

- Plant communities were clearly differentiated by soil types (PMM, FFMM, natural sites). FFMM had similar plant species richness to natural stands with PMM richness being lower. Non-native species richness and cover was greatest in FFMM.
- Plant communities also changed over time with the greatest change from the first to second growing season and less change between growing seasons after that.

- Fertilization tended to decrease species richness of reclaimed areas and homogenized the plant community with the greatest plant community differences due to soil type found in unfertilized areas.
- The combination of weeding and seeding of understory plants resulted in initial plant community differences from the control plots.

PRESENTATIONS AND PUBLICATIONS

Errington, R.C. and Pinno, B.D. Early successional plant community dynamics on a reclaimed oil sands mine in comparison with natural boreal forest communities. Submitted to Ecoscience.

Li, E.H.Y., Pinno, B.D. and Schoonmaker, A. Growth of native plants on reclamation soils varies by soil type and watering regime. In preparation.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Ruth Errington	CFS	Research technician		
Edith Li	CFS	Research Technician		
Derek Mackenzie	University of Alberta	Professor		
Stephanie Jean	CFS/ University of Alberta	BSc		
Pamela Freeman	CFS/ University of Alberta	BSc		
Sanatan Das Gupta	CFS	PDF		
Leah deBortoli	University of Alberta	MSc	January 2016	

Oil Sands Vegetation Cooperative (OSVC)

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting Inc. (WRC)

Industry Champion: Imperial and Shell Canada Energy

Industry Collaborators: All COSIA Land EPA Members as this is an EPA-Led Project

Status: Ongoing

PROJECT SUMMARY

The Oil Sands Vegetation Cooperative (OSVC) was established in 2009 to enable collaborative harvesting and banking of native boreal forest seed for use in revegetation and research. In 2014, the OSVC became a COSIA Land EPA Led project that provided support to the seed collection initiatives that were deployed in the northern Athabasca Oil Sands (NAOS), Southern Athabasca Oil Sands (SAOS) and Cold Lake (COLK) regions. The key deliverable of the OSVC in 2015 was a knowledge gap analysis that highlighted species and aspects in need of further examination and research to assist their use in oil sands reclamation. Ongoing maintenance of a cross-company record keeping system and administration of the cooperative bank was also undertaken.

PROGRESS AND ACHIEVEMENTS

In 2015, the OSVC harvested 5030 litres (L) of seed from 5 seed zones in northeastern Alberta. The following were extracted and registered:

COLK - 3,484 L of seed from 13 seed lots representing 8 species from seed zone CM 3.1.

SAOS – 296 L of seed from 17 seed lots representing 6 species from seed zones CM 2.1, CM 3.1 and LBH 1.5.

NAOS – 1,250 L of seed from 26 seed lots representing 13 species from seed zones CM2.1, CM 2.2 and AP1.1.

Table 1. Species harvested

COLK	SAOS	NAOS
Alnus viridis (green alder)	*Betula papyrifera* (paper birch)	*Alnus incana* (river alder)
Betula papyrifera (paper birch)	*Betula pumila* (bog birch)	*Alnus viridis* (green alder)
Cornus sericea (dogwood)	*Alnus viridis* (green alder)	*Amelanchier alnifolia* (Saskatoon)
Picea mariana (black spruce)	*Vaccinium myrtilloides* (blueberry)	*Arctostaphylos uva-ursi* (bearberry)
Populus tremuloides (aspen)	*Vaccinium vitis-idaea* (bog cranberry)	*Betula papyrifera* (paper birch)
Rhododendron groenlandicum (Labrador tea)	*Viburnum edule* (low bush cranberry)	*Betula pumila* (bog birch)
Salix bebbiana (Bebb's willow)		*Cornus sericea redosier* (dogwood)
Shepherdia canadensis (buffaloberry)		*Prunus pensylvanica* (pin cherry)
		Prunus virginiana (chokecherry)
		Ribes hudsonianum (northern black currant)
		Ribes triste (wild red currant)
		Shepherdia canadensis (buffaloberry)
		Vaccinium vitis-idaea (bog cranberry)

In 2015, the SAOS was formally established and aligned with the existing OSVC system for seed harvest and banking. Although in the past SAOS has harvested seeds, the harvests were focussed on immediate needs. In 2015, the SAOS had their first harvest dedicated to banking seed.

Wild Rose Consulting (WRC) met with COSIA Land EPA members in September to discuss progress on all aspects of the project and included short presentations from research chairs as well as NAIT Northern Boreal Institute. A matrix to analyse knowledge gaps limiting the use of native plants in oils sands reclamation was designed in 2014. In 2015, this was used to survey internal industrial partners regarding species of greatest concern and priority. 19 species were identified as needing further research in the short term and when the external matrix was returned, results were analyzed with these species in mind.

Table 2. Priority species

Acorus americanus (ratroot)	*Lonicera dioica* (twining honeysuckle)	*Rumex maritimus* (golden dock)
Alnus viridis (green alder)	*Populus tremuloides* (aspen)	*Shepherdia canadensis* (buffaloberry)
Amelanchier alnifolia (Saskatoon)	*Prunus pensylvanica* (pin cherry)	*Vaccinium myrtilloides* (blueberry)
Arctostaphylos uva-ursi (bearberry)	*Rhododendron groenlandicum* (Labrador tea)	*Viburnum edule* (low bush cranberry)
Betula papyrifera (paper birch)	*Ribes americanum* (wild black currant)	
Corylus cornuta (beaked hazelnut)	*Ribes lacustre* (bristly black currant)	
Larix laricina (tamarack)	*Ribes oxyacanthoides* (northern gooseberry)	

OUTCOMES AND LESSONS LEARNED

Seed requirements for reclamation in the oil sands region are such that seed harvest cannot be completed on an as-needed basis. Ongoing seed banking is required and should be a key component of oil sands reclamation planning. We need to increase the capacity for seed harvesting and extraction to ensure a continuous supply of high quality seed for reclamation in the future.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting Inc.

Principal Investigator: Ann Smreciu, M.Sc.

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Kimberly Gould	Wild Rose Consulting, Inc.			

Industry Lead Lori Neufeld, Imperial; Robert Vassov, Shell Energy Canada

Wildlife Research and Monitoring

Early Successional Wildlife Monitoring of Reclaimed Habitat on Active Oil Sands Leases – Phase 1

COSIA Project Number: LJ0186

Research Provider: LGL Limited, Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Shell Canada Energy

Status: Year 1 of 5

PROJECT SUMMARY

Wildlife use of naturally occurring upland and wetland habitat in the Athabasca Oil Sands Region is relatively well-understood. However, the ability for reclaimed upland habitats to promote the return to and use of previously disturbed habitats remains under-studied. To address this deficiency, a 5-year wildlife monitoring program is underway to address the requirements for reclamation certification, evaluate wildlife use of the reclamation areas and areas adjacent to the development, assess the return and re-establishment of wildlife on reclamation areas, and to evaluate the effectiveness of practices and principles applied in reclamation areas to improve biodiversity.

Focal taxa representing aquatic, semi-aquatic, terrestrial, and avian species are monitored from reclaimed habitats, mature forest, cleared, burned, and logged juvenile stands on leases operated by Canadian Natural Resources Limited (Canadian Natural), Suncor and Shell. Annual sampling from 2015 through 2019 will be completed to generate a 5-year dataset that can be used to assess how different species of wildlife are distributed relative to reclaimed habitats and to assess whether reclaimed habitats are on a developmental trajectory similar to other juvenile stands in the region.

Data collected from reclaimed and juvenile stands will be compared to the mature forests, which represent the desired endpoint of upland reclamation in the Athabasca Oil Sands Region. The results of the monitoring program will be used to quantify the successful re-establishment of wildlife habitat on each operator's lease [redacted]

The regional dataset will be constructed from data collected on individual leases. The data will serve at least three purposes:

1) The data will help individual operators meet requirements for reclamation certification.
2) Broader-level biodiversity goals associated with reclamation in the Athabasca Oil Sands Region can be quantified and achieved.
3) The regional data set can be used to develop profiles of wildlife use of mature forest stands that represent the desired endpoint of reclamation, of the juvenile regenerating stands, and of the reclaimed stands. These data profiles can then be used to determine if the developmental trajectory of reclaimed habitats parallels that of naturally regenerating juvenile stands and at what point in the development the reclaimed habitats represent the desired endpoint.

PROGRESS AND ACHIEVEMENTS

Sampling in 2015 occurred on Canadian Natural's Horizon Oil Sands, Suncor Energy's Base Lease, and Shell Albian Sands Muskeg River and Jackpine Mines. Sampling was conducted from a total of 30 sites including upland reclaimed habitats (n=16), logged stands (n=2), burned forest (n=2), cleared habitats (n=4), and mature forests (n=6).

Focal taxa included:

- Songbird point counts
- Small mammal live trapping
- Visual encounter surveys for amphibians
- Deployment of autonomous recording units for bats
- Maintenance/deployment of camera traps
- Vegetation/habitat assessments at all sampling locations
- Winter-active animal surveys
- Documentation of all wildlife observed via incidental observations.

