

## **COSIA Land EPA 2014 Mine Site Reclamation Research Report**

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**April 2015**

## 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.*

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Prepared For:

*Canadian Natural Resources Limited*

*Imperial*

*Shell Canada Energy*

*Suncor Energy Inc.*

*Syncrude Canada Ltd.*

*Teck Resources Limited*

*Total E&P Canada Ltd.*

**April 2015**

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# Instrumented Watersheds

# Applying Natural Analogues to Constructing and Assessing Long-Term Hydrologic Response of Oil Sands Reclaimed Landscapes (HEAD3)

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0215

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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.) and 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 Fort 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; wetland-forestlands), successional state; and
- the storage and connectivity (release for other systems) is proportional to the spatial weighting of hydrologic response area (HRA - 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.
- 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 lease-scale to ensure long-term resilience of constructed ecosystems.

Specific objectives to address the hypotheses and questions are addressed in three Scopes of research and eight objectives:

**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.

**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.

**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

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This was the first year of a four-year COSIA project, but represents the continuation of research initiated in the summer 2012 with Syncrude and the Subject Matter Experts. All projects listed for the objectives or deliverables have been initiated and in the first set of scientific publications listed below. The COSIA funds have been incorporated into an NSERC-CRD grant that has been recently submitted 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.

## OUTCOMES AND LESSONS LEARNED

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

### 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 to 2014, sampled through a dry, mesic and wet climate cycle.
- Basic analyses indicate that a large range in nutrient and salinity naturally occurs (both spatially and temporally with climate cycles) between HRAs and between HUs (Plach et al. 2014). Salinities can be high, with EC of greater than 2,000  $\mu\text{S}$  common in shallow groundwater and some surface streams (Olefeldt et al. 2013).
- Regional analyses revealed little difference between burned and unburned landscapes (ponds and peatlands) indicating limited connectivity between surface soils and regional water transport during dry and mesic conditions (Olefeldt et al. 2013).

### 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), 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. 2013, submitted).
  - In coarse-textured landscapes the groundwater flow is influenced by the regional groundwater gradient not local hillslope configuration (Hokanson et al. submitted).

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.

- 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 level below the surface- greatly reducing evaporation and creating accessible 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 of 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 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).

## PRESENTATIONS AND PUBLICATIONS

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Bremer, E., H. Deng, K. Hoffman, B.M. Starzomski, K.J. DeVito, M. Oswald, T. Munir, M. Strack, M. Wood, M.L. Macrae, F. Nwaishi, R.M. Petrone, M. Wang, J. Talbot, T.R. Moore, L.J. Sheppard, J. Drewer, U. Skiba and J.J. Schoenau. 2014. *Monitoring soil nutrients in wetland systems with PRS probes – case studies*. Alberta Soil Science Workshop, Edmonton, AB, Feb. 13–14, 2014.

Bremer, E., H. Deng, K. Hoffman, B.M. Starzomski, K.J. DeVito, M. Oswald, T. Munir, M. Strack, M. Wood, M.L. Macrae, F. Nwaishi, R.M. Petrone, M. Wang, J. Talbot, T.R. Moore, L.J. Sheppard, J. Drewer, U. Skiba and J.J. Schoenau. 2014. *Monitoring Soil Nutrients in Wetland Systems with PRS Probes*. Canadian Geophysical Union, Canadian Society of Soil Scientists Annual Meeting, Banff, AB, May 4–8, 2014.

Carey, S. and R.M. Petrone. 2014. *Water, Energy and Carbon Balance Research: Recovery Trajectories for Oil Sands Reclamation and Disturbed Watersheds in the Western Boreal Forest Report to the Cumulative Environmental Managers Association (CEMA) of Canada*. April, 2014.

Chasmer, L., C. Hopkinson, R. Petrone and K. DeVito. *Assessing rates of biological and morphological change over 40 years with enhanced warming: Boreal Zone, Canada*. 2014. American Geophysical Union Fall Meeting, San Francisco, CA, Dec., 14-18, 2014.

DeVito, K., A. Anderson, N. Kettridge, C. Mendoza, R. Petrone, U. Silins, K. Smith and M. Waddington. 2014. *Threshold responses in regional runoff from a heterogeneous low relief terrain - Western Canada's Boreal Plains*. Geosciences Union Annual Meeting, Vienna, Austria. Apr. 27-May 2, 2014. Geophysical Research Abstracts EGU2014-14540.

DeVito, K., C. Mendoza, R.M. Petrone, N. Kettridge and M. Waddington. 2014. In Press. *Utikuma Region Study Area (URSA) – Part 1: Hydrogeological and ecohydrological studies*. Accepted, July 2014. *Streamline Watershed Management Bulletin*.

Hoecherl, C. 2014. *Hydrogeological analysis of ice lenses in a Canadian boreal burnt peatland using fibre optic distributed temperature sensing*. M.Sc. Thesis, University of Birmingham, Birmingham, UK

Hokanson, K.J. 2014. *Influence of Hydrogeological Setting on Peatland Burn Severity*. M.Sc. Thesis, McMaster University, Hamilton, ON. 98pp.

Hokanson, K.J., M.C. Lukenbach, K.J. DeVito, N. Kettridge, R.M. Petrone and J.M. 2014. *Waddington Hydrogeological setting controls peat burn severity in the Boreal Plains*. Submitted Nov. 1, 2014 *Ecohydrology*.

- Kettridge, N., R.E. Humphrey, J.E. Smith, M.C. Lukenbach, K.J. DeVito, R.M. Petrone and J.M. Waddington. 2014. *Burned and unburned peat hydrophobicity: Implications for peatland evaporation following wildfire*. Journal of Hydrology, 513:315-341. DOI: 10.1016/j.jhydrol.2014.03.019.
- Kettridge, N, M.R. Turetsky, J.H. Sherwood, D.K. Thompson, C.A. Miller, B.W. Benscoter, M.D. Flannigan, M. Wotton and J.M. Waddington. 2014. In Press. *Moderate drop in water table increases peatland vulnerability to post-fire regime shift*.
- Lukenbach, M.C., K.J. DeVito, N. Kettridge, R.M. Petrone and J.M. Waddington. 2014. *Burn severity alters peatland moss water availability: Implications for post-fire recovery*. Submitted, *Ecohydrology*, Oct. 15, 2014.
- Lukenbach, M.C., K.J. Hokanson, K.J. DeVito, N. Kettridge, D.K. Thompson, P.A. Moore, B.M. Wotton, R.M. Petrone and J.M. Waddington. 2014. *Deep Burning In a Northern Forested Peatland*. American Geophysical Union Fall Meeting, San Francisco, CA, Dec. 14-18, 2014.
- 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. 2014. In Press. *Hydrological controls of deep burning in a northern forested peatland*, Hydrological Processes, HYP-14-0622.
- Mendoza, C. and K. DeVito. *Ecohydrology applications to ecosystem reconstruction after oil-sand mining*. 2014. European Geosciences Union Annual Meeting, Vienna, Austria, Apr. 27 to May 2, 2014. Geophysical Research Abstracts EGU2014-9840.
- Olefeldt, D., K.J. DeVito and M.R. Turetsky. 2013. *Sources and fate of terrestrial dissolved organic carbon in lakes of a Boreal Plains region recently affected by wildfire*. Biogeosciences, 10: 6247-6265. doi10.5194-2013.
- Petrone, R.M. 2014. *Canada's Boreal Wetland Resources: Coping with Climatic and Industrial Pressures*. Royal Canadian Institute for the Advancement of Science, Gala Dinner, Toronto, ON, Apr. 25, 2014.
- Petrone, R.M. 2014. *Productivity and water availability: Balancing the role and needs of peatlands in landscape reclamation*. 20<sup>th</sup> Peatland Ecology Research Group's Symposium: Symposium on responsible management of peatlands: Involvement of the industrial sector, Université Laval, Quebec City, QC, Feb. 19-20, 2014.
- Petrone, R.M. and S.K. Carey. 2014. *Water, Energy and Carbon Balance Research: Recovery Trajectories for Oilsands Reclamation and Disturbed Watersheds in the Western Boreal Forest*. American Geophysical Union Annual Meeting, San Francisco, CA, Dec. 14-19, 2014.
- Petrone, R., K. DeVito and C. Mendoza. 2014. In press. *URSA – Part 2: Aspen harvest and recovery Study*. Accepted July, 2014. *Streamline Watershed Management Bulletin*.
- Petrone, R.M., D.K. Thompson, L.E. Chasmer, N. Kljun, M.D. Flannigan, K.J. DeVito and J.M. Waddington. 2014. *Impact of wildfire smoke on regional carbon exchange during the 2011 Utikuma Complex Fire, Alberta, Canada*, Submitted *Forest Ecology and Management*, August 2014.
- Plach, J.M., K.J. DeVito and R.M. Petrone. 2014. *Ecohydrological Controls on Net CO<sub>2</sub> Exchange in a Riparian Peatland Following Upland Tree Removal on the Western Boreal Plain*. Canadian Geophysical Union – Canadian Society of Soil Scientists Annual Meeting, Banff, AB, May 4-8, 2014.

- Plach, J.M., K.J. DeVito and R.M. Petrone. 2014. *Influence of Glacial Landform and Landscape Position on Groundwater and Phosphorus Dynamics of Shallow Lakes on the Boreal Plains*. Geological Society of America Annual Meeting, Vancouver, BC, Oct. 19–22, 2014.
- Plach, J.M., J. Ferone, Z. Gibbons, B.D. Smerdon, A.R. Adhikari, C.A. Mendoza, R.M. Petrone and K.J. DeVito. 2014. *Influence of glacial landform and landscape position on trophic status of shallow lakes on the Boreal Plains*. Submitted October, 2014 *Limnology & Oceanography*.
- Price, J.S., K.J. DeVito, C. Mendoza and R.M. Petrone. *Hydrological challenges and opportunities for reconstructing wetland ecosystems after oil-sands mining*. 20<sup>th</sup> Peatland Ecology Research Group's Symposium: Symposium on responsible management of peatlands: Involvement of the industrial sector, Université Laval, QC, Feb. 19-20, 2014.
- Sutherland, G., L.E. Chasmer, N. Kljun, K.J. DeVito and R.M. Petrone. 2014. *Using high resolution LiDAR data and a flux footprint parameterization to scale evapotranspiration estimates to lower pixel resolutions*. Submitted to Remote Sensing of the Environment, October 2014.
- Sutherland, G., L.E. Chasmer, R.M. Petrone, N. Kljun and K.J. DeVito. 2014. *Using High Resolution LiDAR Data and a Flux Footprint Parameterization to Scale Evapotranspiration Estimates to Lower Pixel Resolutions*. Canadian Geophysical Union – Canadian Society of Soil Scientists Annual Meeting, Banff, AB, May 4–8, 2014.
- Sutherland, G., L.E. Chasmer, R.M. Petrone, S.M. Brown, N. Kljun and K.J. DeVito. 2014. *Evaluating the use of spatially varying vs. bulk average 3D vegetation structural inputs to modelled evapotranspiration within heterogeneous land cover types*. ECO-13-0095 *Ecohydrology*. 7(6): 1545-1559. DOI: 10.1002/eco.1477.
- Thompson, C., C. Mendoza and K. DeVito. 2014. *Potential Influence of Climate Change on Ecosystems Within The Boreal Plains Of Northern Alberta*. Annual Meeting of the Geological Society of America, Vancouver, BC, Oct. 19-22, 2014.
- Waddington J.M., N. Kettridge, K. Hokanson, M.C. Lukenbach, R.M. Petrone, K.J. DeVito. 2014. *Hydrophobicity diminishes peatland evaporation after wildfire*. Canadian Geophysical Union, Canadian Society of Soil Scientists Annual Meeting, Banff, AB, May 4–8, 2014.
- Waddington, J.M. 2014. *Peatland ecohydrology by thinking outside the bog: Shifting paradigms in an era of shifting ecosystems*. Penman Lecture – British Hydrological Symposium, Birmingham, UK, Sep. 2-4, 2014.

## RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta<sup>1</sup>, University of Birmingham<sup>2</sup>, University of Waterloo<sup>3</sup>, McMaster University<sup>4</sup>

Principal Investigator: Kevin Devito<sup>1</sup> and Carl Mendoza<sup>1</sup>, Nick Kettridge<sup>2</sup>, Rich Petrone<sup>3</sup>, Mike Waddington<sup>4</sup>

Name	Institution	Degree	Start Date	Completion Date
Kelly Hokanson	University of Alberta	Research Hydrologist	May 2015	April 2018
Cameron McCann	McMaster University	Ecohydrology Techn.	September 2014	August 2018
Janina Plach	University of Waterloo	PDF	November 2013	October 2013
Paul Moore	McMaster University	PDF	April 2014	March 2016
Craig Thompson	University of Alberta	Ph.D.	January 2010	September 2015
Max Lukenbach	McMaster University	Ph.D.	September 2011	August 2015
Rhoswen Leonard	University of Birmingham	Ph.D.	May 2014	April 2017
Silvia Folegot	University of Birmingham	Ph.D.	May 2014	April 2017
Lindsay James	University of Alberta	M.Sc.	September 2015	September 2017
Midori Depante	University of Waterloo	M.Sc.	September 2014	September 2016
Brandon MacKinnon	McMaster University	M.Sc.	May 2014	April 2016
Cierra Hoecherl	University of Birmingham	M.Sc.	October 2013	October 2014
Mika Little-DeVito	University of Alberta	Undergraduate	May 2013	September 2014
Sarah Irvine	McMaster University	Undergraduate	May 2013	September 2014
Greg Carron	University of Waterloo	Undergraduate	May 2014	April 2015
Corina Zuber	McMaster University	Undergraduate	May 2014	April 2015
Sarah Irvine	McMaster University	Undergraduate	May 2014	April 2015
Sophie Wilkinson	McMaster University	Undergraduate	May 2014	April 2015
Samantha Probert	University of Birmingham	Undergraduate	March 2014	February 2015

Industry Collaborators: Canadian Natural Resources Limited

# Aurora Soil Capping Study: Program Overview

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**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0201

**Academic Institution:** Syncrude Canada Ltd.

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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The Aurora Soil Capping Study (ASCS) is a study to address two issues for oil sands mine operators in the 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, situated on 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 of 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 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 revegetated 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 has been installed to measure such parameters as soil moisture, temperature, groundwater presence and water quality. Individual research programs have also installed a number of instruments to conduct their research within the study. A meteorological station has also 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 recognized a number of research disciplines for research study. The research programs are a combination of SIPs and JIPs. 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)

See above table and individual ASCS COSIA project sections for more details.

Industry Collaborators: None

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

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0099

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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 may affect monitoring systems, 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 expected outcomes include: 1) a better understanding of the physics of water retention and energy balance in these reclamation cover prescriptions over lean oil sand overburden; 2) the optimal thickness of peat/mineral mix and LFH which will result in the reclamation soil having an equal capability to pre-disturbance conditions in terms of soil water in natural a/b ecosites of the region; 3) 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) modules that deal with specific issues in coarse textured, hydrocarbon-affected soils and lean oil sand overburden, as well as young and evolving reclamation soils.

## PROGRESS AND ACHIEVEMENTS

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

Trent Pernitsky (M.Sc. student) is conducting a study to determine the impact of bulk density and PHC concentration on the hydraulic properties of 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 and bulk density are being tested.

Laboratory tests have been completed and analysis is underway. The findings of the study will provide insight into the effect of LOS with variable PHC concentration and bulk density to retain water and the effect to net percolation of water through the overlying soil cover materials.

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

Meghan Johnson (M.Sc. student) conducted a laboratory study using the range of subsoils present in the ASCS. Various treatments were created with these materials, including the addition of a range of proportions of hydrocarbon-affected materials 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 through 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.

Laboratory tests have been completed and analysis is 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 aggregated oil sand materials 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. student) is investigating the water repellency and hydraulic properties of aggregated oil sand materials (AOSM). The objectives of the study are to: 1) investigate potential soil water repellency of AOSM and soil matrix materials; 2) characterize hydraulic properties, such as water retention and saturated hydraulic conductivity, of AOSM collected at various soil 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 and as they weather with time.

In 2013 and 2014 AOSM was collected from different soil reclamation material types and salvage depths of the soils that comprise the different treatments of the ASCS. The SWR and persistence was determined for collected samples using contact angle analysis with a goniometer and autopipette as forms of the WDPT test. The study is also testing the repellency of inner and outer portions of AOSM.

Study tests have been completed and analysis is underway. The study will attempt to determine if there is a relationship with SWR of AOSM and their salvage depth. These tests will also provide insight on the change of AOSM SWR as they weather after salvage, stockpile and use later in soil reclamation.

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

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Mark Sigouin (M.Sc. student) is testing the use of the Cosmic-ray Soil Moisture Probe (CRP) to measure soil water content and snow water equivalent in a reclamation landscape. Landscape-scale measurement of soil water content and snow water equivalent (SWE) (rather than point-scale methods) is important in monitoring the success of surface mine reclamation areas such as those in the Alberta oil sands. 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 area of the CRP is a circular area with a radius of approximately 300 m. The CRP produces an average soil water content reading within its measurement area. The main objectives of this study are: 1) to evaluate if CRP can be used to monitor SWE; and 2) to evaluate the soil water content measurement efficacy of the CRP at a heterogeneous reclamation site.

Work on the first objective began in November 2013 with the installation of a CRP (CRS/1000-B, Hydroinnova) at an agriculture field in Saskatoon, SK. SWE surveys were also performed manually using a snow tube roughly twice per month in the field during the winter of 2013/14. The CRP recorded fast neutron counts per hour throughout the winter. The CRP has been re-installed at the Saskatoon field site for the winter of 2014/15.

In May 2014, a CRP was installed at the ASCS site to assess the efficacy of the CRP in terms of monitoring soil water content at a heterogeneous reclamation site (i.e., various reclamation treatments, tree species and densities, and activities). A CRP was installed in the center of the ASCS at the end of May 2014, followed by calibration of the instrument. Soil samples were collected within 300 m of the CRP throughout the summer to compare to the data collected by the CRP.

Analysis of collected data is currently underway. The measurements obtained from the CRP will be compared with those obtained from the in-situ soil water content sensors at ASCS for the 2014 summer season and SWE for the winter of 2014/2015 at Saskatoon. In May 2015, the CRP will be permanently installed at ASCS for continuous monitoring soil water and SWE at ASCS.

## **Field study on the Effects of Oil Sands Reclamation Covers on Soil Water Storage and Soil Temperature in the Oil Sands**

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Wei Hu (Postdoctoral Fellow) is evaluating the effects of oil sands reclamation covers on soil water storage (SWS) and soil temperature (ST) at Syncrude's 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 are being 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 is also being investigated.

## Modelling Deep Drainage of Two Vegetation Types (Mixed Wood, and Jack Pine) and Two Soil Prescriptions (Peat-Sand-LOS and Sand-Sand-LOS) Based on Two Packing Densities and Different PHC Contents

Wei Hu, Thian Wittayawarakul (Ph.D. student), and Eric Neil are developing a numerical model to simulate water dynamics in layered, coarse textured soils containing oil 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 climate data information for the region. 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) from the soil cover.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

Pernitsky, T. and B. Si. 2014. *Determination of soil hydraulic properties in a reclamation cover using lean oil sand (LOS) as the base soil layer*. Joint CGU and Canadian Society of Soil Science Conference, Banff, AB, May 3-8, 2014.

## RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Bing Si

Name	Institution	Degree	Start Date	Completion Date
Trent Pernitsky	University of Saskatchewan	M.Sc.	September 2011	Tentatively April 2015
Meghan Johnson	University of Saskatchewan	M.Sc.	January 2012	Tentatively April 2015
Henry Chau	University of Saskatchewan	Ph.D.	September 2008	March 21, 2014
Lindsay Tallon	University of Saskatchewan	Ph.D.	September 2010	April 1, 2014
Eric Neil	University of Saskatchewan	M.Sc.	May 2013	Ongoing
Wei Hu	University of Saskatchewan	Post-Doctoral Fellow	September 2013	Ongoing
Mark Sigouin	University of Saskatchewan	M.Sc.	September 2013	Ongoing
Thian Wittayawarakul	University of Saskatchewan	Ph.D.	September 2013	Ongoing
Ivanna Faucher	University of Saskatchewan	M.Sc.	September 2014	Ongoing

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

# Aurora Soil Capping Study: Hydrocarbon Degradation and Mobility

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0219

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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.
- 2) Rates of gas flux from the LOS through the placed soil reclamation to the surface, 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

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In September 2013 Tomasz Korbas completed a M.Sc. studying the degradation and mobility of PHC in LOS overburden. This consisted of surface carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) flux measurements at various depths of the near-surface LOS at the ASCS on three separate occasions in 2010 and 2011, prior to the placement of the soil reclamation materials. Some of the key findings were the following:

- Gas flux rates across the ASCS varied spatially and temporally.
- Consistent with reported literature, temperature was observed to have a significant effect on the rate of PHC degradation as indicated by gas flux measurements at different times of the year. CO<sub>2</sub> flux measurements, considered an indicator of PHC degradation, were positively correlated with temperature.
- High levels of soil moisture caused by rainfall events resulted in a temporary reduction in gas flux rates.
- Occasionally, elevated concentrations of CO<sub>2</sub> and CH<sub>4</sub> were detected.

LOS overburden material was collected from the ASCS and used in a column study to assess degradation and mobility of PHCs. Soil respiration (CO<sub>2</sub>) rates measured from the columns indicate that degradation of the PHCs in LOS is occurring at a relatively slow rate. Only a small portion of the PHC present in the columns were degraded; 15 g/yr of PHC were degraded from 2.8 kg of lean oil sand over 166 days with soil temperatures ranging from 2°C

to 14°C [6°C average]). PHC volatilization was also measured and was two orders of magnitude less than that of PHC degradation. There was a positive linear relationship with soil temperature and CO<sub>2</sub> (indication of PHC degradation).

The results of the laboratory column study also suggest that the LOS may have a low environmental impact to surface or groundwater quality. PHC analysis of the water leachate from the columns returned concentrations below, or slightly above, the analytical detection limit, but within the acceptable concentration for clean water guidelines. Only on occasions when the column temperatures were raised to ≥ 22°C did the F2 portion (carbon chain length of 10 to 16) of the PHC exceeded clean water guidelines; however, this does not reflect average field soil temperature conditions). At 4°C, which is more representative of field soil temperatures, the F2 PHC did not exceed drinking water guidelines and were near the detection limit.

In 2011, Kyle Scale began an 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 model that can be used to evaluate reclamation performance of various soil cover designs being considered for LOS overburden reclamation. Appropriate soil reclamation material types and optimal capping depths will be considered in the assessment.

Work completed to date from Mr. Scale's study includes the following:

- Teflon tubing has been installed at the study site to depths of 0.5, 1, 2, 3 and 4m in the various cover soil treatments (and into LOS) to facilitate measuring methane (CH<sub>4</sub>), carbon dioxide (CO<sub>2</sub>) and oxygen (O<sub>2</sub>) concentration gradients with a field portable gas analyzer.
- Surface and subsurface flux chambers have been installed at three discrete locations on site.
- Field-based laboratory has been erected to house the Columbus Instruments Model 180-C gas analyzer and bank of deep-cycle batteries.
- Long-term CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> gas concentrations have been measured and analyzed for the 2013 and 2014 spring and summer field seasons.
- Laboratory work measuring in-situ gas concentrations and methane oxidation rates using flux chambers and soil vapour probes in representative soil cover treatments re-created in soil column experiments.
- Successful completion of the Ph.D. qualifying exam and official transfer to a Ph.D. program.

Mr. Scale will complete a final year of data collection in 2015. The remaining work activities in this study include the following:

- Final season for field data collection at ASCS.
- Completion of laboratory-based column study.
- Development of numerical model(s) and simulation of various soil cover designs and depths.

The study will conclude at the completion of Mr. Scale's Ph.D. study.

## OUTCOMES AND LESSONS LEARNED

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The following outcomes have emerged from the study to date:

- gas flux rates (indicator of PHC degradation) from LOS overburden is variable and is dependent on PHC concentration (increased gas flux with increased PHC concentration);
- soil temperature has a significant (positive) effect on gas flux rate which is consistent with literature;
- high soil moisture content suppresses gas flux rates;
- portions (pockets) of increased CO<sub>2</sub> and CH<sub>4</sub> may be present in the LOS;
- PHCs present in LOS are relatively stable and degrade at a relatively slow rate; and
- water leachate from LOS may have a low environmental impact to surface and groundwater quality.

## PRESENTATIONS AND PUBLICATIONS

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Submitted paper for review to the journal Environmental Geotechnics:

Korbas, T., I.R. Fleming and K.O. Scale. 2014. *Degradation and Mobility of Petroleum Hydrocarbons in Oil Sands Waste at the Aurora North Mine.*

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Saskatchewan

Principal Investigators: Ian R. Fleming

Name	Institution	Degree	Start Date	Completion Date
Tomasz Korbasz	University of Saskatchewan	M.Sc.	2010	September 2013
Kyle Scale	University of Saskatchewan	Ph.D.	2011	Q3 2016

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

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0201

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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A number of research priorities related to land reclamation in the Athabasca Oil Sands Region have been identified by Syncrude. 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 by Derek MacKenzie of the University of Alberta, in consultation with Syncrude.

### **Study 1 – Impact of Different Capping Materials and Canopy Type on Soil-Plant Relations**

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Research Question 1 – How does plant nutrient availability and uptake by tree species vary in the different soil cover types and depth treatments? And how does it compare with appropriate benchmarks?

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: Effect of Variable Peat: Mineral Mix Ratio on Soil Biogeochemistry and Plant Growth**

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Research Question 1 – How do various coversoil material types affect the foliar material and soil nutrient environment?

Research Question 2 – How do various coversoil material types affect molecular microbial ecology?

Research Question 3 – What role does coversoil material play in mycorrhizal establishment on plant roots?

### **Study 3 – Spatial Pattern Analysis of Soil-Plant Relations to Determine the Success of Land Reclamation**

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Research Question 1 – What are the spatial patterns associated with plant nutrient availability and uptake, and how do they compare with appropriate benchmarks?

Research Question 2 – What are the spatial patterns associated with microbial community structure, and how do they compare with appropriate benchmarks?

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

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 rehabilitate after disturbance and if they are appropriate analogues for comparison to specific oil sands reclamation situations (focusing on soil biogeochemical processes).

## **PROGRESS AND ACHIEVEMENTS**

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### **Study 1 – Impact of Different Capping Materials and Canopy Type on Soil-Plant Relations**

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Soil respiration, available nutrients, temperature, moisture and microbial analyses were measured during the field seasons of 2013 and 2014. Analyses of soil microbial communities included: basal respiration, phospholipid fatty acid analysis, community level physiological profiling in addition to basic soil chemical and physical measurements. The project is nearing completion and is in the final stages of writing for the purpose of completing an M.Sc. in soil science (Mark Howell).

### **Study 2 – Effect of Variable Peat: Mineral Mix Ratio on Soil Biogeochemistry and Plant Growth**

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A greenhouse trial was designed and started in 2014 to identify nutrient properties of reclamation coversoils. Cover soil materials (peat, subsoil and upland surface soil) were collected from the Aurora Soil Capping Study for the greenhouse experiment. A range of peat: mineral mix ratios were established using the supplied peat and subsoil material. The trial will measure early tree establishment in a range of peat:mineral mix ratios to salvaged upland surface soil material. Soil nutrients and mycorrhizal community establishment will also be investigated in the experiment.

### **Study 3 – Using Spatial Pattern Analysis of Soil-Plant Relations to Determine the Success of Land Reclamation (Ph.D. student)**

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In January 2014 Sebastian Dietrich (Ph.D. student) started analyzing 2013 spatial soil respiration and spatial nutrient data collected from two coversoil treatments (upland surface soil and peat) at the Aurora Soil Capping Study as well as for two benchmarks sites (tree harvested site and natural forest fire site). Results were presented in November 2014 at the Soil Science Society of America annual meeting.

Starting in May 2014, Sebastian Dietrich and Maksat Igdyrov (technician) sampled soil respiration data monthly until August on the spatial plots at Aurora and the benchmark sites. To get a better understanding of how the data compares to undisturbed a and b ecosites and severely burned a and b ecosites, two sites were added to the experimental set up in June 2014, which from then on comprises a total of six sites. In June all sites were equipped with two data loggers to record soil moisture at depths of 10 cm, 20 cm and 30 cm and soil temperature at depths of 10 cm and 20 cm. Soil samples were taken on the full spatial set up on each site (n=486) in August 2014 and processing of the samples is underway.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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Dietrich, S.T. and M.D. MacKenzie. 2014. *Can Spatial Patterns of Soil Respiration and Nutrient Availability Indicate Ecosystem Function in the Reclaimed Boreal Environment?* American Society of Agronomy, Crop Science Society of America and Soil Science Society of America International Annual Meeting. Long Beach, CA. Nov. 2-5, 2014.

Howell D.M. and M.D. MacKenzie. 2014. *Implications of topsoil placement depths for microbial communities in oil sands mine reclamation.* Oral presentation at the Soil Science Society of America annual meeting, Long Beach CA.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: M. Derek MacKenzie

Name	Institution	Degree	Start Date	Completion Date
Sawyer Desaulniers	University of Alberta	B.Sc.	May 2013	September 2013
Nicole Filipow	University of Alberta	B.Sc.	May 2013	September 2013
Arezo Amini	University of Alberta	M.Sc.	May 2013	December 2013
Simmon Hofstetter	University of Alberta	PDF	May 2014	September 2014
Maksat Igdyrov	University of Alberta	B.Sc.	January 2014	Ongoing
Mark Howell	University of Alberta	M.Sc.	September 2012	Ongoing
Sebastian Dietrich	University of Alberta	Ph.D.	January 2014	Ongoing
Nduka Ikpo	University of Alberta	PDF	April 2013	Ongoing

Industry Collaborators: None

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

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0100

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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Links between vegetation and soil microbes can operate as major drivers 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. Through improved access to soil resources, many tree species 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 vegetation can be managed to restore diverse communities of ectomycorrhizal fungi is poorly understood. At the Aurora Soil Capping Study (ASCS), the composition and density of tree species have been varied across capping treatments to understand how vegetation can be manipulated to yield rapid canopy development and a diverse community of ectomycorrhizal fungi. Specifically, this study is investigating the effects of different capping treatments on: 1) tree establishment and growth, plant communities, soil resource availability and rooting behavior; 2) the composition of ectomycorrhizal fungal communities; and 3) how physiological properties of tree hosts modify the development of ectomycorrhizal communities. Successional trajectories of ectomycorrhizal communities created through reclamation are also compared with those of selected ecological references. The research will inform our understanding of links among capping materials, tree establishment, and ectomycorrhizal community development for reclamation of upland boreal forests. Specific objectives include:

- assessing the impact of different capping treatments on tree growth and root development over five years;
- assessing the impact of planting density on tree growth and root development over five years;
- assessing the role soil temperature plays in affecting tree growth across different capping materials;
- determining the inoculum potential of ectomycorrhizal fungi of capping materials;
- determining the effects of seedling quality on rhizosphere activity, and community composition of ectomycorrhizal fungi; and
- determining how successional trajectories of soil microbial communities created through reclamation practices compare with those of selected benchmarks.

## PROGRESS AND ACHIEVEMENTS

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Towards Task 1, assessing the effects of the different capping treatments on tree growth and root development, Jana Bockstette (M.Sc. candidate) has led growth measurements of all trees in the capping treatments in 2012, 2013 and 2014. Rooting behavior as a function of capping materials and the configuration of their placement is being investigated by Simon Bockstette (Ph.D. 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 2014, minirhizotron imaging continued, albeit at a reduced frequency (start, mid-season and end of growing season) than in 2013. The collected images are currently being analysed. Soil moisture and temperature were also monitored in 2014.