Sampling occurred in most months, but focused on the snow-free period, with the majority of activities occurring between May and October. All data collected in 2015 are currently undergoing QA/QC procedures and analyses and will be included in March 2016 annual reports

OUTCOMES AND LESSONS LEARNED

Due to the recent initiation of this project there are no outcomes or lessons learned to document at this time.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Limited, Environmental Research Associates

Principal Investigator: Virgil C. Hawkes

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Virgil C. Hawkes	LGL Limited	M.Sc. Senior Wildlife Biologist, Vice-President		

Wildlife Habitat Effectiveness and Connectivity Project

COSIA Project Number: LJ0144

Research Provider: University of Alberta

Industry Champion: Shell Canada Energy

Industry Collaborators: Suncor Energy Inc., Canadian Natural Resources Limited, Syncrude Canada Ltd., Imperial

Status: Year 10 of 10

PROJECT SUMMARY

Oil sands mining activity will result in interim habitat loss, alteration, and fragmentation for resident wildlife during the period between tree clearing and final reclamation (i.e., operational mining). For example, direct habitat loss will stem from the actual development of the mine and its associated infrastructure (e.g., buildings, wastewater ponds, roads, wells, and seismic lines). Indirect habitat loss can also occur if wildlife avoids areas immediately adjacent to the oil sands operations. Avoidance may be related to a variety of factors described above, and the "zone of influence" or "zone of disturbance" extends beyond the physical footprint of individual projects. Habitat loss, alteration, and fragmentation can lead to population declines via:

- Increases in mortality and/or declines in reproductive success if the Athabasca Oil Sands Region no longer provides effective habitat for resident wildlife. There is no set definition of habitat effectiveness in the ecological literature, but it generally refers to the ability of the habitat to support wildlife and how this ability is affected by human disturbance (e.g., Suring et al. 1998; Gaines et al. 2005). For example, mining activity may lead to declines in survival and fecundity because of a loss of forage and calving sites (e.g., Rosenberg et al. 1997; Cameron et al. 2005). Habitat alteration could also indirectly lead to reduced survival rates if linear features increase hunter access to wildlife (e.g., Farmer et al. 2006).
- Displacement or emigration to less disturbed areas outside of the oil sands areas and/or reduced immigration into the oil sands area. Also note that while movement to other areas may temporarily rescue individuals, the longevity of this effect may depend on the inter- and intraspecific interactions among displaced and resident wildlife. For example, displacement of barren-ground caribou near areas of oil and gas disturbance increases local densities, which may increase competition for food and/or predation risk (Cameron et al. 2005).
- Loss of population connectivity if continuous populations become fragmented and/or if metapopulations are disrupted. Population connectivity reflects the movement of individuals – and thereby flow of genes – between subpopulations (Rosenberg et al. 1997). Movement is often facilitated through the use of natural corridors (e.g., valleys and riparian zones; Rosenberg et al. 1997; Chetkiewicz et al. 2006). Its loss can lead to population isolation and/or small populations. Small populations are more likely to experience the negative effects of low genetic diversity, demographic stochasticity, and environmental stochasticity than larger populations (Caughley and Gunn 1996; Rosenberg et al. 1997). However, the role of river valleys as movement corridors in a boreal landscape are largely unknown as most large mammal corridors have been demonstrated in mountainous terrain (e.g., Chetkiewicz et al. 2006).

If extensive enough, oil sands disturbance may cause source habitats within the oil sands area to become sinks and/or prevent the rescuing of sink habitats via recolonization of the oil sands area (e.g., Pulliam 1988). This could eventually lead to local extirpations and the loss of biodiversity in the oil sands region (e.g., Rosenberg et al. 1997; Chetkiewicz et al. 2006). However, the extent of these effects will likely depend on the overall temporal and spatial

scale of the oil sands disturbance. For example, wildlife may move around a single mine with little impact on survival, reproductive success, or population connectivity. Population level effects are more likely to occur as development in the area intensifies both temporally and spatially. This implies that the impact of oil sands activity will be cumulative and not immediately evident at the population level (see Schneider 2002). It also implies that as mine activity ceases and sites are reclaimed, the area may be recolonized by wildlife if habitat effectiveness is restored.

It is also possible that some species will be attracted to the oil sands mining activity, which can create human-wildlife conflicts (e.g., black bears may be attracted to human garbage; Breck et al. 2006). Furthermore, industrial activity has been linked to the northward expansion of invasive species like coyotes and deer (Bayne et al. 2004). These species can displace resident prey and thus may alter existing ecological relationships in the Athabasca Oil Sands Region (Bayne et al. 2004). Both human-wildlife conflicts and invasive species are expected to negatively impact resident wildlife.

This research and monitoring program is aimed at determining three objectives:

- What is the function of the river and adjacent "set aside" buffers?
- How do mine activities and buffers of different widths affect this function?
- If function is affected by mine activities, are these effects important to regional population dynamics (i.e., effects to dispersers; differences in reproductive output; and population connectivity of the species in question)?

PROGRESS AND ACHIEVEMENTS

MOOSE TRACKING COMPONENT HIGHLIGHTS

Field work related to the moose component has been completed and a 2010-13 summary report was produced.

This report was reviewed by Alberta Environment and Parks (AEP) and added to the final Wildlife Habitat Effectiveness and Connectivity (WHEC) report in fall 2015. The abstract is presented here:

Our study found that moose were most often located in fens, cranberry understorey, marshes, and dogwood understorey habitats. They showed strong selection for dogwood understorey and marsh habitat. With the exception of dogwood understorey habitat, all other habitats heavily used or selected by moose were widely distributed throughout the study area. As a consequence, it is not likely that the Athabasca River represents a natural habitat corridor for moose. Any potential loss of the Athabasca habitat corridor would be unlikely to significantly disrupt any movement (including dispersal) by moose throughout the region. Moose avoid active mines but there appear to be no cases where individual moose or pockets of moose are isolated from other moose in the region. We found that moose showed very high overlap (30-40%) between summer and winter ranges and there was only a slight tendency for moose locations to be closer to rivers on average during winter versus summer. Thus overall, we have no evidence to suggest that female moose undergo any sort of migration in and out of river valleys on a seasonal basis. We found strong evidence that moose avoided areas within 250 m around mines.

WOLF TRACKING COMPONENT HIGHLIGHTS

The wolf tracking field components were concluded in 2014, however the final wolf report was added to the final WHEC report and submitted to AEP in fall 2015. The second year of winter snow tracking was completed in January through March of 2014 and monitoring of radio collared wolves continued throughout the year.

MONITORING:

At conclusion of the project (September 2014), there were 45 collar deployments which yielded a total of 241,217 locations. Six of the radio collared individuals dispersed from the study area (39,002 locations) (Figure 1). Wolves selected mainly cranberry understorey, fen, dogwood and shrubland dominated habitats and avoided bog, mine and lake habitats.

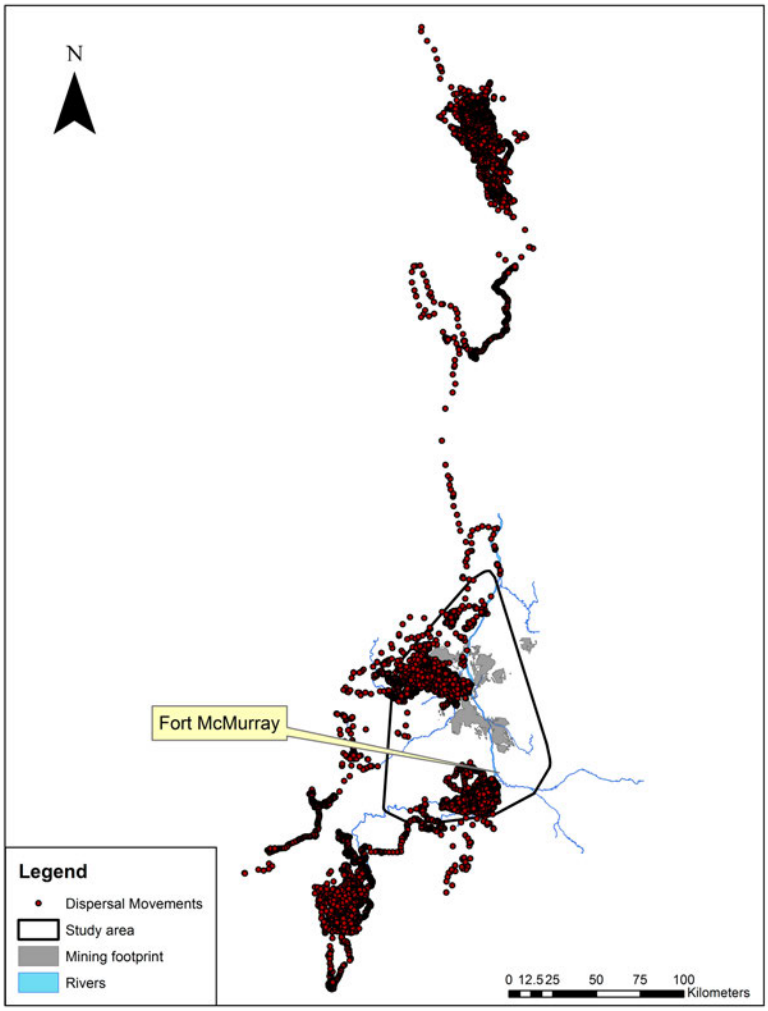


Figure 1. Dispersal movements of 4 wolves as shown by linear traces of locations. The areas of concentrated locations represent the locations of the individuals while in their home range. The wolf study area is shown for scale.

SNOW TRACKING:

Predators such as the grey wolf (Canis lupus) rely heavily on movement to track and hunt their prey. In the winter, snow conditions can constrain locomotion, and can impose important energetic costs on movement. Optimality theory suggests that wolves should minimize these energetic costs when travelling and hunting. Snow tracking data were collected from January to March in 2013 and 2014, with 84 wolf tracks and a total of 2,574 individual snow measurements taken in the 2014 season.

Snow depth and sinking depth on wolf paths were compared to conditions 1 m and 10 m away. Multi-response permutation tests (MRPP) and generalized least squares (GLS) models were used to analyze wolves' selection for snow conditions. Wolves heavily selected for shallower snow, and were able to differentiate between snow depths at very fine scales (<10 m; Figure 2). This selection was consistent across years, and was most pronounced when wolves travelled on linear features and on frozen rivers. Wolves' selection for lower sinking depth (i.e., less penetrable snow) was far less pronounced, and the magnitude of their selection changed over the course of the winter. These results can inform research on energy expenditure, and can be related to movement metrics to test hypotheses on optimal foraging.