As part of assessing the response of tree seedlings to capping treatments, we have also expanded Task 1 (under the Industrial Research Chair in Land Reclamation, COSIA Project #LE0012) to include vegetation surveys to assess the development of plant communities. At this early stage of tree growth canopy cover is not anticipated to have an effect on plant community development, rather development is presumed to be driven by capping material type. Caren Jones (M.Sc. candidate) leads this work, in addition to setting up experiments testing whether forest floor material (FFM) can be strategically placed to promote the dispersal of desirable upland understorey species into surrounding peat-capped areas.

Towards Task 3, assessing the role soil temperature plays in affecting tree growth across capping materials, Shanon Hankin (M.Sc.) and Jana Bockstette (M.Sc. candidate) set up a growth chamber experiment designed to test the influence of early season cold soils and delayed warming on subsequent seedling growth of aspen and jack pine. This experiment was based on two field observations at the ASCS: 1) lower height growth of aspen on peat than FFM; and 2) a temperature profile showing colder temperatures in peat than FFM in spring, which lasted until mid-summer. The experiment was a 3 × 2 factorial in which seedlings were planted into either peat or FFM and exposed to three different soil temperature regimens emulating those observed in the field over a full growing season. Three periods were identified corresponding to different phenological stages of seedlings: (i) the budflush period where soil temperature was held constant for two weeks after the initiation of budflush; (ii) the warming period where shoots of seedlings were expanding and the length of time required to reach a soil temperature of 20°C was varied; and (iii) the growth period where soil temperature was maintained at approximately 20°C for the remainder of the 70 day experiment. These experimental conditions reflect soil temperatures at 15 cm depth when capped with a 30 cm peat cover. Soil temperatures were maintained through the use of water baths. Results indicate that soil temperatures of ≤5°C during budflush in the spring restricted aspen seedling growth. Data on the effects of soil temperature and rate of warming on jack pine are being analyzed.

Towards Task 4, assessing the inoculum potential of ectomycorrhizal fungi of capping materials, Shanon Hankin (M.Sc.) found that salvaged and directly placed FFM, peat and subsoil contain propagules of ectomycorrhizal fungi when assayed by aspen, white spruce and jack pine in the field and growth chamber. All 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 pending publication in Botany.

Towards Task 5, determining the effects of seedling quality on rhizosphere activity, and community composition of ectomycorrhizal fungi, Jake Gaster (M.Sc. candidate) has tracked how exudation of organic carbon changes with carbon stored in roots of aspen, and how root: shoot and nutrient status affect interactions with ectomycorrhizal fungi. In the second experiment, aspen seedlings grown under two different nutrient regimes prior to outplanting

(i.e., standard fertilization and double fertilization) and grown on two different capping materials (peat-mineral mix and reclaimed forest floor) on an oil sands lease were assessed for ectomycorrhizal fungal colonization and root carbohydrate reserves.

We expanded Task 5 to test not only how the composition of ectomycorrhizal fungal communities varies by seedling quality, but also as a response to host phenology. Stefan Hupperts (M.Sc. candidate) leads this research, with the objective of understanding how carbon shortages in host trees affects the ability of ectomycorrhizal fungi to acquire carbon through decomposition of soil organic matter rather than current photosynthates. Identifying the source of carbon used by ectomycorrhizal fungi will help inform how carbon cycling develops in reclaimed sites. During 2014, he profiled enzyme production of ectomycorrhizal fungi collected from the field during aspen dormancy, leaf flush, growth and senescence – phenological stages which greatly alter the amount of carbon available to support symbionts.

Towards Task 6, determining how successional trajectories of soil microbial communities created through reclamation practices compare with those of selected benchmarks, Stefan Hupperts (M.Sc. candidate) collected root samples from seedlings grown in the three cover soils at Aurora (peat, FFM and subsoil) as well as the reference sites and has assessed these roots for the presence and identity of ectomycorrhizal fungi. Reference sites include an intact jack pine forest, a jack pine forest harvested approximately 17 years ago, and a similarly harvested site, with the forest floor removed. Fungi colonizing roots of seedlings planted across the sites are currently being identified by DNA analysis.

## DELIVERABLES AND MILESTONES

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In 2016, final measurements on tree growth across the capping treatments will be performed. This final survey will complete data collection required for Tasks 1 and 2. Measurements on root growth and behaviour will be completed in 2015, where focus will shift to destructively sampling roots, in the form of soil cores and manual excavation of root systems. This sampling strategy will serve the dual-purpose of confirming findings from minirhizotrons and determining the effects of intra- and interspecies competition on overall root system architecture in greater detail. Plant surveys will be performed in 2015 by Caren Jones. All data are collected for Task 3; results of the response of aspen to soil temperature are published in Shanon Hankin's thesis, and results for jack pine will be published in Jana Bockstette's thesis. Task 4 is completed and results are pending publication. All data are collected under Task 5; analysis, interpretation and communication remain. Towards Task 6, another survey of ectomycorrhizal fungi present at the ASCS and the reference sites will be performed in 2015 by a student to be identified.

## OUTCOMES AND LESSONS LEARNED

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- Cover soils high in peat content can result in cold soil temperatures in the spring, reducing growth of aspen.
- Directly salvaged peat, forest floor material and subsoil can be reservoirs for propagules of ectomycorrhizal fungi.

## PRESENTATIONS AND PUBLICATIONS

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Gaster, J., J. Karst and S. Landhäusser. 2014. *Carbon and nutrient dynamics underlying interactions between aspen and ectomycorrhizal fungi*. R.E. Peter Biology Conference, University of Alberta, Edmonton, AB.

Gaster, J., J. Karst and S. Landhäusser. 2014. *The role of seedling nutrient status on development of ectomycorrhizal fungal communities in two soil types following surface mining disturbance*. Submitted to *Pedobiologia*.

Hankin, S., J. Karst and S. Landhäusser. 2014. *Ectomycorrhizal fungal inoculum potential of surface reclamation materials in oil sands mining*. Ecological Society of America Annual General Meeting, Sacramento, CA.

Hankin, S., J. Karst and S. Landhäusser. 2014. *Influence of tree species and salvaged soils on the recovery of ectomycorrhizal fungi in upland boreal forest restoration after surface mining*. Accepted with minor revisions by Botany.

Hankin, S., J. Karst and S. Landhäusser. 2014. *Impact of capping material selection on the recovery of ectomycorrhizal fungi and seedling growth of forest reclamation sites*. R.E. Peter Biology Conference, University of Alberta, Edmonton, AB.

Jones, C. and S. Landhäusser. 2014. *Influence of capping material and seed source proximity on understory vegetation community development*. Forest Industry Lecture Series, Department of Renewable Resources, University of Alberta, Edmonton, AB.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution	Degree	Start Date	Completion Date
Justine Karst	University of Alberta	Research Associate, Ph.D.	August 2011	Ongoing
Simon Bockstette	University of Alberta	Ph.D.	September 2011	Ongoing
Shanon Hankin	University of Alberta	M.Sc.	September 2012	January 2015
Jake Gaster	University of Alberta	M.Sc.	September 2012	Ongoing
Jana Bockstette	University of Alberta	M.Sc.	September 2013	Ongoing
Caren Jones	University of Alberta	M.Sc.	September 2013	Ongoing
Stefan Hupperts	University of Alberta	M.Sc.	January 2014	Ongoing

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

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Ongoing

**COSIA Project Number:** LJ0201

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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This project will help to develop [REDACTED] reclamation techniques on overburden landscapes using coarse-textured (sandy) reclamation soils. Re-establishment of forestland capability associated with water and nutrient limited ecosites on coarse-textured soils is a key target for oil sands reclamation. Using the materials at the Aurora Soil Capping Study, the project will also investigate whether nutrient additions are needed to re-establish nutrient limited soils similar to a natural a/b ecosite.

Specifically the research will investigate the following:

- quantify nutrient pools and forms (with an emphasis on carbon) in sandy cover soils in comparison to appropriate natural analogs;
- investigate the interactions between nutrient additions and redistribution within the soil profiles, and perennial plant root development; and
- quantify the fate of nutrients (i.e., soil retention, plant uptake, versus nutrient losses) following addition.

The research will provide knowledge on the quantitative relationship between the different mineral substrates and organic cover types currently used to reconstruct sandy soils, and the response of key receptors, including plant and soil, to nutrient addition and water movement. [REDACTED]

The following three objectives to be addressed in the overall project plan were proposed as three integrated projects:

- **Quantification of nutrient pools and forms in reconstructed sandy soils and comparison to undisturbed sandy analogs.** Assessing the nutrient reserves that are inherently present in the soil materials used to reclaim the oil sands landscape is the first step towards the definition of [REDACTED] reclamation strategies. In addition, it is critical to determine the distribution and supply rate of these nutrient reserves. While forest floor is expected to contain greater overall nutrient stocks, we hypothesize that nutrient release from this type of material will occur rapidly, so that peat materials, with lower stocks but slower release rates may provide longer lasting nutrient benefits to the reconstructed soils.

- **Quantification of soil retention and nutrient losses following addition.** 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 the soil column textural discontinuities and nutrient retention. We hypothesize that textural heterogeneity will increase retention of the fertilizer nutrients and that this effect will be enhanced in the Bm compared to the BC and C horizons.
- **Investigation of the growth and rooting of aspen seedlings in response to nutrient addition in reconstructed soils.** Specific objectives will provide a detailed understanding of rooting behavior and root distribution in the different reclamation materials, as well as their specific response to nutrient addition in relation to the different textural discontinuities within the soil columns. The rooting behavior of perennial deep rooting species in these soils is crucial to the understanding of the movement of nutrients between different soil layers and the acquisition and storage of nutrients in plant tissue and its incorporation back into the soil through root turnover. We anticipate that textural discontinuities will play a significant role in nutrient acquisition and redistribution capacity of plants.

## PROGRESS AND ACHIEVEMENTS

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The first objective (quantification of nutrient pools and forms in reconstructed sandy soils and comparison to undisturbed sandy analogs) is being addressed through the work of two graduate students, William Barnes and Najmeh Samadi. William is focusing on characterization of the natural analogs, while Najmeh has been quantifying nutrient release from soil materials used during reclamation.

### Natural Sandy Analogs

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William Barnes started his M.Sc. studies at the University of Alberta in September 2013, and has been focusing on characterizing the properties of representative undisturbed sandy soils of the Alberta Oil Sands Region. Specifically, he is investigating what soil properties are most influential for forest productivity in these sandy soils. Some specific key soil features he is examining include: presence/absence of textural discontinuity, depth to first discontinuity, type of discontinuity (change in parent material, clay lamellae, and presence of oil sands), etc. Indicators of soil quality and forest productivity include: soil nutrient availability, total below-ground nutrient stocks and forms, forest floor thickness, tree, shrub, and belowground vegetation biomass.

Specific progress to date includes:

- Selection of 20 coarse textured sites (5.64 m radius plot, 100 m<sup>2</sup> area) exhibiting a wide range in forest productivity.
- Morphological description of one soil pit per site; augering to 2 m; characterization and sampling by genetic horizon.
- Field incubation (40 days) of PRS probes (16 per site) to characterize soil nutrient availability and collection of soil surface moisture samples during both placement and removal of the probes.
- Measurement of forest characteristics for each plot including:
  - Height and diameter at breast height (dbh) of all living trees >1.3 m.
  - Age at breast height for the three tallest trees of each species within each plot.
  - Leaf area index (LAI) using a LiCOR LAI 2200C plant canopy analyzer.
  - Shrub biomass by species (8 m<sup>2</sup> area; two 2 m X 2 m subplots).
  - For roughly half the plots, biomass of forbs, grasses, mosses and lichens was measured. However, due to time constraints percent cover of these groups was visually estimated for the remaining plots.

Ongoing laboratory work includes characterization of about 200 soil samples: texture, pH, electrical conductivity (EC), as well as total C, N, <sup>13</sup>C, <sup>15</sup>N, extractable Fe and Al on a subset of soil fractions and soil horizons.

### Nutrient Release From Organic Amendments

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Najmeh Samadi started her Ph.D. studies at the University of Alberta in September 2013. So far, her work has focused on characterizing the nutrient supply rates (C, N, P) of the organic amendments (peat and forest floor) that will be used in the soil column experiment (Objectives 2 and 3).

Specific progress to date includes:

- Familiarization and modification of the microlysimeter protocol used to quantify potential mineralization rates (i.e.; CO<sub>2</sub> evolution, soluble N and P release) of soil materials in a laboratory setting.
- Long-term laboratory incubation of peat and forest floor amendments began in November 2014.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigators: Sylvie Quideau; Co-Principal Investigators: Miles Dyck and Simon Landhäusser

Name	Institution	Degree	Start Date	Completion Date
William Barnes	University of Alberta	M.Sc.	September 2013	Ongoing
Najmeh Samadi	University of Alberta	Ph.D.	September 2013	Ongoing
Kelti Eaton	University of Alberta	B.Sc.	May 2014	September 2014

Collaborators: AI-Bio, Alberta Innovates-Bio Solutions; Alberta Innovates–Energy and Environment Solutions.

# Aurora Soil Capping Study: Water and Carbon Isotope Methods Development

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0201

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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The objective of this research is 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. A key component of the Aurora Soil Capping Study (ASCS) is to understand the impact of lean oil sand (LOS) deposits on the water quality of ground- and surface water receptors. Specifically, it focuses on leaching of soluble salts, metals and hydrocarbons from LOS. The rate at which these dissolved constituents are flushed from an 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  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$  profiles. The goal is 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  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$ , to quantify net percolation rates through the Fort Hills of the 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  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$  spectrometer corrections for methane-affected pore-gas** – Challenges with measuring pore-gas  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$  measurements in the presence of methane have been identified in previous work at the ASCS. Methane has been measured in the LOS overburden at the ASCS, and thus, protocols for correcting methane interference need 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

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Phase 1 and 2 of the project were conducted by Marcie Schabert as an honours undergraduate research project with the support of Kathryn Dompierre (Research Assistant for this project and Ph.D. candidate for other Syncrude funded research). Matt Buchynski also worked on this project and his current M.Sc. research under Dr. Barbour's Industrial Research Chair (COSIA Project U0210) is working to extend this work to theoretical and numerical aspects of stable isotope transport in unsaturated soils.

This work helped to verify that pore-vapour sampling could be used to define the stable isotope of water composition of pore-water in unsaturated mine overburden. The sampling of pore-gas water vapour samples requires that these samples be collected from sample gas ports to a spectrometer. This component of the study compared the use of cheaper, more readily available Ziploc bags to more expensive and less available Flexfoil bags to determine a preferred bag to transfer collected pore-gas vapour samples to a spectrometer. Ziploc bags did not perform as well as Flexfoil bags, returning a larger deviation in  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$  values from their original headspace values. It was concluded that Ziploc bags are not an effective method of transferring pore-gas to the spectrometer. Flexfoil bags were then tested for their reusability and it was concluded that the bags are reusable with as few as zero flushes with dry air.

Methods of collecting vapour samples were also investigated. Using the laboratory mesocosm, an aquarium pump was hooked up to each port of the mesocosm and vapour was collected in Flexfoil bags for laser spectrometry analysis. After performing tests with two pumps and two machines (Picarro and Los Gatos), the test results found a high level of agreement between the collected vapour samples and direct equilibration using soil samples collected from the mesocosm. Vapour samples could not be collected immediately above a water table within the mesocosm where the aquarium pump was unable to draw sufficient vapour for an accurate measurement.