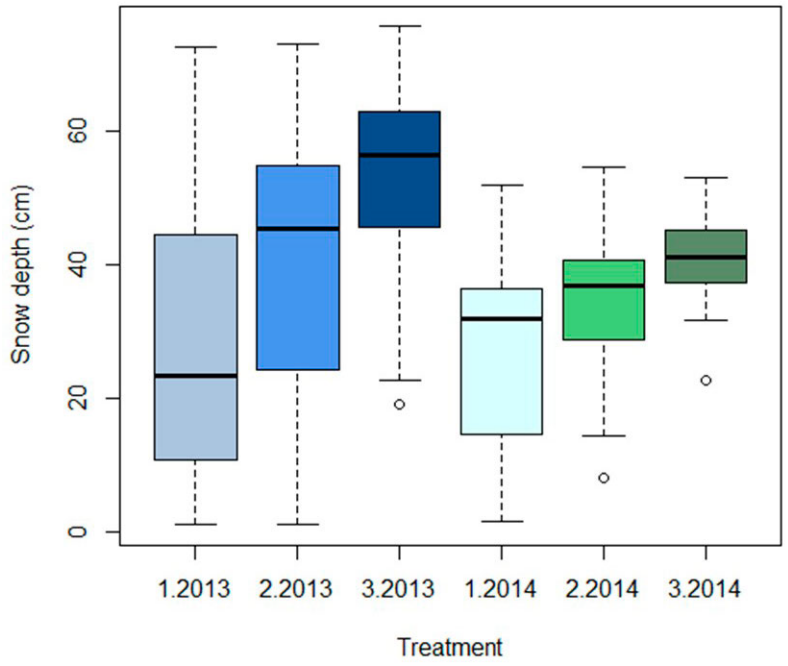
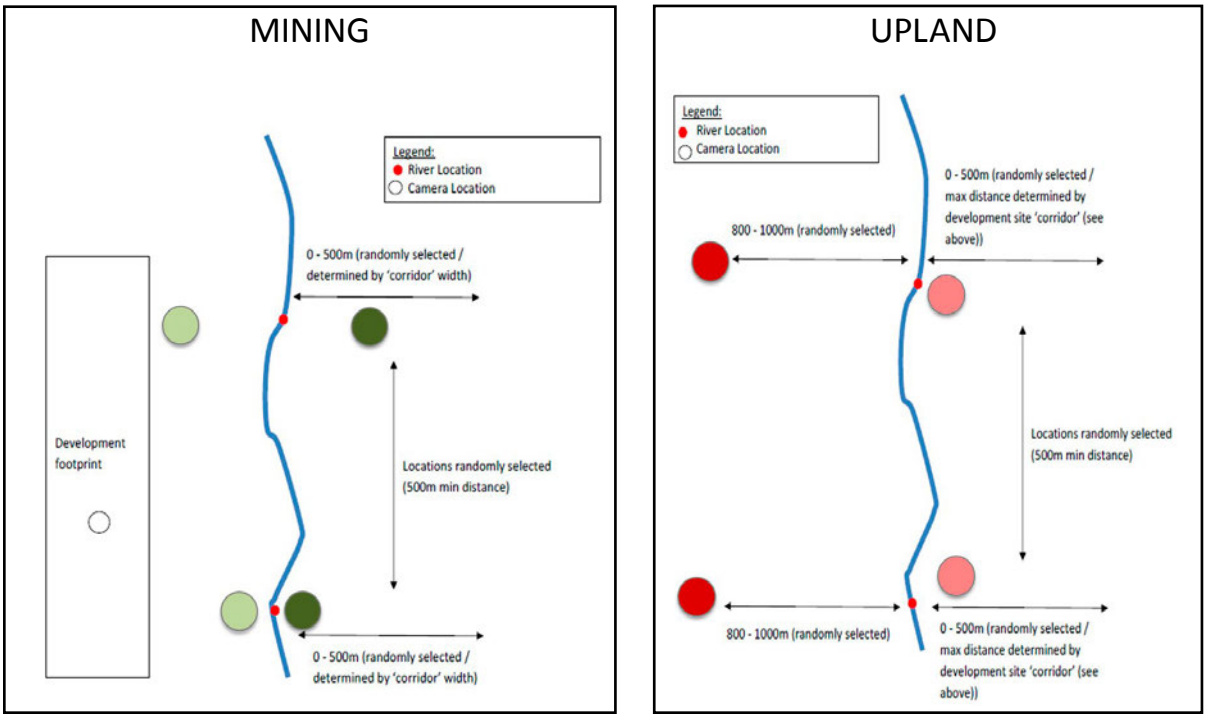


Figure 2: Snow depth measured on (1), 1m off (2) and 10m off (3) wolf tracks in 2013 and 2014.

REMOTE CAMERA COMPONENT HIGHLIGHTS

The sixth and final year of the camera monitoring project was completed in 2015. The camera report was added to the final WHEC report and submitted in fall 2015. Monitoring was conducted (identical to previous years) between May and July of 2015. Along the Athabasca River and five tributaries (Muskeg, Ells, McKay, Steepbank and Clearwater Rivers) 110 cameras were moved to monitor 224 locations for a two week period. Cameras were paired in 'Mining' (Figure 3a) and 'Upland' configurations (Figure 3b). Independent detections separated by three hours of white-tailed deer, black bears, moose and wolves, were extracted from all detections of each species per camera. The detections per trapping hour (DTH) for each species were calculated by dividing the independent detections by the total duration (hours) of each camera's deployment. The DTH values were separated based on upland and river (Upland) buffer (areas close to development) and control (non-developed areas) (Mining) treatment groups. The proportion of cameras with at least one detection per species per treatment group was calculated.



a) b)

Figure 3a/b: Schematic of "mining" camera pair deployment design (a). Light green represent "buffer" locations whereas dark green represent "control" locations. Schematic of 'distance' camera pair deployment design (b). This design was deployed 1-18km from the nearest active mine. Light red represents "river" locations whereas dark red represents "upland" locations.

Summing all six years (2010 – 2015) of the camera project, a total of 60,678 images were collected at 1265 camera locations. Of the 18 mammal species detected, the top species detected on the cameras overall were: moose (25,892 images), white-tailed deer (14,898 images), black bear (10,627 images) and wolf (580 images). Comparing all 'buffer' cameras 'control' cameras, we observed more detections of bear, moose and deer within buffer areas, and more detections of wolves in the control, though none of these differences were statistically significant (Figure 4).

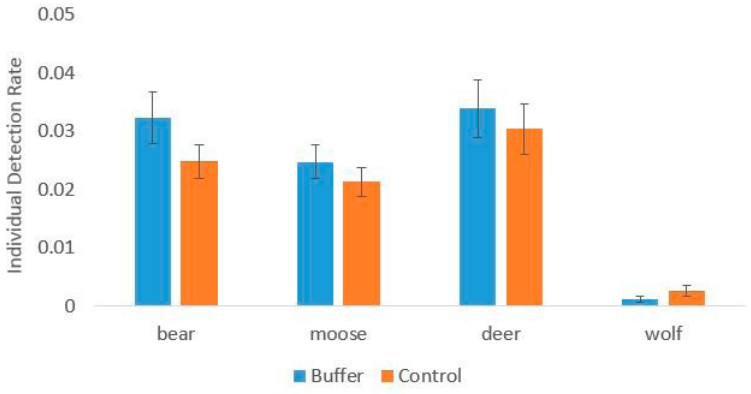


Figure 4. Detection rate (per day) for bear, moose, deer, and wolves in buffer (areas between mines and the river) and control (cameras placed across the river from active mining). Error bars are =+/- 1 SE.

Within upland areas, bear, moose, and deer all had slightly higher detection rates near the river versus in uplands but the differences were only statistically significant for moose (Figure 5).

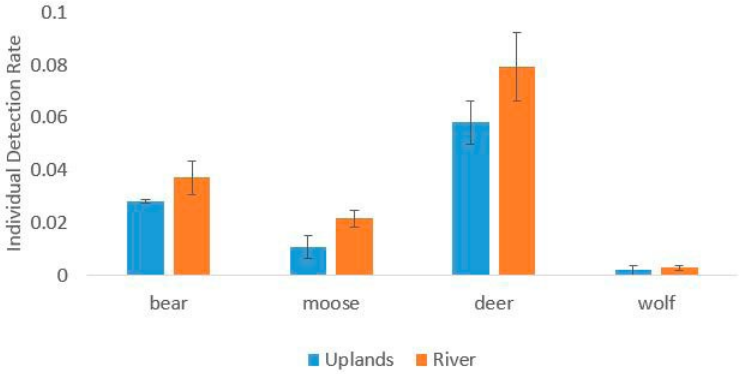


Figure 5. Detection rate (per day) for bear, moose, deer, and wolves in upland (cameras placed >500m from river) and river (cameras placed within 500m of the river) locations. Error bars are =+/-1 SE.

When we examined the detection rates for each species as a function of distance from active mines (Figure 6) there was no indication that moose, bears or deer had higher detection rates farther away from mines.

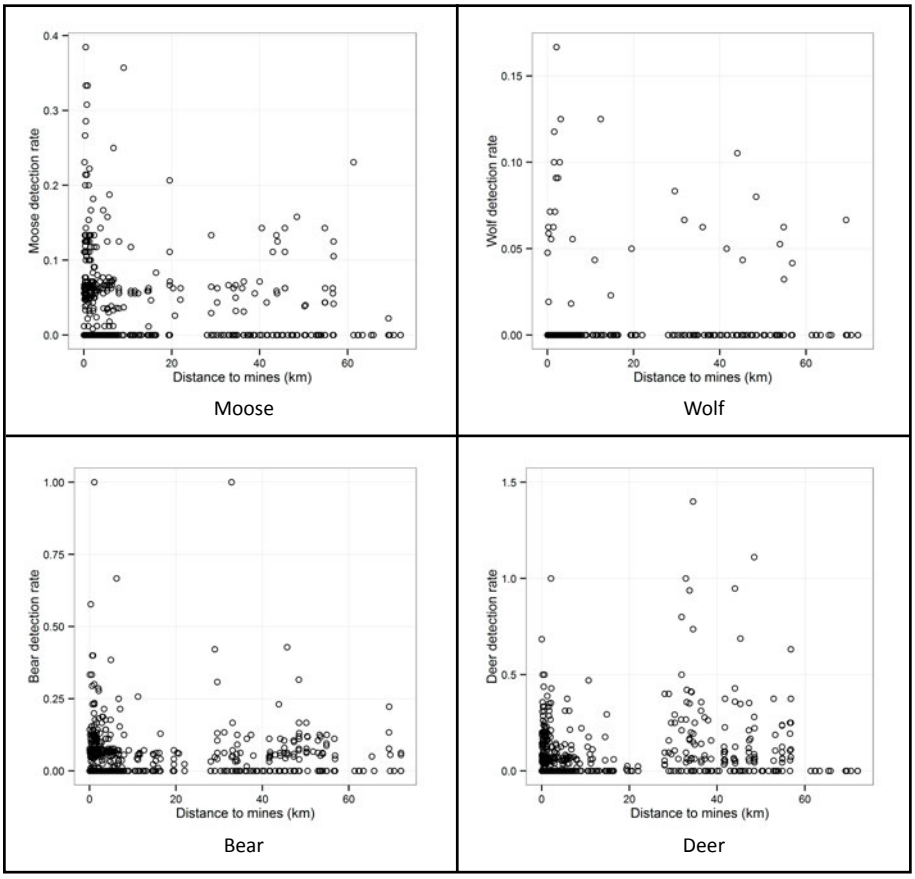


Figure 6. Detection rates per day as a function of distance from the nearest mine. Camera locations both in river and upland locations are included in the analyses.

The preliminary assessment of the camera monitoring component indicated a wide array but overall low detection rates of mammal species in the Oil Sands Region. Common species did not show evidence of reduction in detection rates near buffers created by current mining activity or show increases with greater distances from mines. The camera program results support the conclusions found in the moose and wolf studies.

OUTCOMES AND LESSONS LEARNED

Data have been provided above and several papers are expected to be published in 2016.

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PRESENTATIONS AND PUBLICATIONS

Reports:

Three reports have been prepared and submitted to Alberta Environment and Parks (AEP):

- Moose Final Report;
- Wolf Final Report; and
- Camera Final Report.

Publications

Publications are expected on the following topics in 2016:

- moose habitat use and selection in a highly industrialized environment;
- examining wolves' fine-scale selection for snow conditions using snow tracking data; and
- energetic implications of travelling through snow.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Stan Boutin

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Monitoring Avian Productivity and Survivorship in the Oil Sands Region (Boreal MAPS)

COSIA Project Number: LJ0214

Research Provider: Owl Moon Environmental Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Devon, Husky Energy, Imperial, Cenovus, TEPCA, ConocoPhillips, Suncor Energy Inc. and Hammerstone

Status: 2011 – Present (annual participation)

PROJECT SUMMARY

Monitoring Avian Productivity and Survivorship (MAPS) is a continent-wide mark-recapture (bird-banding) program dedicated to understanding population demographics and vital rates (i.e. reproduction, recruitment, survival) of landbird species. Indices of avian vital rates provide a strong indication of habitat quality and complexity. In northeastern Alberta, there is interest in understanding boreal forest ecology in response to industrial operations and reclamation efforts. Receipt of reclamation certification depends in part on demonstration that a reclaimed area has achieved a minimum level of ecological function and diversity, and that the habitat has achieved "equivalent capability" to that present before disturbance. Understanding how birds use unaffected habitats and to what degree reclaimed habitats provide similar resources required for reproduction and/or survival for a given community of species will support the development of reclamation trajectories.

Vital rate data are currently lacking for landbird species that rely on the boreal forest, many of which are experiencing population declines. The underlying causes are poorly understood. Productivity and survivorship data for these species may provide insight into the underlying causes of these population trends. Low or declining productivity would indicate that effects are occurring on the breeding grounds, while low or declining survivorship would suggest that the effects are caused on the wintering grounds or during migration.

The *Monitoring Avian Productivity and Survivorship in the Oil Sands Region* (Boreal MAPS) program has been established to provide avian vital rate data in support of understanding habitat quality in reclaimed areas, with the ultimate goal of supporting reclamation certification processes. Three objectives form the foundation for the Boreal MAPS program:

1) To advance the understanding of avian population dynamics and diversity in reclaimed habitats and in habitats subject to disturbances associated with industrial and human activities, as compared to natural, unaffected areas;
2) To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest; and
3) To provide a platform for other researchers undertaking complementary projects.

In 2011, six MAPS stations were established in the oil sands region, the program was expanded to 24 stations in 2012, to 35 stations in 2013, and to 37 in 2014. Stations have been established in an approximate ratio of 1:1 natural stations vs. those in reclaimed or disturbed habitats.

At each MAPS station an array of eight to 14, 12-m mist nets are operated for six hours per day on six days between June 10 and August 8 in accordance with standardized protocols developed by The Institute for Bird Populations. Captured birds are banded with a Canadian Wildlife Service-issued, uniquely numbered, aluminum leg band, and

data on species, age, sex, breeding characteristics, and moult status are recorded, along with biometrics such as wing length and weight. Age classes are assigned as HY (hatched during the current calendar year) or AHY (hatched one or more calendar years earlier) and most AHY birds are separated into SY (hatched last calendar year) or ASY (hatched two or more calendar years ago). Computer entry, data proofing, and verification of banding, mist-net effort, and breeding status data are completed using specially designed data entry, verification, and editing programs. For analyses, the number of adult birds captured per 600 net-hours is used as an index of adult population size and post-fledging productivity is estimated by the ratio of capture rates of individual young to adult birds captured.

Through 2014, 19,310 captures were recorded, of which 14,767 were of previously unbanded birds, representing 84 species. Data from 2015 are being processed. A number of species of concern (i.e., listed either provincially or within the Canadian Species at Risk Act) have been captured during the five years. For several species, including Canada Warbler, sufficient numbers of new and previously-banded individuals have been and continue to be captured each year to allow derivation of vital rates in the near future. With the data from 2015, we will have data for 5 years from 6 stations, and for 4 years from an additional 18 stations. With many of the analyses requiring a minimum of 5 years of data, we are now approaching the point where analyses will yield meaningful results, in particular, the survivorship index.

Vegetation structure has been quantified at each MAPS station. These data will be used to evaluate relationships among avian population sizes, productivity, survivorship and diversity and habitat quality in natural, reclaimed and disturbed areas. Our preliminary results indicate that complex habitat structure is important in providing habitat supportive of avian use of the habitat (Foster et al., 2012). Our results also indicate that newly reclaimed areas are supporting nesting and reproduction of early successional species, particularly sparrows. We expect that as vegetation becomes established and vertical structure develops, we will observe a succession in the complex of species using the habitat, and that tracking this trajectory will permit an evaluation of the effectiveness of the reclaimed areas. We anticipate that our data will be useful in determining the extent to which avian use of habitats on disturbed areas and near human disturbances (e.g., fixed plant facilities) is altered in terms of reproduction and survivorship. These analyses will include common species, as well as species of concern at provincial and national levels.

At the population level, adult population sizes of most species nesting in the habitats in our MAPS stations declined from 2011 to 2013, with a small reversal of this trend possibly apparent in 2014 likely indicative of natural cycling processes. The data from 2015 will extend our ability to evaluate trends in populations at a level broader than at the reclaimed, disturbed and natural habitat level. Continentally, the populations of many of our target species are in decline, however, within this general trend are cycles in these populations driven by factors at many levels (i.e., climate, food abundance, habitat connectivity, wintering ground habitat quality). The acquisition of long-term continuous datasets is a fundamental requirement for understanding short-term to long-term cycles, and how local habitat effects (reclamation, disturbance) are superimposed on these cycles.

Results from the first four years of the Boreal MAPS Program in northeastern Alberta indicate that we are acquiring meaningful station-specific indices of adult population size, post-fledging productivity, and species diversity data for at least 20 target species. The MAPS protocol is very well-suited to provide population-level avian data within reclaimed and disturbed habitats in comparison to undisturbed habitats, and to obtain critical baseline data on avian demographic patterns for birds reliant on the boreal forest in northeastern Alberta.

PROGRESS AND ACHIEVEMENTS

Data from the 2015 program are nearing completion of QA/QC procedures, and will be finalized in the near future for analyses. These analyses can be used to demonstrate the effectiveness of reclaimed habitats and those subject to various human disturbances relative to natural habitats in terms of reproduction and survivorship of a large number of avian species.

This program began in 2011, and at this stage, an end date has not been defined.

OUTCOMES AND LESSONS LEARNED

We continue to see the relationship between habitat complexity, defined as a habitat with high vegetative structure, and adult population sizes, productivity, and diversity. Reclamation programs that include planting of ground cover, low and high shrubs, and large canopy tree species will have a higher probability of attracting larger numbers of individual birds and species to the habitat for nesting.

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RESEARCH TEAM AND COLLABORATORS

Institution: Owl Moon Environmental Inc.