Direct connection of the Los Gatos spectrometer was also tested on the mesocosm. This may provide an opportunity to sample directly in the field rather than transferring gas samples to the laboratory. The Los Gatos was connected directly to the gas ports of the mesocosm and was compared to the previous measurements. Each port was measured using five pulse injections and the average of the five pulses was recorded as the sample value. After testing, it was determined that the Los Gatos pump was unable to draw sufficient sample from the deepest ports of the mesocosm (where there are also elevated levels of saturation) to return accurate measurements. A multiport sampling device was then used alongside the Los Gatos to pull samples from each gas port at a specified time interval. Preliminary results showed that the direct sampling method can be automated. Gas port valves were also changed between the multi-port device and gas ports to test connections for improved vapour capture for analysis. A stainless steel metal probe was also tested in the direct sample method. The probe was successful, but clogged easily and did not provide reliable results.

Proof of concept testing is now being performed on bench-scale columns (1 to 1.5 m in height) of sandy soil. In these tests, the transport of a pulse of recharging water which contains a deuterium tracer will be tracked as it migrates through the column. This data will then be simulated using a numerical simulation of water and stable isotope of water transport in both water and aqueous phases.

Phase 3 of the program evaluated techniques to correct spectrometer measurements with samples containing methane pore-gas. Cavity ring-down spectroscopy is an optical linear absorption spectroscopy technique that acquires extremely precise optical spectra, which when combined with a precise wavelength measurement, can

provide precise concentrations and isotopic ratios. This has the potential to allow rapid and direct measurements of  $\delta D_{H_2O}$  and  $\delta^{18}O_{H_2O}$  values of groundwater samples. However, hydrocarbons, which are abundant in the LOS (including methane), can cause interference and erroneous  $\delta$  values. Hendry et al. (2011) published a paper examining the effect of methane on the  $\delta$  values of pore water in core samples and a method of correcting these interferences. In general, the  $\delta^2H$  values decreased by approximately 480 ‰ and the  $\delta^{18}O$  values increased by approximately 39 ‰ at a methane concentration of approximately 1,500 ppmv. The  $\delta^2H$  and  $\delta^{18}O$  values were corrected to pre-spiked values using an algorithm. Testing of core samples has shown that the algorithm provides accurate and repeatable  $\delta^2H$  and  $\delta^{18}O$  values and methane concentrations in pore water. Ongoing work to remove all potential organics from vapour samples prior to removal of  $\delta$  values is being conducted.

Phase 1 and 3 of the program are complete and Phase 2 (Infiltration column testing) is currently underway. The final phase of reporting and paper production will begin when all laboratory studies are completed.

## OUTCOMES AND LESSONS LEARNED

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The following outcomes are emerging from the study:

- standardized methods to collect pore-gas water vapour samples for laboratory analysis;
- evaluation the potential to use analytical equipment in the field for in-situ measurements; and
- an algorithm to correct for methane-affected pore water vapour samples.

## PRESENTATIONS AND PUBLICATIONS

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Buchynski, M.G., S.L. Barbour and M.J. Hendry. 2014. *Estimating Diffusion Rates of the Stable Isotopes of Water in Unsaturated Mine Waste*. 2014 GSA Annual Meeting, Vancouver, BC, Oral Presentation, Abstract only published (No. 246546) in GSA Abstracts with Programs Vol. 46, No. 6, Session 161: " T161-3 (Hendry, Barbour): Application of Isotopes of Water to Characterize Hydrogeological Processes in Mine Environments", Published Abstract, Oct. 20, 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Saskatchewan

Principal Investigators: Lee Barbour and Jim Hendry

Name	Institution	Degree	Start Date	Completion Date
Marcie Schabert	University of Saskatchewan	B.Sc. Student	January 2012	February 2013
Kathryn Dompierre	University of Saskatchewan	Research Engineer	January 2012	February 2013
Matthew Buchynski <sup>(a)</sup>	University of Saskatchewan	M.Sc. Student	September 2013	In Progress

<sup>(a)</sup> Matt Buchynski began his M.Sc. with the support of this study. He is finishing his M.Sc. under Dr. Barbour's Industrial Research Chair for which a separate COSIA report (LJ0210) has been provided.

Industry Collaborators: None

# Coal Watershed Research and Development Program

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0160

**Academic Institution:** University of Saskatchewan, Montana State University, McMaster University, University of Illinois, SRK Consulting, Integral Ecology, O’Kane Consultants Inc., WorleyParsons Canada, BGC Engineering

**Industry Champion:** Teck Resources Limited

## PROJECT SUMMARY

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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 both 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.

## Research Synthesis and Technology Transfer

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Rapid technology transfer was one of the two focal objectives of the applied R&D program since its commencement. 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 these 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.

The first efforts at Technology transfer have been completed with re-issuing of an update of Teck's internal guidance document, Mine Design for Water Quality Management for Assessment by Long Range Planning Engineers. Going forward, this process will be further flushed out and incorporated into Teck's adaptive management plans.

## Progress and Achievements

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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;
- saturated zone design and operation; and
- reclamation and Se management.

The first field year for the Se- and watershed-focused applied R&D program occurred in 2012 with eight major areas of activity. Substantial time and resources have been invested in sampling and instrumenting research areas to commence water, CI and energy balance data collection. This program continues to answer major research questions and many of the original research projects continued through 2014. Additional focal areas were added in subsequent years, including research into nitrate management and flooded pits, and an increased focus on evaluating practical strategies for mine design.

## Ex-Pit Waste Rock Dumps

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### **How can Teck lower amounts of Se (and other CIs) from ex-pit waste rock dumps (new and legacy)?**

Research in this area commenced immediately in 2012, with a comprehensive core drilling program to obtain samples and to install gas, temperature and groundwater monitoring instruments (where possible and appropriate) in a range of legacy dumps across the Elk Valley, B.C. and at Cardinal River near Hinton, AB. Samples from the drill program were sent to the University of Saskatchewan and Montana State University for their R&D projects related to this topic and the other focal areas. Dump gas and temperature monitoring instruments were installed at various locations to collect data to support the university and industry research projects on waste rock geochemistry and flow systems. As well, groundwater monitoring wells were installed, the data from which are directed to the university and industry researchers to address catchment-scale and waste rock dump-scale water and CI fluxes. As well as the legacy facilities, a full scale demonstration dump, the Turncreek Dump was constructed at Fording River Operations (FRO) specifically to allow evaluation of bottom-up dump construction.

This dump was intensively sampled during construction to establish time zero conditions. Tracers were placed on each of the lifts as part of the research program to evaluate rates and patterns of flushing of CIs in dumps constructed in this manner. Following completion of construction, the dump was instrumented with gas and temperature monitoring devices, similar to the legacy dumps discussed previously. Work at the research leach pads constructed at Cardinal River Operations (CRO) and Line Creek Operations (LCO) in 2007 continued as fundamental questions were addressed that related to Se and Cl geochemistry and how to address the issue of scaling research results from lab to pilot to commercial.

The component projects in the ex-pit waste rock research program area are too early in development to provide lessons or outcomes that are ready for release to the public.

### **Water Balances for Water Management Decisions**

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**How can Teck determine the efficacy of water and Se management practices (like water treatment) at the local and regional watershed level to maximize the cost effectiveness of management actions?**

Research commenced with McMaster University on water balances for mine-affected montane watersheds. Snow surveys were conducted as part of this program, the data from which are utilized by researchers in all other focal areas.

Groundwater information collected as part of the overall R&D drilling program and the saturated zones program informs the water balance research. Surface water balance instrumentation (climate and soil monitoring) was installed at three elevations at West Line Creek (WLC) to contribute to the McMaster University research program. The results from the reclamation focal area are also closely integrated with this focal area.

The majority of the projects in this program area are being completed by graduate students at various stages of their programs. As a result, there are no lessons or outcomes available that are ready for release to the public.

### **Rock Drain Design and Operation**

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**How does rock drain design and use affect release of Se and other CIs?**

Drilling and sampling activities were carried out at Elkview Operations (EVO) in Bodie dump and the West Line Creek (WLC) dump, samples of which also contribute to advancing understanding of ex-pit waste rock questions. The Bodie dump was also instrumented with a climate and soil monitoring station. Snow surveys were conducted to enable development of a surface water balance for the dump, and determine contributions of the ex-pit waste above the rock drain to Se loadings in the drain. Information from the climate and soil moisture monitoring station at Bodie also contributed to key questions in Focal Area 5. This focal area is in its final year of investigation, with the M.Sc. student scheduled to complete her thesis in 2015. As a result, no lessons or outcomes are available that are ready for release to the public.

### **Saturated Zone Design and Operation**

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**How effective are watershed designs that include saturated zones in attenuating releases of Se and other CIs, and what are their implications for overall water management?**

The approach taken for research on saturated zones was to conduct preliminary sampling and instrumentation of two saturated zones at CRO; one being an existing saturated fill from which seeps are emerging which have low Se values (CRO-B5). The second being a new fill (Cheviot Creek Pit Backfill CC3) which may be used as a treatment vessel. An inventory and compilation of available rock and water chemistry data of saturated fills, tailings areas and Coal Coarse Rejects (CCR) deposits at all of Teck's Coal mining operations in British Columbia and Alberta was

conducted to provide data to inform conceptual model development and to aid in screening of options for future field research or demonstrations. In addition to the drill sampling of saturated and sub-oxic zones, ground water wells were installed in the natural groundwater zone at LCO WLC and in the waste rock fills at CRO B5 and CRO CC3. The results of these investigations coupled with early laboratory results and performance data from fills in the Elk Valley and Cardinal River indicate submerged rock fills are one of the most promising source control options. Increased R&D effort will continue for the next few years as Teck attempts to resolve the remaining technical uncertainties that prevent its broad implementation.

Many of the results of this program are currently contained in student research projects, the results of which are not ready for release to the public.

### **Reclamation and Se Management**

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**How do various waste dump reclamation options (cover systems, vegetation treatments, landform design) affect release of Se (and other CIs)?**

**How do they perform in meeting the other reclamation objectives (end land use objectives, including ecosite re-establishment, biodiversity, habitat, etc.)?**

Surface treatments or management (i.e., soil covers, vegetation, landform shaping or use of mesotopography) of waste rock influence surface water balances, thereby affecting the quantity and location of water entry into waste rock piles or fills, and subsequently the behaviour of CIs in those piles/fills. These treatments also influence achievement of end land use targets. In 2012 activities were commenced to investigate the effects of revegetation status, mesotopography and soil cover on surface water balances. The focus of these efforts was on identification and instrumentation of a suitable range of legacy sites representing a range of revegetation prescriptions, soil covers and use of mesotopographic landform design to correlate with surface water balance data to inform go-forward research design. A complex soil cover study area was also constructed at Teck's Greenhills Operation. Soil moisture and climate stations were installed at the suite of locations identified in the Elk Valley and at Cardinal River to develop surface water balances for a range of aspects, elevations, reclamation prescriptions (soil vegetation and landform) and reclamation ages to address the issue of range of variability and to acquire sufficient data to populate a preliminary reconstructed montane ecosite edaphic grid. Vegetation, soil and wildlife assessments were co-located with surface water balance instrumentation with the goal of commencing the development of an ecohydrologic classification system to be able to evaluate the efficacy of various reclamation options in assisting with Se management as well as their efficacy in meeting end land use targets. A draft of this ecohydrologic classification and planning system was developed. Student research projects at McMaster University also contributed to quantifying the surface water balances.

Focal Areas 6 through 10 were identified as new focal areas for the applied R&D program. In some cases research was already being advanced and in other cases a DQO process was undertaken to define the required projects.

### **Effectiveness of Explosives (Nitrates) Management on Minimizing Release of Nitrates and Follow-on Effects to Water Treatment/Se Release**

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This topic area was identified in the June 2012 stakeholder DQO session. No specific research has commenced to address this topic area, although nitrates were a key focus in the projects being conducted by the University of Saskatchewan, Montana State University, Environment and SRK as nitrates influence Se reduction processes.

Projects in this area are closely linked to those under Ex-Pit waste rock and Submerged Rock fills. Results from these projects are not ready for release to the public.

## Flooded Pits

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Teck has conducted bench and pilot in-situ testing with carbon amendments in previous years, and based on the results of these studies, the technology has been scaled up to treat an entire lake. The in-situ carbon technology involves amending surface water with organic carbon, which serves as an electron donor amendment to support microbial reduction of selenate and/or selenite (the electron acceptors) to insoluble elemental selenium and selenide species. This research will help understand lake physical and chemical stratification and turnover regime as well as nutrient mixing dynamics for management of Se and Cl.

## Processing Plant Waste: Tailings- How Are They Different With Respect to Release of Constituents of Interest?

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An inventory of tailings deposits was conducted as part of the saturated fill inventory (Focal Area 4) to inform saturated zone conceptual model development and site selection for research activities. Lab-scale studies were undertaken, with evidence of Se attenuation in tailings. Further research in this area will likely be limited due to the small volumes of water these facilities can safely handle.

## Calcite Management

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Substantial research and monitoring into calcite had been conducted prior to the commencement of the applied R&D program, and that work continued through 2014. Further research questions were defined and projects initiated in 2012, along with the other program areas listed here. Results from these projects are not ready for release to the public.

## DELIVERABLES AND MILESTONES

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Research project summaries for 2014 will be available to COSIA April 1, 2015 in the Research and Technology Development Progress Report March 2015.

## OUTCOMES AND LESSONS LEARNED

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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, 2015.

## PRESENTATIONS AND PUBLICATIONS

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Barbour, S.L., M. Jim Hendry and S. Carey. 2014. *Characterizing Net Percolation through Coal Mine Waste Rock Dumps Using High-resolution Profiles of Stable Isotopes of Water*. Presentation at the Geological Society of America Annual Meeting, 19-22 October, 2014, Vancouver, BC: Session T161. Application of Isotopes of Water to Characterize Hydrogeological Processes in Mine Environments.

Birkham, T., S.L. Barbour, A. Goodbrand, L. Tallon, J. Szmigielski and R. Klein. 2014. *Measuring groundwater discharge to streams with distributed temperature sensing technology*. Paper and presentation given at the B.C. Mine Reclamation Symposium Sept 22-25, 2014 Prince George BC.

Birkham, T., M. O'Kane, A. Goodbrand, S.L. Barbour, S.K. Carey, J. Straker, T. Baker and R. Klein. 2014. *Near-surface water balances of waste rock dumps*. Presentation and paper given at the B.C. Mine Reclamation Symposium (TRCR). Sept 22-25, 2014 Prince George BC.

- Bodle, K, R. Macur, L. Kirk, D. Skorupa and B. Peyton. 2014. *Effects of Oxygen on Selenate Reduction in Coal Waste Rock*. Presentation to Montana State University Student Research Celebration, April 14, 2014 Bozeman, Montana.
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## RESEARCH TEAM AND COLLABORATORS

Name	Institution	Degree	Start Date	Completion Date
Jim Hendry	University of Saskatchewan	Principal Investigator	2012	N/A
Lee Barbour	University of Saskatchewan	Principal Investigator	2012	N/A
Brent Peyton	Montana State University	Principal Investigator	2012	N/A
Lisa Kirk	Montana State University, Enviromin	Principal Investigator	2012	N/A
Matthew Fields	Montana State University	Principal Investigator	2012	N/A
Sean Carey	McMaster University	Principal Investigator	2012	N/A
Chris Kennedy	SRK Consulting	Principal Investigator	2012	N/A
Stephen Day	SRK Consulting	Principal Investigator	2012	N/A
Daryl Hockley	SRK Consulting	Principal Investigator	2012	N/A
Dan Charest	Teck Coal	Env. Officer	2012	N/A
Clara Qualizza	Teck Coal	R&D Manager	2012	N/A
Justin Straker	Integral Ecology	Principal Investigator	2012	N/A
Mike O’Kane	O’Kane Consultants Inc.	Principal Investigator	2012	N/A
Tyler Birkham	O’Kane Consultants Inc.	Principal Investigator	2012	N/A
Randi Thompson	BGC Engineering	Principal Investigator	2012	N/A

Industry Collaborators: none

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

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0127

**Academic Institution:** McMaster University, University of Waterloo and Integral Ecology Group

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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 reclamation 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 reclamation assessment that are directly linked to the fundamental processes of reclamation 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

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**For WP1,** new activity has just begun and there has been limited progress beyond maintenance of bio-meteorological stations at the research sites to ensure continuity in quality data. As of January 2015, staff and graduate students working on this project have been identified and hired and will focus on Work Package 1 (Process Ecohydrology). This work package focuses on understanding and quantifying the linkages between hydroclimatology (water table, soil moisture and tension distributions, ET), soil physical properties and nutrient (N, P, K) availability and pathways and carbon exchange (NEE) at the ecosystem scale for existing installations.