Principal Investigator: Kenneth R. Foster

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Christine M. Godwin	Owl Moon Environmental Inc.	Co-Principal Investigator		
Peter Pyle	The Institute for Bird Populations	Staff Biologist		
Ron Taylor	The Institute for Bird Populations	Staff Biologist		
Lauren Helton	The Institute for Bird Populations	Staff Biologist		
Danielle Kaschube	The Institute for Bird Populations	MAPS Coordinator		
James Saracco	The Institute for Bird Populations	Research Ecologist		

Bison Research, Mitigation and Monitoring

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck Resources Limited

Industry Collaborators: Shell Canada Energy

Status: Year 1 of 2

PROJECT SUMMARY

Funding for this project is being provided by Teck and Shell and the work is technically directed by the Ronald Lake Bison Herd Technical Team (RLBHTT), as the work is of keen interest to multiple parties. The study is using Global Positioning System (GPS) telemetry data previously collected from March 2013 – March 2015 and, ground cover data layers (e.g., vegetation, anthropogenic disturbance, fire) to develop resource selection function (RSF) models that will describe seasonal habitat selection patterns for wood bison in the Ronald Lake region. Results of this work will form a foundation for a long-term study into the ecology and conservation of the Ronald Lake wood bison population and provide much-needed information for wildlife managers and land use planners for a region poised to experience increased levels of anthropogenic disturbance and associated levels of human activity. In addition to bison range tracking and responses to human activities, other project themes under the Bison Research, Mitigation and Monitoring Program include: population dynamics; predator populations; disease surveillance; mitigation conservation offsets.

The primary objectives of the study are to better understand:

- the spatial distribution of male and female bison on an annual and seasonal basis;
- patterns of habitat selection; and
- the influence of natural and anthropogenic disturbances on the Ronald lake bison habitat selection.

PROGRESS AND ACHIEVEMENTS

The study will run from August 2015 to approximately March 2016. Progress that occurred in 2015 that supports achieving the stated objectives included:

OBJECTIVE: To better understand the spatial distribution of male and female bison annually and seasonally

- GPS location data collected from March 2013 – March 2015 were screened for potential errors. The final screened data set is comprised of 26 individual bison.
- 100% minimum convex polygons (MCPs) were developed to quantify bison home ranges. As an alternate method, utilization distributions (UDs) were estimated.

OBJECTIVE: To better understand the influence of natural and anthropogenic disturbances on the Ronald lake bison habitat selection

- Data layers containing anthropogenic disturbance (e.g. seismic lines, well site clearings, etc.) in the home range of the Ronald Lake bison herd were updated, along with associated metadata files.

- Photographs from 100 remote cameras mobilized on the landscape in a Before-After Control-Impact sampling design were collected and processed. Bison images were captured on roughly 50 separate events.

OUTCOMES AND LESSONS LEARNED

- Emerging outcomes or lessons learned in 2015 include:
- Bison bull collaring was not successful. Bull monitoring periods were short, presumably due to collar failures.
- Home range can be affected by sample size. Continued monitoring will help delineate annual and seasonal home ranges.
- UDs provide more conservative estimates of home range than MCPs.
- The Ronald Lake bison herd does not use the area east of the Athabasca River.

PRESENTATIONS AND PUBLICATIONS

A written progress report was provided to the RLBHTT in November 2015. Because this work delineates important seasonal habitat and the Ronald Lake bison are pressured by hunting, particularly in the winter, results have not been made public in the interest of protecting the herd from further hunting.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Scott Nielsen, Mark Edwards, Golder Associates

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Scott Nielsen	University of Alberta	Associate Professor, Alberta Biodiversity Conservation Chair		
Mark Edwards	University of Alberta	Adjunct Professor		
Martin Jalkotzy	Golder Associates	Senior Wildlife Ecologist, Principal		

Government Collaborators: Alberta Environment and Parks, Environment Canada, Parks Canada

Aboriginal Collaborators: Athabasca Chipewyan First Nation, Fort Chipewyan Metis, Fort McKay First Nation, Fort McKay Metis, Fort McMurray First Nation, Fort McMurray Metis, Mikisew Cree First Nation

Environmental Research and Monitoring

Horizon Lake Monitoring

COSIA Project Number: LI0011

Research Provider: Canadian Natural Resources Limited, Golder Associates

Industry Champion: Canadian Natural Resources Limited

Status: Year 6 - Ongoing

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of developing the Horizon Oil Sands Project (Horizon), which includes the development of a compensation lake (Wāpan Sākahikan) to permanently compensate for areas of fish habitat that will be affected by Horizon developments. The primary purpose of the compensation lake development, hereafter referred to as Horizon Lake, is the establishment of suitable habitat that will support self-sustaining resident fish populations. The measure of success for the compensation lake will be based on satisfying conditions identified in Canadian Natural's Fisheries Act Authorization, which states that the compensation habitat must "achieve permanent fish habitat productive capacity gains that offset fish habitat productive capacity losses to meet a compensation ratio of 2:1 based on fish biomass productivity." Horizon Lake is located approximately 60 km north of Fort McMurray within the Tar River watershed. The lake has a surface area of 76.7 ha with a maximum depth of approximately 20 m.

Canadian Natural designed and implemented a monitoring program in 2008 to track the establishment and development of the lake. The aquatic monitoring program for Horizon Lake is designed to monitor the development of the compensation lake as productive fish habitat. The monitoring parameters include documentation of the existing fish population, water and sediment quality, plankton and benthic invertebrate communities, and growth of macrophytes and shoreline vegetation.

OUTCOMES AND LESSONS LEARNED

Note: Results of the 2014 monitoring program became available in 2015 after the publication of the COSIA Land EPA Mind Site Reclamation Research Report and are therefore presented in this report.

FISH POPULATION

A total of 10 species of fish have been sampled during the monitoring activities in Horizon Lake since the lake filled in 2008. These include: Arctic grayling, burbot, white sucker, longnose sucker, brook stickleback, fathead minnow, finescale dace, lake chub, trout-perch and slimy sculpin. No finescale dace were captured in 2014. With only a limited number of individuals captured in previous years. Arctic grayling were captured in Horizon Lake in 2014. In total, 3,844 fish were caught during fish sampling efforts in 2014. Forage fish species comprised 80% of the total 2014 catch.

Slimy Sculpin and Arctic Grayling were sampled throughout the lake but the catch numbers are still low for these species. A number of fish were PIT tagged during the 2014 sampling period and recaptures of these species is increasing.

FISH ABUNDANCE AND PRODUCTION ESTIMATE

As in 2013, hydroacoustic surveys conducted in 2014 were utilized to make fish abundance and production estimates. Based on the four species considered for the production estimates (fathead minnow, lake chub, longnose sucker and white sucker) in the analysis, the estimated fish production in Horizon Lake is 1,328 kg/year based on abundance estimates using the mark-recapture results and 2,449 to 2,667 kg/year based on hydroacoustic abundance estimates. Sucker species comprised nearly 90% of the estimated annual production of the lake based on the mark-recapture abundance estimate and approximately 82% of the production based on the hydroacoustic abundance estimates. Lake Chub were estimated to have a greater contribution to the total production using the hydroacoustic abundance estimate.

The estimated total production:biomass (P:B) ratios for Horizon Lake ranged from 0.387 to 0.396. The P:B ratio has increased compared to estimates from previous years.

WATER QUALITY

Temperature profiles in Horizon Lake indicated high variability, between 10°C at the bottom and 23°C at the surface, during the summer. During winter, temperatures were warmer at the bottom (4°C) than at the surface (0°C). Water temperatures were within the preferred temperature ranges of the fish species within Horizon Lake, including Arctic Grayling, White Sucker and Longnose Sucker.

Field measurements of pH from the vertical profile data indicate variability in pH in the water column, ranging between 6.6 and 8.5; this range is within the tolerance ranges of the lake community of fish.

Dissolved oxygen (DO) concentrations indicated that oxygen concentration is not limiting within the upper 5 m of the lake for the fish species in the lake. In summer at depths below 10 m, DO concentrations were below 2 mg/L, but there was abundant access to oxygenated water in the lake. Arctic Grayling would be the species most likely limited by higher temperatures near the surface and lower DO concentrations at depth, particularly in the late summer.

When temperature and DO results are considered in combination, Arctic Grayling distribution could be restricted during the late summer within Horizon Lake to a band of habitat between 5 m and 10 m depth where both temperature and DO are within their tolerance range. Alternately, Arctic Grayling may remain in the Tar River until fall turnover has occurred.

Through the 2008 to 2014 monitoring period, total alkalinity, Dissolved Organic Carbon and total dissolved solids (TDS) were higher during winter and decreased during the open water season. The total suspended solids (TSS) values in 2014 were highest in spring. Total phosphorus (TP) concentrations were also higher during spring, reflecting the higher TSS concentrations caused by spring runoff. Total nitrogen (TN) concentrations remained similar throughout 2014. Chlorophyll a concentrations were higher in summer, with the peak concentration in August, consistent with the seasonal trends in phytoplankton density and biomass, which also exhibited a late-summer peak and then gradually declined through the early fall.

Overall, water quality in Horizon Lake in 2014 was generally similar to water quality observed during previous years. Low variation in total nitrogen concentration, and lower concentrations of TDS and other ions were measured during the open water season. Chlorophyll a concentrations measured in 2014 indicate there was no summer algal bloom in 2014. In terms of water quality, Horizon Lake was relatively similar to other nearby lakes.

SEDIMENT QUALITY

Sediments collected from Horizon Lake varied in particle size. Total organic carbon (TOC) was low compared to natural lakes in the region. Concentrations of arsenic were above the Interim Sediment Quality Guidelines (ISQG). Total manganese concentrations were above the Lowest Effect Level (LEL) guidelines at the three locations in Horizon Lake. And total nickel concentrations were above the LEL guidelines at two locations in Horizon Lake, which is commonly observed in the region. Concentrations of all other parameters tested were below sediment quality guidelines in 2014.

PLANKTON

In 2014, Phytoplankton and zooplankton taxonomic richness, biomass, and abundance differed from previous years in Horizon Lake. However, the communities were consistently dominated by similar taxa among years. After a four-year increasing trend in Horizon Lake, mean annual phytoplankton taxonomic richness decreased slightly between 2013 and 2014. An overall increase in mean annual total phytoplankton abundance has been observed since 2008, while mean annual total phytoplankton biomass was similar among years, with the exception of 2013. Cyanobacteria, chrysophytes, and cryptophytes have consistently been the dominant or sub-dominant groups by abundance and cyanobacteria were consistently the dominant group by biomass in Horizon Lake from 2008 to 2014. Differences in dominance between abundance and biomass are the result of differences in cell sizes (i.e., larger taxa which were present in small numbers did not dominate based on abundance, but dominated based on biomass because of their large size).

In 2014, seasonal peaks in phytoplankton abundance occurred in early October, while seasonal peaks in biomass occurred in late July to August. In 2014, the dominant phytoplankton group, by abundance and biomass, varied depending on the sampling event.

Mean annual zooplankton taxonomic richness was similar among years in Horizon Lake. Mean annual zooplankton abundance and biomass were also similar among years, with the exception of 2012. Over time the dominant group by abundance and biomass has consistently been rotifers or cyclopoid copepods in Horizon Lake.

In 2014, the seasonal peak in total zooplankton abundance occurred in early October, while the seasonal peak in total zooplankton biomass occurred in early August; with similar biomass observed in October. The dominant zooplankton group, by abundance and biomass, varied depending on the sampling event.

Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both seasonally and temporally (Findlay and Kling 2001 and Paterson 2002). This natural variability has been observed in phytoplankton and zooplankton taxonomic richness, biomass, abundance, and community composition in Horizon Lake over time. The observed seasonal and temporal changes in phytoplankton community composition are likely caused by short-term changes in nutrient composition and other physical factors within the lake (e.g., fluctuations in water depth, wind mixing, and temperature). Zooplankton graze on phytoplankton; therefore, they respond directly to changes in the phytoplankton community. In turn, they can further influence phytoplankton biomass, abundance, and community composition through top-down control (Carpenter and Kitchell 1984).

BENTHIC INVERTEBRATES

The benthic invertebrate community in Horizon Lake was characterized by low density and richness in 2014. Overall, benthic invertebrate density has been decreasing at most sites since 2010. However, the extent of this decline differed among habitat types. The number of benthic invertebrate taxa was similar or slightly higher in 2014 than in other years. As in 2011 to 2013, the benthic community in mid-lake, littoral and near-shore areas was dominated by

midges and aquatic worms in 2014. This contrasts with the results from the 2010 sampling session, in which aquatic worms did not form a substantial component of the benthic community in mid-lake sites. In 2014, mid-lake sites switched from midge-dominated to aquatic worm-dominated at two sites, and the proportion of other benthic invertebrate groups increased.

LITERATURE CITED

Carpenter, S.R., Kitchell, J.F. 1984. Plankton community structure and limnetic primary production. Amer Nat 124:159-172.

Findlay, D. L. and H. J. Kling. 1976. A species list and pictorial reference to the phytoplankton of central and northern Canada. Fisheries and Environment Canada, Fisheries and Marine Service, Manuscript Report No. 1503. 619 pp.

Paterson M. 2002. Ecological Monitoring and Assessment Network (EMAN) Protocols for Measuring Biodiversity: Zooplankton in Fresh Waters. Available at: http://www.ec.gc.ca/Publications/7A547B5A-FBD2-42BC-8C6E-98E826F4C9EE%5C FreshwaterMonitoringProtocolZooplanktonFreshwater.pdf. Accessed: March 2015.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Natural Resources Limited

Boreal Swamp Reclamation (Phase 2: Addressing Knowledge Gaps)

COSIA Project Number: LJ0114

Research Provider: Native Plant Solutions – Ducks Unlimited Canada

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Teck Resources Limited

Status: Year 2 of 5

PROJECT SUMMARY

The project is the second phase of an investigation into swamp reclamation in the Oil Sands Region. The first phase was an in-depth literature review of swamp ecology, hydrology and reclamation, and an analysis of the knowledge gaps that impede the ability to successfully reclaim swamp wetlands. The second phase underway now is a research study designed to address the knowledge gaps identified in Phase 1.

The objective of the study is to provide information to the oil sands industry on the reclamation of swamp wetlands. This will be accomplished through the investigation of vegetation, soils, hydrology and landform elements in natural conifer swamps in the region.

The three-year study is scheduled to begin in 2016 with the installation of groundwater wells and piezometers which will increase our understanding of swamp hydrology including the position of water tables, the vertical and horizontal movements of groundwater, hydrological relationships to the surrounding landscape, and the water chemistry of ground and surface water. These wells and piezometers will be instrumented each spring to collect multiple years of data to examine both seasonal and annual variations in swamp hydrological parameters. Vegetation surveys will be conducted in 2016 and 2017 to better understand the vegetation communities in conifer swamps, and how key vegetation species position themselves in the overstorey/understorey with respect to associated species and hydrology. Microtopography (hummocks and hollows) of the sites will also be studied.

In the summer of 2017 soils will be studied, classified and described within each site, and the variability of chemical and physical soil characteristics within and between swamp study sites will be examined.

PROGRESS AND ACHIEVEMENTS

In 2015 ground access to 3 natural swamps study sites were verified remotely using GIS and further confirmed by travelling the routes. The 2015 work identified access challenges and provided solutions for the upcoming 2016 sampling year. The identified ground access routes and staging areas will accommodate the mobilization of field equipment needed to continue with the next phase of the project.

OUTCOMES AND LESSONS LEARNED

This study is in its early stages so there are no emerging outcomes or lessons learned.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Native Plant Solutions/ Ducks Unlimited Canada

Principal Investigators: Lisette Ross and Bruce Friesen-Pankratz

Shell Albian Sands Mine Reclamation Monitoring Using High Resolution Data from Unmanned Aerial Systems

COSIA Project Number: LJ0193

Research Provider: Precision Hawk

Industry Champion: Shell Canada Energy

Status: Year 1 of 2

PROJECT SUMMARY

The goal of the UAS (Unmanned Aerial Systems) reclamation monitoring program in 2015 is to gather, evaluate, and analyze airborne collected data from reclaimed areas. It also seeks to further the development of vegetation measurement and reclamation materials stockpile volumes using an innovative approach and technology. The project will utilise the existing capability of UAS to provide very high resolution imagery acquisition and also seeks to evaluate new sensors – LiDAR and VHIR.

The specific project objectives are to:

- Use Unmanned Aerial Systems (UAS) to capture very high resolution data using three different sensors in visible, Near-Infrared and LiDAR. Using a LiDAR sensor on a UAS is a first in Shell and still in the early experimental stage.
- Generate very high resolution (2.5cm pixel resolution) aerial imagery and elevation data.
- Develop an advanced spatial analysis technique to measure and monitor vegetation growth in natural and reclamation areas and calculate Reclamation Material Stockpile (RMS) volumes.

PROGRESS AND ACHIEVEMENTS

Visible and near infrared imagery at better than 3.7 cm spatial resolution were collected in early August, 2015 for 3 areas of interest at the Shell Albian Sands Mine in Fort McMurray. Imagery was collected with the Lancaster Rev. IV at approximately 100 meters above ground level. The Lancaster is a 3 pound fixed wing unmanned aerial vehicle (UAV) with a 1.2 m wingspan and a swappable payload bay for collecting data with various sensors.

Orthomosaics and 3D terrain models for all surveys were successfully generated. Ground surveyed tree data from each location were used to assess the vertical accuracy of all 3D models and to ultimately choose the best product to include in the tree height analyses and delivery. Digital surface model (DSM) with 20cm vertical accuracy was created from each survey's densified point cloud.

OUTCOMES AND LESSONS LEARNED

Preliminary analyses are being evaluated for method improvements for 2016.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Precision Hawk

Principal Investigator: Greer Monterastelli

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Greer Monterastelli	Precision Hawk			

Early Community Development in Reclaimed Landscapes of the Wapisiw Lookout Riparian Zone and Associated Wetlands

COSIA Project Number: LJ0112

Research Provider: University of Windsor

Industry Champion: Suncor Energy Inc.

Status: Year 5 of 5

PROJECT SUMMARY

Suncor Energy Inc. (Suncor) is the first oil sands company to have transformed an oil sands tailings pond (Pond 1) into a surface solid enough to be actively reclaimed and revegetated. The 220-hectare watershed is now composed of a growing mixedwood forest, streams and a wetland (Wapisiw Wetland), which supports a variety of native plants and wildlife. It was anticipated that novel initiatives to provide habitat structural complexity (small islands, hibernacula, snag trees, rock piles), carbon (LFH and peat-mineral reclamation soils) and propagules (seedlings and vegetated plugs selected according to the Riparian Classification and Monitoring Guidelines), will have facilitated developmental processes.

The objective of the program is to provide baseline information on the initial successional processes that can be used to track the development of plant, amphibian, and avian communities toward an integrated, self-sustaining ecosystem that is functionally equivalent to a natural marsh.

Each year since 2010 (the year of construction) the study has tracked species richness, community composition, and abundance of selected taxa (amphibian, avian and riparian vegetation) in Wapisiw Wetland and up to 8 reference wetlands of various ages and construction characteristics, in order to assess age-specific effects and inter-annual variation. Amphibian species composition and abundance were assessed annually in spring 2011, 2013, 2014 and 2015 using calls, netting, and visual records at each study wetland. Nest boxes around the study wetlands were assessed by frequency of use, fecundity, and fledgling success annually between 2011 and 2015. The presence of avian species around the wetland watershed was tracked by 10-minute point counts each spring from 2011 to 2015. Aquatic invertebrates were sampled from Wapisiw Marsh itself in 2010, 2014 and 2015.

A within-wetland focus of this study contrasted the effects of soil type (peat-mineral vs. LFH) and revegetation strategy (seedling/vegetated plug vs. natural colonization) on riparian vegetation establishment in 12 plots (30 x 100 x 40 ft) along the shoreline of Wapisiw Wetland. Permanent transects were designed within each plot. Point and quadrat assessment of plant composition and vegetation cover was annually assessed from 2010 to 2015. For more details on the experimental design see Suncor (2012).