Key findings from previous studies that served as the impetus for the current work include:

- Forty-one years of total growing season water and carbon flux data over eight sites (four reclamation, four regeneration) were evaluated using eddy covariance micrometeorological towers. Evapotranspiration (ET) dominates the loss of water from ecosystems of the Western Boreal Plain, and as a process it is largely driven by climate (radiation, temperature, precipitation). For the examined reclamation sites, soil type and available water holding capacity does not appear to be a limitation on establishing upland ecosystems. There is a strong link between leaf area index (LAI) and ET, which suggests LAI provides a good first-order metric of stand water use.
- There is considerable variability in ET among years and among sites. ET fluxes observed at both reclamation and regeneration sites are similar to those observed in mature and disturbed boreal forest stands using data from the published literature. For the growing season, aspen forests lose more water than their coniferous counterparts. In addition, clonal rooting systems allow aspen forests to recover more quickly after disturbance than reclamation sites in terms of their ET rates. For reclamation sites, there is considerable variability in ET associated with vegetation establishment.
- Carbon fluxes (particularly gross ecosystem photosynthesis) at reclamation sites are similar to those reported at regenerating sites and mature sites in the published literature, with some exceptions. Following disturbance, ecosystems typically lose C due to the presence of labile material at the surface, which enhances respiration. At reclamation 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 shows clear discrimination among ecosystem types as aspen stands assimilate more carbon per unit weight of water than conifers. WUEs also change with time as ecosystems become more effective at transpiring water through plant pathways compared with bare-soil evaporation, which allows an assessment of ability to limit water loss without carbon uptake.
- Results highlight the importance of biophysical data to understand how reclamation systems compare with regeneration from fire or forest harvest disturbance. While stand-level metrics will remain the method of site assessment, biophysical data will provide empirical evidence as to the possible causes of success and failure on a site.

**For WP2:** Integral Ecology Group's work on this project commenced in the summer of 2013, and continued through 2014. This work involved co-located ecological measurements (for soils and vegetation) at current or historic eddy-covariance-tower sites (eight reclamation, eight regeneration). Measurements are conducted in 182 permanent sample plots at these sites (84 reclamation, 98 regeneration). Data collected at each plot include, where applicable, soil description, particle size and chemical parameters, vegetation description, stand characteristics, leaf-area index and foliar chemical parameters. These data have been compiled and checked and are ready for synthesis with the data from the co-located flux towers.

**For WP3:** This project consists of syntheses of data collected in WP1 and WP2, and previous related work. Initial synthesis discussions have begun and a timeline for future research meeting and knowledge synthesis activities established.

## DELIVERABLES AND MILESTONES

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This project is entering year two of five.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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No publications have been produced at this time. Presentation was made at the COSIA LAND EPA workshop in Calgary, January 2015.

## RESEARCH TEAM AND COLLABORATORS

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Institution: McMaster University and University of Waterloo

Principal Investigator: Sean Carey and Richard Petrone

Name	Institution	Degree	Start Date	Completion Date
Stacey Strilesky	McMaster / Carleton	Ph.D.	September 2014	August 2018
Gordon Drewitt	McMaster University	Research Associate	January 2015	December 2017
Shishir Handa	University of Waterloo	Ph.D.	September 2014	August 2018

Institution: Integral Ecology Group

Principal Investigator: Justin Straker

Researchers: Jeff Anderson, Trevor Baker

Industry Collaborators: Suncor Energy Inc.

# Evaluating the Success of Fen Creation

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0098

**Academic Institution:** University of Waterloo

**Industry Champion:** Suncor Energy Inc.

## PROJECT SUMMARY

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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; and
- determine 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 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

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Construction of the Nikanotee fen boardwalk was completed, allowing for safe and efficient research to be conducted by Highly Qualified Personnel (HQP) and monitors.

Installation of the permanent on-site research laboratory is now complete, with power and storage facilities. This has provided HQP both shelter, warmth and a safe muster point during bear sightings.

Ponded depressions (from peat settlement/placement) at the western side of the constructed fen were infilled with salvage peat material in early 2014. These were later planted and/or mulched according with the planting plot plan led by the Colorado State University team.

A detailed site survey with the University of Waterloo differential GPS unit has been completed, allowing for very detailed digital elevation models to accurately map micro-topographical influences in water table and vegetation growth. This will be paired with a 3D laser scan in early 2015 as input variables hydro-geochemical transport modelling with accurate landscape material gradients, dimensions and established hydraulic characteristics.

Five M.Sc. students defended their theses, four of whom were the original students starting on the project in 2011. A total of nine articles have gone for journal peer-review from these students with more in preparation.

Hydrological investigation of the reference fen sites is ongoing. The saline reference fen has been characterized geo-chemically, findings of which are applicable to future constructed fen systems in how natural systems cope with sodium management by means of pond inter-connectivity, ridge-depression sequences and the nature of saltwater upwelling and its spatial-distribution in a natural fen system.

Sufficient quality data has been generated by the dual (fen and upland) eddy co-variance systems to generate a two year site hydrometeorological analysis demonstrating the constructed fen is functioning as a small carbon sink for atmospheric carbon.

Coke under the incubation conditions mirroring the constructed system, does not appear to be available to leach; the field results to test whether the system is functioning as the incubations suggest are under analysis.

## DELIVERABLES AND MILESTONES

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**Determine if upland facilitates sufficient recharge flow to the fen, if salts and NAs leach from cover soil rooting zones and how quickly they flush from the tailings aquifer.**

In determining recharge to the fen via the upland, the reclaimed slopes that form the boundaries of the watershed have been investigated to identify controls on water dynamics within two contrasting reclaimed slopes, quantify downslope water movement and to determine the functioning of reclaimed slopes in the context of landscape-scale design. Two subsurface trenches were installed to validate calculated subsurface flow in the slopes.

The more recently reclaimed slopes had low surface infiltration rates resulting in surface runoff during large precipitation events throughout the summer, with subsurface flow observed on older reclaimed slopes due to surface infiltration rates 3x greater than more recently reclaimed slope surfaces as well as higher  $K_{sat}$  values at

depth. Downslope movement of water on older slopes is occurring via shallow perched subsurface stormflow, over soil layers with low infiltration rates (although it is highly dependent upon antecedent moisture conditions and available water storage capacity); while infiltration-excess overland flow is more likely to dominate water fluxes on more recently reclaimed slopes (less dependent on antecedent/soil water storage conditions).

Recharge to aquifers from snowmelt within the constructed watershed was severely restricted by the presence of ground frost that constrained infiltration of snowmelt water. Substantial surface runoff was observed from all reclaimed slopes, including those designed to reduce runoff and increase water storage. Snow depth is the greatest at changes in slope (i.e., where upland meets the slopes), suggesting wind redistribution is the dominant control on snow distribution, which is in-keeping with the high aerial fetch of the fen. Basin-averaged peak snow water equivalent (SWE) was 100 mm with this varying upon the presence (109 mm SWE) or absence (85 mm SWE) of vegetation.

Results (2013-2014) found saturated hydraulic conductivity of placed upland and fen materials to be lower than targeted. Implications of this include delayed lateral transport of contaminants but also a potential short circuiting of water flow via a discharge zone near the toe of the upland instead of through the peat. Hydraulic gradients (upwards) are strongest at the toe of the upland, which indicates that the below-target hydraulic conductivity of the underlying coke layer is constraining the equal distribution of hydraulic pressures beneath the fen.

The upland is still below target saturation levels. Field data from 2012 to 2014 found the heavy clay fraction and over-stripped nature of the LFH upland cover material impeded infiltration, limiting preferential flow paths and thus aquifer recharge. Remedial modifications made to the upland appear effective with recharge ponds dug behind hummocks storing water, allowing for increased infiltration into the upland aquifer; closer examination is required to determine the quantity of recharge. Flushing rates for contaminants within sand may be increased beneath these recharge ponds. Occurrence of surface runoff (event-based) from the upland was measured with flumes constructed along the toe of the transition zone. Single-ring infiltrometer measurements are determining the efficacy of remedial tilling measures to mitigate the poor infiltration of the overstripped LFH. However, generally water table levels are rising with a saturated zone developing, relative to 2013 data. The aforementioned overland flow occurred over the surface of the upland, leading to rapid fen water table response and a flashy site discharge behaviour during intense precipitation events. The average fen water table was within 10 cm of the surface.

Overall, Nikanotee fen has received water of sufficient quality for vegetation growth, with all major contaminants and measurements of concern still below threshold concentrations. The pH has remained between 6 to 8 across the system, however it has increased slightly (more basic) since 2013. Electrical conductivity (EC) remained between 1,000 to 3,500  $\mu\text{S}/\text{cm}$  across the system with a decrease in EC apparent at the south end of the system and an increase along the transition zone between upland and fen over time. There was an obvious increase in EC at the marginal nests within the fen where the upward vertical hydraulic gradient is strongest but could also be due to short cutting of water laterally into fen peat at the toe of the upland as previously mentioned.

Sodium concentrations in the south end of the upland decreased with time, similar to the decrease in EC, from 272 to 171 mg/L, from Oct 2013 to June 2014 from average groundwater well values (n=3). However, sodium concentrations were spatially variable across the fen, ranging from 19 to 202 mg/L (well values). Naphthenic acid concentrations at the south end of the upland decreased from 30.2 mg/L in October 2013 to 27.0 mg/L in June 2014 (based on average well values (n=3)). Concentrations of NA increased at the transition zone, 27.4 to 40.1 mg/L over 10 months, through to June 2014 (average well values, n=3). There is a strong increase in NA concentrations along the margin of the fen (in the transition zone), at piezometer depths of 0.9 m and 1.5 m but remained stable

at 32 mg/L at 225 cm. The 1.5 m piezometer concentrations increased 26.5 to 31.4 mg/L between October 2013 and June 2014 and the 0.9m piezometer concentration rose 3 to 8.4 mg/L between October 2013 and June 2014, respectively. Aerial dust deposition was between 10 to 700 g/m<sup>2</sup>/year (avg. 250 g/m<sup>2</sup>/year) across the site watershed, composition analysis of this dust is ongoing.

**Find if transport and attenuation processes in fen peat hold these contaminants below plant toxicity thresholds.**

An assessment of the contaminants most likely to leach from placed construction materials (based on expected geochemical conditions) has been undertaken in the laboratory to evaluate the transport and hydraulic properties of the placed peat to inform baseline data for a geochemical transport model. Samples of tailings sand, petroleum coke and peat were collected while the fen was constructed with ICP-MS analysis and microwave-acid digestion of major elements ongoing. Batch experiments have been conducted to assess leaching and transportation, with batch output analysed for major cations, anions, pH, EC, TOC and NA. Peat cores were run through Flow-Through Reactor systems using chloride tracers to understand transport properties of the peat at depth (1.5 m) at the interface with the sand/coke underdrain and in the potential vadose zone (0.5 m).

Substrate digestions found the petroleum coke underdrain material contains ~1,000 mg/kg of vanadium (V), suggesting a high leaching potential. However, actual bio-availability of leachable vanadium is unknown. Batch incubations found V concentration did not increase significantly over 12-week incubation. Additionally, no other potential heavy metal contaminants sourced from the petroleum-coke were found to leach significantly. This suggests that under stable anaerobic conditions, pH (7.5 to 8.5) of the experiment, at low temperature (~3°C) potential heavy metal contaminants to the fen are immobile.

**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?**

Flux data from 2014 showed the constructed fen operated as a slight net carbon sink (-0.45 g C m<sup>-2</sup>) based on daily averages derived from net ecosystem productivity (NEP) as the vegetation was more established than in 2013 where it was a source (1.35 g C m<sup>-2</sup>). The upland is still operating as a source of atmospheric carbon, but the carbon flux has decreased from 4.57 to 2.17 g C m<sup>-2</sup>, from 2013 to 2014, respectively.

Nutrient cycling varied with re-vegetation strategy. Seedling treatment plots showed the highest nutrient turnover, relative to control and moss transfer plots. Plots with mulch application showed reduced soil EC and temperatures. The combination of seedling and moss transfer showed potential for facilitating the recovery of biogeochemical processes and microbial activity through rhizosphere effect and higher microbial biomass. Over time, biomass accumulation in the rhizosphere of pioneer sedge species may abet the recovery of peat stratification and associated ecosystem functions in the fen like those existing at reference fen sites.

Nikanotee Fen was found to have greater humic and aromatic dissolved organic carbon (DOC) fractions compared to the reference fen sites, likely due to limited vegetation input in the first year years of the constructed fen. Laboratory incubations illustrated the effects of temperature and salinity acting on substrate type in determining DOC production, quality and bioavailability. Net DOC production differs significantly between reference sites and Nikanotee Fen. Sedges and trees produced the largest amount of DOC per unit dry mass followed by peat and bryophytes at the reference sites. This contrasts with the constructed fen substrates (petroleum coke, tailings sand and LFH), which produced very little DOC compared to reference fens outflow values.

The bioavailability of the DOC varied according to chemical composition differences (of the DOC), a result of the contributing substrate. Non-vegetation substrates at the constructed fen produced more aromatic and higher molecular weight DOC than vegetation substrates at reference fens. Hence DOC at the constructed fen was more recalcitrant and less bio-available, with a large proportion of DOC utilized for microbial growth resulting in CO<sup>2</sup> release while little was utilized by methane producing microbes.

The constructed fen includes plots with different vegetation types/treatments with variance in moisture conditions due to peat property/surface elevation differences. Roaming meteorological rover data found available energy differences between different plot types. Mulched plots had lower and less variable ground temperatures and lower ground heat fluxes. Moisture losses from lysimeters supported these data, mulched plots having reduced mass losses versus bare vegetation plots. Vascular lysimeters showed largest mass fluxes, a result of transpiration losses. Chamber-measured vapour fluxes backup the lysimeter data. Pore water pressures were consistently the lowest (high tension) in the bare peat control plots, increasing in plots with moss cover and highest in mulched plots. Mulched plots showed higher soil moisture values on average, maintained for longer periods following precipitation. Surface relative humidity was highest under the mulch cover, where soil temperatures were lowest, likely due to the effects of shading. On average, evapotranspiration patterns follow a trend of pond > vascular > bare peat > moss. Reduced evapotranspiration and presence of near-surface microclimates appear to protect mulched plots from moisture stress, with elevated soil moisture and pore water pressures at these plots. Overall, average daily evapotranspiration at the fen increased slightly between 2013 and 2014, 2.64 to 2.95 mm, respectively. Upland evapotranspiration decreased substantially from 2.53 to 1.41 mm, 2013 to 2014, respectively.

**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 fen reflect those at the RF sites, determining if these communities develop the ability to degrade naphthenic acids.**

Data trends in 2014 showed growth and spread of vascular species to be more influenced by pre-existing moisture gradients at the fen than defined plot treatments. *C. aquatilis*, *J. balticus* and *S. microcarpus* appear more productive in wetter portions of the fen, while *C. inexpana* is most successful in drier areas lacking in ponded water. The canopy coverage of all species is increasing, with high density plantings of *C. aquatilis* reaching almost 100% canopy coverage. Tiller development of *J. balticus* has increased from 15 to 30 tillers/m<sup>2</sup> to 100 to 400 tillers/m<sup>2</sup> between August 2013-2014. Above ground biomass production in Block 2 of the planting plan of the vegetation plots ranges from 100 to 500 g/m<sup>2</sup>, with *J. balticus* having greater biomass production than *C. aquatilis*. Confined bucket tests for below-ground production monitoring have shown *Betula* woody species the least productive for below-ground biomass, with *Triglochin maritima* the most productive, 2013 to 2014.

In-situ photosynthesis has been assessed via chlorophyll samples extracted from the upper 1cm of the bryophyte layer for chlorophyll and carotenoid content analysis, which is pending. A sub-study looking at moss survival rates during immersion is focusing on controls on bryophyte establishment. *T. nitens*, *A. palustre*, *S. warnstorffii* and *D. aduncus*, the four desired donor moss species were submerged at stepped time intervals (up to 8 weeks) with chlorophyll samples gathered before and after immersion. Once removed from the water, mosses were translocated into bare peat at the fen to evaluate recovery. Success of these immersion experiment mosses will go towards determining inundation tolerance times for differing moss species, essential given the likelihood of ponding at future constructed fen sites.

In examining revegetation methods, inclusive donor salvaged moss material; assessment of the donor vegetation site was undertaken, inclusive of greenhouse gas (GHG) exchanges. Twelve months post-salvage, total plant recovery at the donor site reached 72%, 13% of which was moss cover. Adjacent control site was 88% moss cover, 132% total plant cover. Repeated measures analysis of CH<sub>4</sub> and CO<sub>2</sub> flux comparisons between the donor site and the adjacent undisturbed control indicate the donor site to be a CO<sub>2</sub> sink during summer growth season, not significantly different from the control. While gross productivity was significantly higher at the control site (due to greater vegetation cover) greater respiration of the retained vegetation largely explains minor flux differences in CO<sub>2</sub> between the donor/control sites. Results indicate greater methane fluxes at the donor site vs. control, likely associated with the higher water table and percent cover of sedge vegetation at the donor site, higher water table a function of the ground surface being lowered by the moss salvage. While these results suggest GHG emissions to be altered at the moss donor site, CO<sub>2</sub> sink function returned rapidly post-salvage.

A preliminary conclusion about microbial community response to presence of naphthenic acids can be drawn by comparing substrate-induced respiration response of peat samples from the reference fens to the negative control (pure water) and those exposed to naphthenic acid-rich oil sands process water (OSPW). Comparisons indicate that such exposure has little effect on 'baseline' microbial metabolism provoked by addition of water to peat from the saline or 'rich' reference fen, but that the peat samples from the 'poor' reference fen exposed to OSPW exhibit greater substrate-induced respiration. Possible explanation comes from its poor fen status, with relatively little available labile carbon in the peat, hence the microbes metabolize available substrates, like the NAs present in the OSPW. Comparatively, the saline reference fen is also of poor nutrient status, but additional Na from the OSPW likely exceeds and becomes limiting to the peat microbiota, hence a lack of metabolic response to additional carbon sources when OSPW is added to saline peat substrate. The more nutrient-poor the reference site, the higher the turnover of labile carbon (hence its made less available) so the greater a metabolic response when sources (like OSPW) are provided.

Peat samples collected at reference sites and at the constructed fen in 2014 are being profiled for microbial communities by ribosomal tag on cores, with concurrent analysis of peat and porewater chemistry (DOC, phenolics, organic acids) analyses. These are being coupled to ancillary data including plant community, water table depth and peat temperature collected at time of sampling.

## OUTCOMES AND LESSONS LEARNED

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Sub-plot variability of placed peat hydro-physical properties is being investigated, with results so far showing very large heterogeneity of placed peat substrate. Understanding the ranges of heterogeneity and the scales of measurements required to grasp these ranges is key when designing new systems. Salvaged peat will not behave similarly to its donor site, nor necessarily be homogeneously disturbed during placement, meaning greater ranges in properties should be allowed for and factored into modelling efforts.

All placed construction materials have shown lower than expected hydraulic conductivities. Coke, peat mineral mix and peat (across all depths) have increased in saturated hydraulic conductivity between 2013 and 2014. The tailings sand aquifer has shown no change in hydraulic conductivity due to the absence of settlement.

Recharge to aquifers from snowmelt within the constructed watershed was low. The presence of ground frost constrained infiltration of snow melt water. Substantial surface runoff was observed from all reclaimed slopes, including those designed to reduce runoff and increase water storage. This is indicative of the importance of including snow dynamics when designing landscape-scale constructed ecosystems. These dynamics are very poorly understood on the Boreal plain generally considering how snow can be up to 30% of the annual water balance of

fens in the Fort McMurray region. Given the necessity to retain available moisture for reclaimed wetlands in a mined landscape (where water retention is difficult), better understanding of these dynamics is critical to improving future reclamation design.

Success of moss establishment in the immersion experiment is helping determine inundation tolerance times for differing moss species. This allows for suggested “working windows” for salvage moss in constructed wetlands. Furthermore, it is quantifying the importance of desired water table levels and control that can be exerted over water tables through outflow design, to aid in establishment success. This is essential given the large likelihood of ponding and microtopographical depressions at future constructed fen sites as seen from peat settlement at the Nikanotee Fen.

The immobility of V from petroleum coke (when subject to controlled pH ranges and anoxic conditions) has been a surprising finding. It has implications for coke stockpiling protocols and how V mobility can be reduced in the immediate (storage) environment. While assessment of the field reality (outside of a laboratory setting) of its immobility is ongoing, it may open the door for consideration of coke as a construction material in more saturated wetland systems (assuming certain conditions can be consistently met, i.e., pH, anoxia).

## PRESENTATIONS AND PUBLICATIONS

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Bocking, E. and J.S. Price. 2014. *Analyzing the impact of a raised road on peatland tree growth*. Canadian Geophysical Union. Banff, AB, May 4-7, 2014.

Bocking, E. and J.S. Price. 2014. *Assessing the response of Picea mariana to water table change from road construction in a poor fen*. Canadian Geophysical Union, Hydrology Section. Toronto, ON, Jan. 19, 2014.

Bocking, E. and J.S. Price. 2014. *Road effects on a poor fen in northern Alberta*. PERG/GRET: 20<sup>th</sup> Symposium Peatland Ecology Research Group. Quebec City, QC, Feb. 19-20, 2014.

Bocking, E. and J.S. Price. 2014. *Using dendrochronology to analyze water table change in a road-impacted fen*. Canadian Association of Geographers. St. Catherine’s, ON, May 30, 2014.

Borkenhagen, A. and D.J. Cooper. 2014. *Developing methods for vegetating constructed peatlands in Alberta’s Oil Sands Region*. International Erosion Control Association Conference: Environmental Connection. Nashville, TN. Feb. 25-28, 2014.

Borkenhagen, A. and D.J. Cooper. 2014. *Featured Interview: 10 Minutes with Andrea Borkenhagen*. Erosion Control. Official Journal of the International Erosion Control Association. July-August 2014. Accessible at [http://www.erosioncontrol.com/EC/Articles/IECA\\_CISEC\\_Online\\_Training\\_Modules\\_26106.aspx?pageid=2a0fe4e8-6d11-452f-b256-294a55051e07](http://www.erosioncontrol.com/EC/Articles/IECA_CISEC_Online_Training_Modules_26106.aspx?pageid=2a0fe4e8-6d11-452f-b256-294a55051e07).

Borkenhagen, A. and D.J. Cooper. 2014. *Peatland Reclamation in the Oil Sands Region of Alberta*. Restoration Case Studies Seminar, Fort Collins, CO, USA. Sep. 4, 2014.

Borkenhagen, A. 2014. *Recreating peatland initiation conditions: methods for reclaiming Alberta’s Oil Sands Region*. M.Sc. Thesis. Colorado State University, Fort Collins, CO.

Goetz, J.D. 2014. *An evaluation of moisture dynamics and productivity of Sphagnum and Tomenthypnum mosses in western boreal peatlands, Canada*. M.Sc. Thesis. University of Waterloo, Waterloo, ON.

- Goetz, J.D. and J.S. Price. 2014. *Understanding the hydrological function of moss morphology on desiccation tolerance: comparing water dynamics and productivity of Tomenthypnum and Sphagnum mosses.* Hydrology Section in the AGM of the Canadian Geophysical Union. Banff, AB, May 4-7, 2014.
- Ketcheson, S.J. and J.S. Price. 2014. *An assessment of the hydrology of a constructed fen in the Athabasca oil sands region, Alberta, Canada.* PERG/GRET: 20<sup>th</sup> Symposium Peatland Ecology Research Group. Quebec City, QC, Feb. 19-20, 2014.
- Ketcheson, S.J. and J.S. Price. 2014. *Fen reconstruction after oil sands extraction: design considerations and the importance of snow.* Water Institute Research Symposium, Waterloo, ON. May. 1, 2014.
- Ketcheson, S.J. and J.S. Price. 2014. *Snow dynamics and water fluxes within a constructed watershed in Northern Alberta, Canada.* American Geophysical Union Conference, San Francisco, USA. Dec., 2013. (Poster) also presented at World Wetlands Day, Waterloo, ON. Jan. 31, 2014.
- Ketcheson, S.J. and J.S. Price. 2014. *Snow hydrology of a constructed watershed.* Hydrology Section of the Canadian Geophysical Union Eastern Students Conference. Toronto, ON, Jan. 18, 2014.
- Ketcheson, S.J., C.M. Wells and J.S. Price. 2014. *The role of transient hillslope connectivity on the hydrology of a fen peatland in the Western Boreal Plains, Alberta.* Hydrology Section in the AGM of the Canadian Geophysical Union. Banff, AB, May 4-7, 2014.
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- Khadka, B. 2014. *Dissolved Organic Carbon Dynamics in Constructed and Natural Fens in Athabasca Oil Sands Development Region near Fort McMurray, Alberta.* M.Sc. Thesis. University of Calgary, Calgary, AB,
- Mahmood, S. and M. Strack. 2014. *Methane dynamics of undisturbed fens in the oil sands region of Alberta.* Biogeoscience Section in the AGM of the Canadian Geophysical Union. Banff, AB, May 4-7, 2014.
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- Mahmood, S. and M. Strack. 2014. *Study of carbon and nutrient dynamics of reference fen ecosystem in oil sands region of Alberta.* 51st Annual Geography Department Conference, University of Calgary, Calgary, AB,.
- Nwaishi F.C., R.M. Petrone and J.S. Price. 2014. *Implications of peat-substrate management practices on constructed fens' peat quality and the recovery of biogeochemical functions in reclaimed peatland.* Biogeoscience Section of the Canadian Geophysical Union Eastern Students' Conference. Toronto, ON, Jan. 18, 2014
- Nwaishi, F., R.M. Petrone, J.S. Price and R. Andersen. 2014. *Towards developing a functional-based approach for constructed peatlands evaluation in the Alberta oil sands region, Canada.* Accepted.

- Nwaishi, F., R.M. Petrone, J.S. Price, R. Slawson and R. Andersen. 2014. *Impacts of donor-peat management practices on peat quality and the functional characteristics of a constructed peatland in the Alberta oil sands region, Canada. Ecological Engineering*. Submitted.
- Nwaishi, F.C., R. Petrone, R. Slawson, J.S. Price and R. Andersen. 2014. *Evaluating the recovery of biogeochemical functions in a reclaimed fen*. Biogeoscience Section in the AGM of the Canadian Geophysical Union. Banff, AB, May 4-7, 2014.
- Phillips, T.J. and R.M. Petrone. 2014. *Characterizing evapotranspiration in a Western Boreal Plain Saline Fen in Fort McMurray, Alberta*. Hydrology Section in the AGM of the Canadian Geophysical Union. Banff, AB, May 4-7, 2014.
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- Price, J.S., K. DeVito, C. Mendoza and R.M. Petrone. 2014. *Hydrological challenges and opportunities for reconstructing wetland ecosystems after oil-sands mining*. In Responsible management of wetlands: Implications of the industrial sector. International Peat Society/PERG/GRET: 20<sup>th</sup> Symposium Peatland Ecology Research Group. Quebec City, QC, Feb. 19-20, 2014.
- Scarlett, S.J. and J.S. Price. 2014. *Controls on evapotranspiration of a constructed peatland, Fort McMurray, Alberta*. PERG/GRET: 20<sup>th</sup> Symposium Peatland Ecology Research Group. Quebec City, QC, Feb. 19-20, 2014.
- Scarlett, S.J. and J.S. Price. 2014. *Soil moisture and surface-atmosphere interactions of a constructed peatland, Fort McMurray, Alberta*. Hydrology Section of the Canadian Geophysical Union Eastern Students Conference. Toronto, ON, Jan. 18, 2014.
- Simhayov, R. and J.S. Price. 2014. *Implications of creating a fen with petroleum coke*. Biogeoscience Section of the Canadian Geophysical Union Eastern Students Conference. Toronto, ON, Jan. 18, 2014.
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- Wells, C.M. and J.S. Price. 2014. Hydrology and geochemistry of a saline spring fen in the Athabasca oil sands region, Alberta, Canada. *Hydrological Processes*. Submitted.
- Wells, C.M. and J.S. Price. 2014. *The hydrogeologic connectivity of a low-flow saline spring fen peatland within the Athabasca oil sands region, Canada. Hydrogeology Journal*. Accepted with revisions.
- Wells, C.M. 2014. *The hydrology and geochemistry of a saline spring fen peatland in the Athabasca Oil Sands Region of Alberta*. M.Sc. Thesis. University of Waterloo, Waterloo, ON,

## RESEARCH TEAM AND COLLABORATORS

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Industry Collaborators: Imperial and Shell Canada Energy

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

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0009

**Academic Institution:** Lakehead University

**Industry Champion:** Canadian Natural Resources Limited

## PROJECT SUMMARY

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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 may also assist in shaping evolving regulatory approaches to reclamation and water management and support components of progressive reclamation.

The Project is funded by a Natural Sciences and Engineering Research Council of Canada Collaborative Research and Development Grant with Industry Partners: Canadian Natural Resources Limited (CNRL), Suncor Energy Inc. (Suncor), Syncrude Canada Ltd., Total E&P Canada Ltd., Tervita Corp., Alberta Newsprint Company, Alberta-Pacific Forests Industries Inc., Hinton Pulp, Millar Western Forest Products Ltd. (Whitecourt Pulp Division) and Slave Lake Pulp. Environment Canada and the Oil Sands Research and Information Network provide additional support to key elements of the Project. Researchers, graduate students and research staff span universities in three provinces, which include Lakehead University, University of Alberta, University of Lethbridge and University of Saskatchewan.

The objectives of FORWARD III are organized in a framework consisting of four components. Within each component, two phases of research were planned. Phase 1, now complete, compiled and synthesized existing information on reference watershed in the Oil Sands Region resulting in a set of initially calibrated hydrological models; established and monitored newly constructed reclaimed sites (Site 1 and Site 2); and maintained and monitored nine long-term sites established during FORWARD I and II (2001-2011). We are now in Phase 2, which will advance the modelling tools with ongoing and new research within all components of the project.

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 manipulation of landform designs of proposed mine closure plans. [REDACTED]

[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 and impacts to bio-indicators from anthropogenic load will characterize acute and chronic toxicity to amphibians, macroinvertebrates and fish of organic and inorganic contaminants associated with oil sands extraction. Amphibians are a focus because of their known sensitivity to broadly distributed low-level contaminants, particularly trace organic compounds.

## PROGRESS AND ACHIEVEMENTS

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### **Component 1: Modelling**

Preliminary application of the SWAT<sub>BF</sub> model on five reference watersheds in proximity to Project study sites showed promising results. A technical report on this work was prepared for the Oil Sands Research Information Network (OSRIN) and is available at <http://hdl.handle.net/10402/era.34250>.

A large pool of water quality data were synthesized and the hydrodynamic and water quality model EFDC was calibrated.

Snow sampling took place in March 2013 and 2014 at Site 1 and Site 2. Samples were analyzed for water chemistry, trace metals, isotopes and polycyclic aromatic hydrocarbons.