PROGRESS AND ACHIEVEMENTS

In 2015, the avian component of the study surveyed a total of 22 natural and reclaimed wetlands in May and June, 2015. A total of 69 species was observed in 2015. The mean number of avian species detected (with standard deviation) was 16.5 (+/-5.1). Twenty-one species were observed at Wapisiw Marsh, the greatest number observed at any constructed wetland, and significantly greater than the overall mean for all wetlands ($p<0.001$).

The most commonly encountered species of birds in 2015 were similar to those observed in previous years: White-throated Sparrow (14 wetlands), Red-winged Blackbird (13 wetlands), Tree Swallow and American Robin (11 wetlands), Chipping Sparrow (9 wetlands), and Sora and Song Sparrow (6 wetlands). This list includes primarily song birds with the exception of the Sora which is a rail species.

In 2015, Wapisiw Wetland continued to support among the greatest number of bird species and attracted as many or more tree swallows as other, older constructed wetlands. Five of 8 nest boxes were colonized, and recruitment success was 100%. Occupancy was comparable to that of two other constructed wetlands at which nest boxes were present. However, boxes at those wetlands were subject to bear predation. Wapisiw Wetland appears to provide adequate habitat to support the richness of bird species and fledging success expected in a natural wetland of equivalent size in the study region even though it is younger and structure (i.e. vegetation) and habitat (i.e. food sources) are still under development within the wetland.

Male boreal chorus frogs and male Canadian toads were detected at Wapisiw Wetland in spring 2015, indicating that it is sufficiently connected to other amphibian habitat that male amphibians have found it. Tadpoles of boreal chorus frogs were also observed

In 2015, riparian vegetation richness, cover and biomass continued the year-over-year increases observed in previous years.

Project start date: 2011. Project end date: 2015.

OUTCOMES AND LESSONS LEARNED

Outcomes and lessons learned will be provided in a final report that is scheduled for completion in March 2016.

PRESENTATIONS AND PUBLICATIONS

None in 2015.

RESEARCH TEAM AND COLLABORATORS

Senior Principal Investigator: Dr. Jan Ciborowski, University of Windsor

Co-Principal Investigator: Dr. Lee Foote, University of Alberta

Co-Principal Investigator: Dr. Danna Schock, Keyano College

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Jan J.H. Ciborowski	University of Windsor	Professor		
Lee Foote	University of Alberta	Associate Professor		
Danna M. Schock	Keyano College	Environmental Technology & Biology Instructor		
Mallory Hazell	University of Alberta	M.Sc.	2014	2016
Kellie Menard	University of WIndsor	M.Sc.	2014	2016
Amalia Despenic	University of Windsor	Hon. B.Sc.	2012	2016
Katrina Lukianchuk	University of Windsor	Research Assistant		
Crystal Kelly	University of Windsor	Research Assistant		

Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel

COSIA Project Number: LJ0227

Research Provider: Suncor Energy Inc., Hatfield Consultants, Millennium EMS Solutions Ltd.

Industry Champion: Suncor Energy Inc.

Status: Year 1 of Ongoing

PROJECT SUMMARY

In March 2005, Suncor Energy Inc. received approval to construct a tailings storage facility for the Millennium Mine project in the upper portion of the McLean Creek watershed. The construction of the tailings pond required the alteration of 3,870 m^2 of fish habitat in upper McLean Creek and approximately 53,000 m^2 of the McLean Creek wetlands system. As part of the project development, a compensation plan was prepared by Suncor, which included a new diversion channel to maintain flow to lower McLean Creek, and a dispersed-flow wetlands system. The South Tailings Pond (STP) Wetlands Complex was constructed between 2004 and 2006; the development included approximately 66 hectares of semi-permanent wetlands and an additional 82 hectare inundation zone consisting of a series of four cross-dykes, with re-vegetation encouraged through natural colonization. Fisheries and Oceans Canada (DFO) specified that monitoring in the area must take place to compare the development of the constructed wetlands condition/function to natural wetlands over time, to ensure the constructed wetlands conform to regional norms and meet DFO expectations.

A long-term wetland monitoring program for McLean Creek and the STP Wetlands Complex has been implemented since 2006 to track hydrologic conditions, water and sediment quality, and benthic invertebrate and vegetation communities through the ecological progression of the constructed wetlands. The monitoring program was designed to compare any changes in wetland condition/function over time to the natural wetlands in the upper portion of the McLean Creek watershed.

Many wetland monitoring programs in Alberta are effects-based as stipulated in project environmental approval conditions. Effects-based monitoring programs have a primary goal of measuring and quantifying potential (predicted) environmental or biological changes resulting from ongoing projects; however, little guidance exists for monitoring of created wetlands to address or minimize the effects of development. Specifically, no guidelines existed for setting performance standards and success criteria for the STP Wetlands Complex.

The objectives of this study are to:

- Establish performance indicators (i.e., measurable ecological indicators for each monitoring component) and success criteria (e.g., range of conditions from natural wetland systems); and
- Determine the variability in performance indicators over time and how they compare to the criteria in order to judge whether success has been achieved across all conditions (i.e., annual and seasonal variability). The performance indicators and success criteria were developed to evaluate whether the ecological function of the created STP Wetlands Complex is sustainable and consistent with the natural wetland systems in the watershed.

The “Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel” provides an outline of the performance indicators and success criteria to determine when the ecological function of the

STP Wetlands Complex conforms to regional norms. The data gathered will help determine the success of these constructed wetlands.

PROGRESS AND ACHIEVEMENTS

Monitoring continued in 2015, the data review and analysis will be included in the 2015 McLean Creek / STP Wetlands Complex annual report (April 30th, 2016). A summary of the 2014 assessment (Hatfield and MEMS, 2015) is provided below:

Comparisons of performance indicators of each monitoring component to the reference range of variability (i.e., success criteria) indicated that there are some performance indicators that have not achieved the success criteria, including those particularly related to water and sediment quality at all constructed wetlands; benthic invertebrate and phytoplankton communities at wetland STP-2; and zooplankton communities at wetland STP-4. Although the results of the vegetation community assessment indicated that wetlands STP-2, STP-3, and STP-4 did not meet the success criteria due to lower plant species diversity and lower percentage of obligate species in the submergent zones of these wetlands, it was apparent from the data collected over time, that there continues to be a progression towards reference conditions as the constructed wetlands continue to mature. Wetland STP-1 had attained consistent functioning to the reference wetlands, based on 2014 data.

OUTCOMES AND LESSONS LEARNED

Results of the 2014 monitoring program indicate that since their construction, there has been a positive progression in the development of benthic, vegetation, and plankton communities in the compensation habitat of the STP Wetlands Complex. Despite a few isolated differences, indices of the biological communities are relatively consistent between reference and test stations of the McLean Creek watershed. Overall, the results indicate that hydrologic, chemical, and biological conditions of McLean Creek and the STP Wetlands Complex are representative of a functioning and healthy ecosystem. However, they did not meet all success criteria in 2014 indicating that more time is needed for the constructed wetlands to show similar function to natural (reference) wetland systems.

PRESENTATIONS AND PUBLICATIONS

Hatfield Consultants and Millennium EMS Solutions Ltd. 2014. Criteria to Assess the Ecological Function of the STP Wetlands Complex. Prepared on behalf of Suncor Energy Inc. December 2014. North Vancouver, BC.

Hatfield Consultants and Millennium EMS Solutions Ltd. 2015. Suncor Millennium project 35(2): 2014 monitoring program for the McLean Creek watershed. Prepared on behalf of Suncor Energy Inc. April 2015. North Vancouver, BC.

RESEARCH TEAM AND COLLABORATORS

Institution: Suncor Energy Inc.

Principal Investigator: Sarah Aho, Sr. Hydrologist

Name	Institution or Company	Degree or Job Title
Heather Keith	Hatfield Consultants	Project Manager
Melissa Langridge	Hatfield Consultants	Senior Environmental Specialist
Margaret Magai	Millennium EMS Solutions Ltd.	Vegetation Ecologist
Laura Patterson	Millennium EMS Solutions Ltd.	Vegetation Ecologist

Fisheries Sustainable Habitat Committee: Refinement of Fish Habitat Pre-Disturbance Models

COSIA Project Number: LJ0225

Research Provider: Hatfield Consultants, Ecofish Research

Industry Champion: Suncor Energy Ltd.

Industry Collaborators: Shell Canada Energy, Canadian Natural Resources Limited, Imperial, Total E&P Canada Ltd., Teck Resources Ltd.

Status: Final Year of 3-Year Study

PROJECT SUMMARY

Developing the oil sands resource in northeast Alberta often results in both temporary and permanent losses of fish and fish habitat. To properly offset those impacts as required by Fisheries Act Authorizations, it is necessary to understand and quantify the level of disturbance using a scientifically defensible and repeatable measurement of habitat. This same approach can then be used to ensure a commensurate amount of compensation habitat is provided (referred to as "offsets", to reflect terminology used in the amended Fisheries Act). The regional habitat suitability index (HSI) models currently in use for this purpose were developed using a combination of scientific literature and expert judgment and have not been validated.

The primary goal of the Fisheries Sustainable Habitat (FiSH) Committee's Refinement of Fish Habitat Pre-Disturbance Models Program (the Program) is to develop a dataset that will allow scientists to refine the existing HSI models to quantify fish habitat in the Athabasca oil sands region in a reliable and scientifically credible manner. The Program has been implemented in two phases. Phase 1 consisted of creating a database of existing fish and fish habitat data collected in support of individual operator programs. Phase 1 provided a synopsis of the information collected to date, which allowed data gaps to be assessed and also identified compatible data that could be used as direct inputs to the process of refining and validating the HSI models. Phase 1 was completed in 2013, and found that individual operators had obtained substantial data for several fish species, but that the information was not sufficient for a number of key fish species, especially commercial, recreational and Aboriginal fishery species. Historically, the various site-specific studies collected data on a limited set of species because the majority of the study areas were located in the upper portion of tributary watersheds, which predominantly consist of small streams and wetland areas.

Phase 2 of the Program involved the design and implementation of a three-year study focused on collecting data for key riverine species. These species had not being captured in sufficient quantities in past years, to facilitate model validation and refinement. Phase 2 aims to meet the following key objectives:

- Collect fish habitat use observations to address the data gaps identified in Phase 1.
- Develop a methodology to integrate data from previous studies into the Phase 2 analysis.
- Assess sample size requirements for model validation.
- Explore relationships in the data that may lead to new suitability indices.
- Develop regionally specific HSI models that are validated with empirical data.
- Satisfy HSI model validation conditions in a number of operator Fisheries Act Authorizations.

PROGRESS AND ACHIEVEMENTS

2015 represents the third and final year of Phase 2 data collections. 192 mesohabitat units were sampled over the course of the study, and 180 fish and fish habitat records were collected for the five priority fish species (Arctic grayling, burbot, northern pike, walleye, and longnose dace). In 2015 alone, 2,884 fish were caught from 68 mesohabitat units located within 14 different streams. Over 30 habitat variables were measured at each mesohabitat unit, encompassing aspects of channel structure (stream size, water depth, and substrate composition), habitat complexity (types of cover), water velocity, and water quality (temperature, pH, and dissolved oxygen).

Fish habitat modelling is currently underway, which is providing the necessary evidence to refine the HSI models for 14 fish species from the Athabasca oil sands region. The fish species include the priority fish species noted above, two sucker species (longnose sucker and white sucker) and some small-bodied fish species (brook stickleback, finescale dace, fathead minnow, lake chub, pearl dace, slimy sculpin, and troutperch). The analysis uses a model selection and weight-of-evidence approach to identify habitat variables that limit fish abundance. These variables will then be incorporated into a revised HSI model for each species. Draft revised HSI models will be reported to the FiSH Committee in the spring of 2016.

OUTCOMES AND LESSONS LEARNED

Data collections for the Phase 2 Program are complete, but data analyses are still underway. Outcomes and lessons learned are not currently available for release to the public. Once the draft HSI models have been developed, a meeting will be organized to share the results.

PRESENTATIONS AND PUBLICATIONS

The draft final report is currently being written and will be submitted to the FiSH Committee for review in the spring of 2016. The new HSIs and supporting analysis may be submitted to a peer-reviewed scientific journal for wider public availability. A Field Sampling Protocols Manual was also developed during the first year of Phase 2.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants[1], Ecofish Research[2]

Principal Investigators: Daniel Moats[1] Dr. Todd Hatfield[2] Dr. Morgan Hocking[2] Steve Tang[1]

Name	Institution or Company	Degree or Job Title	Degree Start Date (For Students)	Completion Date (For Students Only)
Daniel Moats	Hatfield Consultants	Project Director		
Dr. Todd Hatfield	Ecofish Research	Scientific Advisor		
Dr. Morgan Hocking	Ecofish Research	Modelling Specialist		
Steve Tang	Hatfield Consultants	Project Manager		

Government Collaborators: Fisheries and Oceans Canada, Alberta Environment and Parks

Compensation Lake Studies

COSIA Project Number: LJ0260

Research Provider: Golder Associates

Industry Champion: Imperial

Status: Year 3 – Ongoing

PROJECT SUMMARY

Construction of the Kearl Oil Sands (KOS) Phase I Compensation Lake (Muskeg Lake) was completed in 2010. Monitoring to evaluate the biological development of the lake commenced when the basin was filled in 2013. Muskeg Lake is connected to Kearl Lake via a connector channel. The purpose of Muskeg Lake is to provide permanent compensation for fish habitat impacted by the KOS project and the overarching objective of the study is to evaluate the effectiveness of the constructed lake to support self-sustaining fish populations.

To understand this early biological development of Muskeg Lake, the following parameters are monitored and evaluated:

- Water and sediment quality
- Fish habitat and population
- Benthic invertebrate in littoral and pelagic habitats
- Aquatic vegetation establishment
- Phytoplankton and zooplankton

PROGRESS AND ACHIEVEMENTS

Water quality: Results show that Muskeg Lake was well oxygenated, slightly alkaline, with low concentrations of total suspended solids (TSS) in 2015. Concentrations of total and dissolved metals were generally within the range of the concentrations in previous years. Concentrations of dissolved arsenic, barium, copper, molybdenum, nickel, thallium, and uranium were higher in Muskeg Lake than Kearl Lake throughout 2015. Concentrations of calcium, hardness, and total dissolved solids were generally within the ranges observed during previous years, but were higher than the concentrations in Kearl Lake.

Nutrient concentrations were within the ranges of concentrations in previous years, and similar to Kearl Lake.

Naphthenic acids, total recoverable hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) were below the detection limits (DLs) in all samples with the exception of quinoline in spring.

Sediment quality: Concentrations of sediment quality parameters in Muskeg Lake were generally lower than those observed in previous years (2013 and 2014) in the lake. Sand was the dominant fraction of inorganic bottom sediments and total organic carbon (TOC) content was low, which is unusual for natural lake sediments in the region. However, Muskeg Lake is newly constructed and it is expected that over time the fine sediment fraction of Muskeg Lake sediments and TOC will increase to values typical of natural lakes.

Concentrations of metals were generally low and similar to those observed previously; however, a number of metal concentrations (i.e., calcium, magnesium, manganese, and uranium) and sulphur concentration were higher than those observed in 2013 and 2014. Concentrations of hydrocarbons were generally lower than those observed

previously, with the exception of total recoverable hydrocarbons. Concentrations of PAHs were generally lower than those observed in previous years.

Fish and fish habitat: A general fish inventory (i.e., species presence and relative abundance) was completed during both the spring and late summer surveys. The inventories consisted of minnow trapping and single-pass boat electrofishing in shallow littoral habitats along portions of the shoreline, and gill netting in deeper pelagic habitats. Evaluation of constructed habitat features was accomplished taking high resolution sonar imagery of large woody debris structures, root wads, boulder gardens and rocky substrate (i.e., cobble fields) at the location of the relevant features.

A total of seven fish species were captured in spring and late summer. The total number captured and average weight is summarized below:
Brook Stickleback (*Culaea inconstans*): 546 (average weight 1.5 g)
Fathead Minnow (*Pimephales promelas*): 526 (average weight 3.9 g)
Finescale Dace (*Phoxinus neogaeus*): 532 (average weight 1.4 g)
Lake Chub (*Couesius plumbeus*): 371 (2.5 g)
Pearl Dace (*Margariscus margarita*): 46 (average weight 2.1 g)
Longnose Sucker (*Catostomus catostomus*): 1 (not weighed)
White Sucker (*Catostomus commersonii*): 10 (average weight 415.6 g)

The habitat data recorded for Muskeg Lake was a qualitative assessment of the habitat features (large woody debris structures, rock substrates, boulder gardens, and root wad structures) installed at various locations around the lake, with observations made using an underwater camera and a high-resolution DIDSON sonar. Of the 13 large woody debris structures in the lake, five were examined with the underwater camera and found to provide high quality cover, while the remaining 8 structures were too deep to make observations with the underwater camera system used. Small minnow species were observed at the time of the assessment in the vicinity of the large woody debris structures. The rock substrates were found to provide potential spawning habitat for both small-bodied and large-bodied fish species. The boulder gardens and root wad structures were too deep to make accurate observations with the underwater camera system. For all large woody debris structures, root wads, rocky substrate, and boulder gardens within the deepest areas of the lake, the DIDSON system was used to capture high resolution sonar imagery. Small minnow species were observed at the time of the survey utilizing the large woody debris structures and root wads placed in the deeper areas of the lake. Rocky substrate observed in the sonar imagery appeared to be free of fine substrate.

In addition to a habitat assessment of Muskeg Lake, a detailed bathymetry survey of the Lake was conducted in 2015 in order to provide detailed information on the topography of the lake bed. The bathymetry shows that, at the time of the survey, Muskeg Lake had 23.4% littoral zone (i.e., 3 m deep or less), a maximum depth between 7 and 8 m, and an average depth of 4.09 m.

Due to equipment malfunction, continual water temperature monitoring data was not collected during the 2015 monitoring survey.

Aquatic vegetation: Aquatic macrophyte data collected consisted of a qualitative assessment of the aquatic macrophyte stands that were planted throughout the lake in 2013, consisting of 25 stands of Richardson's pondweed propagules and 10 stands of bulrush propagules. Thirteen of the pondweed stands were planted in the shallow littoral zone (≤0.5 m deep) and twelve were planted in the deeper littoral zone (>0.5 to 1.5 m deep). Bulrush stands were planted along the lake shoreline. Success of the Richardson's Pondweed plantings was observed to be low to nil for shallow plantings and nil for deeper plantings. For pondweed stands planted in the shallow littoral zone, vigor, survival, and percent of rooted plants were all low to nil. There was no evidence of spreading of the

shallow pondweed stands. Pondweed stands planted in the deep littoral zone were unsuccessful. In addition to the planted vegetation, aquatic vegetation of the Chara genus, northern watermilfoil (*Myriophyllum exalbescens*), and white water buttercup (*Ranunculus longirostris*) were observed at locations examined in the shallow littoral zone of Muskeg Lake, with northern watermilfoil dominating the deeper littoral zone, indicating natural colonization by these plants. Bulrush plantings were successful, with stands along the shoreline of Muskeg Lake showing high survival, moderate to high vigor, and evidence of spreading.

Benthic invertebrate and plankton: Data were collected in fall 2015 but sample analysis was not completed at the time of this report.

OUTCOMES AND LESSONS LEARNED

This study is in its early stages so there are no emerging outcomes or lessons learned.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates

Principal Investigator: Golder Associates