Core monitoring began in 2013 with the establishment of four sites at Site 1 (Main Swale 1, Main Swale 2, Main Wetland, Swale 13) and two at Site 2 (PWET 1, PWET 2) in addition to nine reference sites in the Virginia Hills established during earlier phases of the Project. Hydrologic, water quality and meteorological monitoring was conducted May through October in 2013 and 2014. Water samples collected were analyzed for standard water chemistry (TP, TDP, NO<sub>2</sub>, NO<sub>3</sub>, NH<sub>4</sub>, TN, pH, alkalinity, colour, cations, anions, DOC), trace metals and isotopes.

Piezometers were installed at ten locations on CNRL RA1 to allow for the assessment of water quality and quantity within the coversoil and subsoil layers. In addition, water quality was examined at opportunistic wetlands on both LFH and peat-mineral-mix coversoils. At Site 1, water level and temperature monitoring, as well as flow velocity measurement, continued at three swale sampling locations established in 2013, while newly installed Isco automated water samplers allowed for the examination of water quality during rainstorm events. In addition, water level and temperature infrastructure was installed at Site 1 to look at the link between water level in the wetland and flow in the swales. Water quality was also assessed at the swales and in the wetland. The data from this work will be used to modify the SWAT<sub>BF</sub> model for reclaimed sites, which can characterize how water moves from upland to aquatic areas and then within aquatic areas at Site 1. It will also be used to track the movement of contaminants in these reclaimed systems and will help to build benchmarks for reclamation success from a water quality and hydrology perspective. Water quality and hydrology data collection also continued at nine reference sites in Whitecourt, AB to provide useful baseline data for calibration and testing of the modified SWAT<sub>BF</sub> model for reclaimed sites.

In addition to the hydrology and water quality work occurring in Fort McMurray and Whitecourt, new soil moisture, temperature, conductivity probes were purchased and will be installed at each of the 10 piezometer locations at CNRL RA1 in Spring 2015. In Whitecourt, 12 automated soil temperature-moisture stations, operational during FORWARD II, are being reinitialized this winter. Data from these Whitecourt stations will give baseline information on soil conditions, which will aid in developing the vegetation/forest growth component of the SWAT model, as well as providing model inputs on soil moisture dynamics. Monitoring of meteorological conditions also continued at two automated stations in Whitecourt and one station at Site 1.

### **Component 2: Soils**

Plants and peat-mineral samples were collected at 10 different slope positions along two transects (one engineered cover, one standard cover) at Site 1 as well as samples from Site 2. Microbial community structure determined by phospholipid fatty acid (PLFA) analysis showed microbial biomarkers varied somewhat by slope or cover. Also, no variation occurred in the ratio of fungal and bacterial biomarkers, and the total number of PLFAs and bacterial endophyte populations were significantly affected ( $P < 0.05$ ) by slope and cover type.

Denaturing Gel Gradient Electrophoresis (DGGE) of endophytic bacteria profiles varied depending on slope positions and cover type had no influence on clustering.

Root-associated bacteria including rhizosphere and endophytic bacteria successfully colonized barley plants growing on reclamation sites. The role of these endophytes in assisting plant growth is still under investigation.

Soil physical characteristics revealed that field saturated hydraulic conductivity was comparable between covers but that substrate at 50 cm depth influenced the variability in measurements. Extractable soil phosphorus levels, were lower on reclaimed covers compared to undisturbed sites, while soil pH and EC showed the opposite trend.

### **Component 3: Vegetation**

In this study, CEMA long-term soil and vegetation plots located on an oil sands lease were examined to see how the dynamics of non-woody species (herbs, grasses, sedges, mosses, lichens) and shrub vegetation abundance, diversity and composition were affected by substrate, overstorey composition and time since reclamation.

Results demonstrated that plant communities' substrate had the strongest influence on abundance, richness, and composition within the oil sands reclamation area. They also suggest that substrate is the most dominant factor, particularly within the clay overburden and secondary overburden substrates. Results have also shown understory biomass is limited by over-story composition. Overall, total biomass was shown to increase through time and tree diversity.

### **Component 4: Toxicity**

The basic toxicity assessment of binary PAH-metal mixtures using an isobole approach and *Hyalella azteca* is now complete. The data are currently being written up in the form of a manuscript for publication. An imaging assay using fluorescent stains was developed to characterize preferential tissue uptake and accumulation patterns, particularly for metals. A behavioural assay to evaluate contaminant effects on ecologically-meaningful behaviours in *Hyalella* was also recently developed. As well, a contaminant uptake and accumulation model that will be useful for predicting metal-PAH mixture toxicity is being developed.

A multi-way reciprocal cross-transplant experiment using *H. azteca* was successfully executed in 2014. Invertebrate subjects were collected from two natural (reference) sites and two reclaimed (test sites). A lab-reared population of *H. azteca* was also used to strengthen the ability for lab-to-field extrapolations. All five populations were multiply replicated and represented at all exposure sites (i.e., two natural sites and two test sites), where they

were held for 28 days. Despite challenging conditions in the field this year (including severe reductions in water depth), mortality data in this in-situ exposure were assessed. Specimens were collected and preserved, and await biomarker (e.g., EROD) and contaminant assessment. Data from this year's field season are currently being analysed.

An amphibian study has completed a third field season on an oil sands lease area and compiled data on survival, population density, and body condition and growth of two species of amphibians: Wood Frogs (*Lithobates sylvaticus*) and Boreal Chorus Frogs (*Pseudacris maculata*). An evaluation and comparison to the previous year's data will be performed once results of the analyses of liver and water samples collected this year are complete.

Preliminary results show that Boreal Chorus Frog and Wood Frog survival is similar between all wetlands (72% to 99% survival), except for animals raised on one oil sands site (0% to 19% survival). The average snout-to-vent length (mm) of animals is similar between all wetlands. However, the average body condition (mg/mm) of animals varied by wetland and requires further analysis. Water, sediment, and algae samples were collected from each wetland. In addition, researchers collected tailings materials used, or similar to those used, in the construction of these wetlands. To date, the water and fluid tailings samples have been analyzed for acid concentration (AEF). The average AEF concentration of the wetlands ranged from 72.0 to 10.4 mg/L and AEF of tailings ranged from 119.3 to 8.1 mg/L. Researchers are in the process of determining the concentration of acids that can be attributed to industry versus the concentration of natural background acids.

## PRESENTATIONS AND PUBLICATIONS

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Blain, N.P., B.L. Helgason and J.J. Germida. 2014. *Microbial communities associated with the natural vegetation at the Bitumont provincial historic site*. Canadian Society of Soil Science and Canadian Geophysical Union Joint Meeting, Banff, AB, May 4–8, 2014.

Gauthier, P.T., W.P. Norwood, E.E. Prepas and G.G. Pyle. 2014. *Metal-PAH mixtures in the aquatic environment: a review of co-toxic mechanisms leading to non-additive outcomes*. Aquatic Toxicology 154: 253-269.

Gauthier, P.T., W. Norwood and G. Pyle. 2014. *Effects of metal-PAH mixtures on the survival, accumulation of metals, and ROS production in *Hyalella azteca**. SETAC North America 35<sup>th</sup> Annual Meeting, Vancouver, BC. Nov. 9–12, 2014.

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Gauthier, P.T, W. Norwood and G. Pyle. 2014. *The result of acute co-exposures to metals and polycyclic aromatic hydrocarbons (PAHs) on the bioaccumulation of metals, survival, and behaviour of *Hyalella azteca**. Genomes to Biomes, Montreal, QC, May 24–29, 2014.

Germida, J., N. Blain, E. Mitter, S. Chharbra, R. deFreitas and B. Helgason. 2014. *Reclamation of oil sands mining sites in Canada: opportunities and challenges for phytotechnologies*. 11<sup>th</sup> International Phytotechnologies Conference, Heraklion, Crete, Greece. Sep. 30 to Oct. 3, 2014.

MacDonald, R.L., H.Y.H. Chen, B. Palik and E.E. Prepas. 2014. *Influence of harvesting on understory vegetation along a boreal riparian-upland gradient*. For. Ecol. Manage. 312: 138-147.

- Martin, N., Z. Burkus, P. McEachern and T. Yu. 2014. *Naphthenic acids quantification in organic solvents using fluorescence spectroscopy*. *J. Env. Sci. Health, Part A: Toxic/Hazardous Substances & Environmental Engineering*. 49(3): 294-306, doi: 10.1080/10934529.2014.846631.
- Mitter, E., R. de Freitas and J.J. Germida. 2014. *Plant microbe associations for reclamation of oil sands mining sites in Canada*. 20th World Congress, Jeju, Korea, June 8–13, 2014.
- Mitter, E.K., R. de Freitas and J.J. Germida. 2014. *Microbial communities associated with annual barley planted on oil sands reclamation sites in Alberta, Canada*. Canadian Society of Soil Science and Canadian Geophysical Union Joint Meeting, Banff, AB, May 4–8, 2014.
- Novak, K. and K.C.J. Van Rees. 2014. *Soil characteristics for reclaimed, fire-disturbed and undisturbed forested soils in northern Alberta, Canada*. Canadian Society of Soil Science and Canadian Geophysical Union Joint Meeting, Banff, AB, May 4–8, 2014.
- Novak, K. and K.C.J. Van Rees. 2014. *Soil properties for reclaimed, fire-disturbed and undisturbed forested soils in northern Alberta, Canada*. Soils and Crops, Saskatoon, SK, Mar. 11–12 2014.
- Sobey, T.M. and H.Y.H. Chen. 2014. *Plant abundance, diversity, and composition following reclamation in Alberta's oil sands*. The 99th ESA Annual Meeting. From Oceans to Mountains: It's All Ecology, Sacramento, CA, Aug. 10–15, 2014.
- Terrel, V.C.K., J.L. Klemish, N.J. Engbrecht, J.A. May, P.J. Lannoo and M.J. Lannoo. 2014. *Amphibian and reptile responses to reclaimed coal spoil grasslands*. *J. North Amer. Herpetology* 2014(1): 59-68.

## RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Ellie E. Prepas

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Emily (Xue) Chen	University of Alberta	Research Associate	November 2014	November 2015
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Yin Chu	University of Saskatchewan	Visiting Scholar	July 2014	June 2015
Patrick Gauthier	Lakehead University	Ph.D.	January 2012	June 2015
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Industry Collaborators: Alberta Newsprint Company; Alberta-Pacific Forests Industries Inc.; Environment Canada; Hinton Pulp; Millar Western Forest Products Ltd. (Whitecourt Pulp Division); Oil Sands Research and Information Network; Slave Lake Pulp; Suncor Energy Inc.; Syncrude Canada Ltd.; Tervita Corp.; and Total E&P Canada Ltd.

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0210

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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 predominant oil sands landforms: overburden shale and tailings sands. Two relatively large (100 to 1,000 ha) closure landforms - 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 shale overburden dump, and Sandhill Fen Tailings Sand Hummocks, TSH).

The overall objectives are as follows:

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

## PROGRESS AND ACHIEVEMENTS

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Major activities over the past year involved the following:

- Near completion of sample analyses (90%) from 2013 field drilling program. This program included near continuous coring of a sand tailings dyke, shallow shale overburden dump, a deep shale overburden dump and a natural (undisturbed profile). Testing include major ion chemistry, geotechnical properties, and stable isotopes of water.

- Field instrumentation at SWSS (Sand tailings dyke) - A collaborative summer program was planned and executed for multiple scale monitoring of soil water dynamics at South West Sand Storage. A new Eddy-Covariance System (EC) was purchased and installed in cooperation with Dr. Sean Carey at McMaster University. The soil moisture loading measured from the Geological Lysimeters is being compared to estimates of daily changes in stored water measured using more conventional soil monitoring stations (O’Kane station) and the EC Geolysimeters have also been installed at an undisturbed site and two shale dumps with data interpreted by an M.Sc. student.
- A hydrogeosphere model of SWSS (sand tailings) is being developed by a Ph.D. student.
- Laboratory testing including column testing is underway to characterize rates of advective and diffusive stable isotope of water transport in unsaturated sand tailings (M.Sc. Student).
- Field methods of sampling the stable isotopes of water through vapour sampling are under development (MEng Student).
- A prototype CPT-TDR probe to track deep water content profiles through sand tailings and overburden shale has been developed and is being prepared for field trials (M.Sc. student).
- The stable isotope of water catalogue for the Mildred Lake Mine site (meteoric and site wide waters) continues to be expanded.

## OUTCOMES AND LESSONS LEARNED

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There are a number of areas in which there are likely to be important contributions to the overarching goal of characterizing and monitoring the long-term hydrogeology of oil sands mine closure landforms. Some of these include the following:

- Mapping of Site-wide Water using Stable Isotopes of Water
  - A new local meteoric water line (LMWL) has been developed and should be applicable to interpretation of stable isotope of water data in the region. No previous line for the region existed (Baer and Barbour 2013, 2014; Baer 2014).
  - Unique isotopic signatures have been identified for process water, shale pore-water, and recent fresh meteoric water.
  - 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. 2014).
- CPT-TDR
  - The prototype CPT-TDR sensor will provide a rapid method of mapping stored water volumes within the upper 10 m of reclaimed landforms. Combined with vapour sampling, this may provide a rapid, inexpensive way to obtain time and space integrated estimates of recharge.

## PRESENTATIONS AND PUBLICATIONS

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Amos, M., S.L. Barbour, S.L. D. Pratt and B. Si. 2014. *Development of a Time Domain Reflectometry Sensor for Cone Penetration Testing*. GeoRegina, 2014, 67<sup>th</sup> Canadian Geotechnical Conference Proceedings, Sep. 28 to Oct. 1, 2014.

Barbour, S.L. 2014. *Tracking Water Movement in Closure Landforms in Oil Sands Mines - Extending Temporal and Spatial Monitoring Scales*. 2014 GSA Annual Meeting in Vancouver, British Columbia, Oral Presentation, Abstract only published (No. 246104) in GSA Abstracts with Programs Vol. 46, No. 6, Session 145-2: Pardee Keynote Session P3 (Ferguson, Manning), "Energy Resource Development and Groundwater: Looking Broader and Deeper II", Oct. 20, 2014.

Buchynski, M.G., S.L. Barbour and M.J. Hendry. 2014. *Estimating Diffusion Rates of the Stable Isotopes of Water in Unsaturated Mine Waste*. 2014 GSA Annual Meeting, Vancouver, British Columbia, Oral Presentation, Abstract only published (No. 246546) in GSA Abstracts with Programs Vol. 46, No. 6, Session 161: " T161-3 (Hendry, Barbour): Application of Isotopes of Water to Characterize Hydrogeological Processes in Mine Environments", Published Abstract, Oct. 20, 2014.

Pratt, D.L., M.J. Hendry, S.L. Barbour and E. Schmeling. 2014. *Optimization and Configuration of a Hydrocarbon Gas Removal System for the Determination of  $\delta^2H$  and  $\delta^{18}O$  on Picarro CRDS*. 2014 GSA Annual Meeting, Vancouver, British Columbia, Oral Presentation, Abstract only published (No. 246284) in GSA Abstracts with Programs Vol. 46, No. 6, Session 161-2: " T161 (Hendry, Barbour): Application of Isotopes of Water to Characterize Hydrogeological Processes in Mine Environments", Oct. 20, 2014.

## RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Dr. S. Lee Barbour

Name	Institution	Degree	Start Date	Completion Date
Dr. Jim Hendry	University of Saskatchewan	Collaborator	January 2012	In Progress
Dr. Bing Si	University of Saskatchewan	Collaborator	January 2012	In Progress
Dr. Garth van der Kamp	Environment Canada	Collaborator	January 2012	In Progress
Dr. Carl Mendoza	University of Alberta	Collaborator	January 2012	In Progress
Dr. Sean Carey	McMaster University	Collaborator	January 2012	In Progress
Dyan Pratt	University of Saskatchewan	Research Engineer	April 2013	In Progress
Brenda Bews	University of Saskatchewan	Research Engineer	January 2012	In Progress
Mingbin Huang	University of Saskatchewan	Research Scientist	January 2012	In Progress
Thomas Baer	University of Saskatchewan	M.Sc.	January 2012	March 2014
Mike Amos	University of Saskatchewan	M.Sc.	September 2012	January 2015
James Tipman	University of Saskatchewan	M.Sc.	September 2013	In Progress
Mengna Lu	University of Saskatchewan	M.Eng.	February 2014	June 2014
Matthew Buchynski	University of Saskatchewan	M.Sc.	September 2013	In Progress
Arash Janfada	University of Saskatchewan	Ph.D.	January 2012	Withdrew August 2014
Fatemeh Madaeni	University of Saskatchewan	Ph.D.	August 2013	In Progress

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0210

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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This Industrial Research Chair (IRC) in Mine Closure Geochemistry aims to develop a more comprehensive understanding of the geochemical characteristics and evolution of oil sands mine wastes and associated waters within closure landscapes. An interdisciplinary field and laboratory research program was developed to examine interactions among chemical, biological and physical processes within these landscapes, and therefore to build a more integrated understanding of influences on water chemistry. This research focuses strongly on understanding relationships between biogeochemical cycling of carbon, iron and sulfur, hydrogeological processes and the release, transport and attenuation of dissolved constituents. Particular emphasis is being placed on examining these processes at environmental interfaces including grain margins and material boundaries. Resulting information will serve as the foundation for geochemical and conceptual models to aid closure planning.

This IRC research program is principally focused on centrifuge cake and petroleum coke deposits, and on examining the geochemical implications of interactions between these and other materials under potential closure scenarios. Concurrent research on both materials will address four principal objectives over a five-year period:

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

These research objectives will be accomplished through a series of interdisciplinary research activities aimed at improving our understanding of the biogeochemical evolution of centrifuge cake and petroleum coke deposits. Initial field studies are examining spatial and temporal variability in the biogeochemical characteristics of existing cake and coke deposits. These data will be used to develop initial conceptual models, which will be refined through subsequent laboratory experiments. Column and batch experiments will examine mechanisms of contaminant release, transport and attenuation under controlled laboratory conditions. Field experiments will examine the biogeochemical implications of potential cake and coke storage scenarios. Geochemical modelling of these systems will provide further insight into the mass-transfer and mass-transport processes controlling water chemistry in closure landscapes. Results of this research will inform the development of conceptual models to assess implications of various storage and reclamation scenarios.

## PROGRESS AND ACHIEVEMENTS

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Substantial progress was made during 2014 toward meeting research Objective 1, which focuses on characterizing existing deposits of centrifuge cake and petroleum coke. This research involved large field sampling campaigns and, therefore, a substantial amount of in-kind support. Samples derived from these campaigns are being analyzed to constrain geochemical, mineralogical, microbiological and physical properties.

**Centrifuge Cake:** A total of 60 core samples were obtained at 27 locations within four centrifuge cake deposits. These deposits included two test deposits constructed in 2010 (truck deposit, gypsum-truck deposit) and two production scale deposits (EV1, EV2). These core samples were frozen and shipped to the University of Saskatchewan for analysis. Solids were submitted to a certified laboratory for analysis of petroleum hydrocarbons (CCME method). Additional samples were incubated for: (i) determination of pore water gas concentrations (i.e., carbon dioxide, methane); and (ii) extraction and sequencing of microbial DNA. Pore water was extracted from the samples by high-speed centrifugation using a method that limited introduction of oxygen to the samples. Geochemical measurements (i.e., pH, Eh, alkalinity, iron(II), ammonia, hydrogen sulfide) were performed immediately. Remaining samples were preserved and submitted for analysis at Syncrude's Research and Development Laboratory. These analyses began in May 2014.

**Petroleum Coke:** A total of 132 samples were obtained at 12 locations within three coke deposits. These deposits included coke beach (six locations), coke watershed (three locations), and coke cell 5 (three locations). Multi-level monitoring wells were installed at coke beach (five locations) and coke watershed (three locations) immediately following core sample collection. Detailed geochemical sampling of these wells was completed in August 2014. Measurements of stable isotopes of water were completed by October, 2014. Analysis of pore-water samples for major ions, trace elements and naphthenic acids at Syncrude's Research and Development Laboratory is ongoing. Analysis of coke solids began in November 2014.

Overall, these research activities are progressing well and should be completed on originally proposed timelines.

## OUTCOMES AND LESSONS LEARNED

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This project is in year one of a five year program. This project is not yet at the stage to report on outcomes and lessons learned.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications prepared in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Saskatchewan

Department: Geological Sciences

Principal Investigator: Matthew Lindsay

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Kaitlyn Scott	University of Saskatchewan	M.Sc.	September 2013	In progress
Jake Nesbitt	University of Saskatchewan	M.Sc.	May 2014	In progress
Qingyang Liu	University of Saskatchewan	M.Sc.	September 2014	In progress

Industry Collaborators: None

## Sandhill Fen: Program Overview

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**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** Syncrude Canada Ltd.

**Industry Champion:** Syncrude Canada Ltd.

### PROJECT SUMMARY

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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. has undertaken over 30 years of research and monitoring efforts on understanding and developing best practices for out-of-pit landforms 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 SFRW is located in the North West corner of Syncrude's East in-Pit (EIP). EIP is the former east mine, which was actively mined from 1978 to 2000. Since mining, EIP has been back-filled hydraulically with composite tailings. The SFRW area is 57 ha. It contains seven 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, 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. The hummocks were planted with a standard 2,000 stems per hectare reclamation tree mix (Aspen, White spruce, and Jack pine), as well as some shrub species. There are density trail experimental treatments located on all the hummocks, which were planted at 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 ha 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 one 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;
- land form design guidance, especially hummock landform technology; and
- wetland reclamation guidance.

## PROGRESS AND ACHIEVEMENTS

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The SFRW has recognized a number of research disciplines for research study. The research programs are discrete projects integrated under the larger SFRW 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 their accompanying sections of this document.

## RESEARCH TEAM AND COLLABORATORS

Project Type	COSIA Project Number	Project Title	Program Length	PI's
Single Industry	LJ0204	Water and Carbon Balance in the Constructed Fen	5 years 2012 to 2016	McMaster University and Carleton University Dr. Sean Carey Dr. Elyn Humphreys
Single Industry	LJ0204	Forest reconstruction on upland sites in the Sandhill Fen Watershed	5 Years 2012 to 2016	University of Alberta Dr. Simon Landhäusser Dr. Brad Pinno
Single Industry	LJ0122	The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development	4 Years 2012 to 2015	Southern Illinois University and Villanova University Dr. Dale Vitt Dr. Stephen Ebbs Dr. Kelman Wieder
Single Industry	LJ0204	Hydrogeologic Investigation of Sandhill Fen and Perched Analogues	4 Years 2012 to 2015	University of Alberta Dr. Carl Mendoza Dr. Kevin DeVito
Single Industry	LJ0204	Biogeochemical investigation in Sandhill Fen	3 years 2011 to 2013	McMaster University Dr. Lesley Warren
Single Industry	LJ0204	Influence of peat depth, hydrology and planting material on reclamation success within a created fen-like setting	3 years 2013 to 2015	University of Alberta Dr. Lee Foote
Single Industry	LJ0204	Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality	2 years 2014 to 2015	University of Windsor Dr. Jan Ciborowski
Single Industry	LJ0204	Sandhill Fen Geospatial Metadata and Mapping System	Ongoing 2010 to Present	University of Windsor Alice Grgicak

# Sandhill Fen: Biogeochemical Investigation in Sandhill Fen

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Work Completed

**COSIA Project Number:** LJ0204

**Academic Institution:** McMaster University

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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This research has conducted an investigation of iron-sulfur biogeochemical cycling in uncapped CT in the North East Pit (NEP) and compared them to those obtained for sand-capped Fen CT that is the focus of the associated NSERC CRD submission. Executing the three-year scope allowed us to link the various geochemical reactions to microbial processes, and constrain the seasonal and restoration evolution of these microbial processes with the goal of determining which outcomes are most likely and pose the highest risk; enabling the design of controls to reduce the risks.

## PROGRESS AND ACHIEVEMENTS

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Research development in 2014 has focused on summarizing field and experimental results, identifying the factors / processes that could explain the observed highest H<sub>2</sub>S concentrations, both aqueous and gaseous, within the structural sandcap layer. In 2014, much work was also focused on finalizing analyses, summarizing overall research findings and generating manuscripts and theses from the project (six M.Sc. theses completed, one Ph.D. underway, one manuscript accepted, one submitted, five in preparation / near submission state).

A one-year extension March 2014 to March 2015 on this NSERC-funded project has enabled results generation and synthesis and completion of theses, preparation of manuscripts and final reports.

## OUTCOMES AND LESSONS LEARNED

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All final reports and publications with summary findings are scheduled for publication in 2015. See list of publications below for detailed results.

## PRESENTATIONS AND PUBLICATIONS

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Bowman, D.T., G.F. Slater, L.A. Warren and B.E. McCarry. 2014. *Identification of Individual Thiophene-, Indane-, Tetralin-, Cyclohexane-, and Adamantane-type Carboxylic Acids in Composite Tailings Pore Water from Alberta Oil Sands*. Rapid Communications in Mass Spectrometry in press.

Bradford, L. 2014. *Microbial Community Response During Oil Sands Reclamation*. M.Sc. Thesis. McMaster University.

- Bradford, L.M., L.A. Ziolkowski, N. Ngonadi, L.A. Warren and G.F. Slater. 2014. *Constraining microbial carbon sources and potential for petroleum metabolism during oil sands reclamation*. Organic Geochemistry (to be submitted November 2014).
- Bradford, L.M., L.A. Warren and G.F. Slater. 2014. *Evaluating changes in microbial community abundances during oil sands reclamation via phospholipid fatty acid analysis*. Journal of Environmental Monitoring (to be submitted November 2014).
- Cilia, C. 2013-2014. *Assessing the occurrence of aqueous intermediate sulfur redox species through combined solution total sulfur, sulfate, and hydrogen sulfide analyses*. Undergrad Thesis. McMaster University.
- Kendra, K.E., A. Brady, G.F. Slater and L.A. Warren. 2014. *Integrated Genomic, Lipid and Geochemical Characterization of An Oil Sands Composite Tailings Deposit*. International Society for Microbial Ecology Journal (to be submitted October 2014).
- Kendra, K.E., T.E. Colenbrander-Nelson, S.E. Holland, L. Bradford, G.F. Slater and L.A. Warren. 2014. *Evolutionary trends in S biogeochemistry of an oil sands composite tailings deposit associated with initiation and establishment of pilot wetland dry reclamation*. Chemosphere (to be submitted October 2014).
- Overbeeke, G. 2013-2014. *Petroleum hydrocarbon distributions in a constructed fen as part of oil sands reclamation*. Undergrad Thesis. McMaster University.
- Reid, M. 2014. *Biogeochemical Zonation in an Athabasca Oil Sands Composite Tailings Deposit Undergoing Reclamation Wetland Construction*. M.Sc. Thesis. McMaster University.
- Reid, M.L. and L.A. Warren. 2014. *Characterizing sulfur biogeochemical gradients in an Athabasca oil sands Chemical Geology* (to be submitted October 2014).
- Reid, M.L. and L.A. Warren. 2014. *Interactive roles of fines particles, wetland organic carbon inputs and sulfur reducing bacteria in H<sub>2</sub>S generation within a composite tailings dry reclamation deposit*. Environmental Science and Technology (to be submitted October 2014).
- Van Erden, L. 2014-2015. *Assessment of microbial growth and carbon sources in submerged oil sand tailings*. Undergrad Thesis. McMaster University.
- Warren, L.A. 2014. *Integrating metagenomics with biogeochemistry in mine contexts*. Ontario Genomics Institute, Toronto, ON, May 2014.
- Warren, L.A. 2014. *Integrating metagenomics with geochemistry in mining applications*. Genome Atlantic Canada, Fredericton, NB, November 2014.
- Warren, L.A. 2014. *Metagenomics and mining: how to develop game changing knowledge platforms to improve sustainability*. Ontario Genomics Institute, Board of Governors, Toronto, ON, July 2014.
- Warren, L.A. 2014. *Microbial S biogeochemistry of oil sands composite tailings GSA, Vancouver, BC, October 2014*.
- Warren, L.A. 2014. *Molecular and geochemical characterization of oil sands composite tailings*. ISSM, Pacific Grove, CA October 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: McMaster University

Principal Investigator: Lesley Warren

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Lauren Bradford	McMaster University	M.Sc.	2012	2014
Michelle Reid	McMaster University	M.Sc.	2011	2014
Lori Van Erden	McMaster University	B.Sc.	2012	2015
Gavin Overbeeke	McMaster University	B.Sc.	2012	2014
Carlo Cilia	McMaster University	B.Sc.	2012	2014

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** University of Windsor

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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 Athabasca oil sands wetlands (CFRAW) program has documented that the most important determinants of zoobenthic community composition in young marsh-like wetlands of the oil sands mine area are water quality (dissolved oxygen concentration, pH, salts and naphthenic acids), substrate characteristics (mineral vs. organic sediments 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

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Sampling during the 2014 field season entailed assessing zoobenthic community composition/early-stage development and associated covariate information at 72 aquatic locations in 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 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. Sorting and invertebrate identification of samples collected in 2013 were completed; those collected in 2014 are in progress for reporting in fall 2015. The zoobenthic vegetation/substrate/water quality association information will be integrated with complementary remote sense and in-situ survey data on vegetation across the wetland to estimate fen-wide distribution, abundance and emergence potential of particular invertebrate assemblages for comparison with natural systems and for time trend analyses.

In addition, invertebrate community composition was done in the wet meadow areas of a suite of natural wetlands with fen characteristics sampled in 2014 using the methodology previously developed to provide information on fen-dependent aquatic and semi-aquatic taxa from areas that lack the standing water upon which traditional aquatic sampling depends (sticky traps, vacuum samples of vegetation and surface litter and aerial sweeps).

Environmental features and biological associations of the submerged sites sampled in 2013 and 2014 were compared.

## DELIVERABLES AND MILESTONES

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This was year two of a three year program.

## OUTCOMES AND LESSONS LEARNED

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Overall, during the 2014 field season evidence of rapid colonization by diverse flying insects was observed throughout the fen despite salinity levels that might be expected to impede survival. No longitudinal variation in community composition or abundance was observed. Analyses of semiaquatic and terrestrial invertebrate samples are in progress. Next year's sampling will test important hypotheses about the role of salts and possible associations among peat, plants and invertebrate fauna. Together, the data collected by this project will provide comparative reference information that can be used to account for intra-fen variation in environmental conditions and the resulting range of natural variation in key measures of zoobenthic composition and biodiversity.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Windsor

Principal Investigator: Jan Ciborowski

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0122

**Academic Institution:** Southern Illinois University

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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This project addresses questions centered on plant establishment and development of critical ecosystem functions on a soft tailings deposit which has been reclaimed to a 57 hectare wetland complex at Syncrude base plant. This research follows the research done at Syncrude's u-shaped cell. That research guided which species might be selected for wetland and specifically fen species establishment on tailings substrates, indicated that invasive species may be a real concern, and that several species tolerate the salinity predicted for tailings closure features. Despite these advances in knowledge, little is known about how plants will respond to reclamation conditions, nor how (or even if) critical ecosystem functions will return. The specific research being addressed in this program will be:

- Chemical gradients within Sandhill fen:
  - vertical and horizontal gradients in base cations, pH, and alkalinity; and
  - wetness.
- Species establishment responses:
  - vascular plant establishment and growth;
  - moss establishment and growth;
  - invasive species; and
  - changes in resource allocation (light, nutrients).
- Community development:
  - development of community complexity and species richness; and
  - effects of density and competition.
- Nitrogen mineralization, nitrification, and utilization:
  - atmospheric inputs;
  - DIN/DON pools; and
  - development of microbial communities.
- Reference sites:
  - naturally occurring young fens (5 to 10 years old) as benchmarks; and
  - old fens.

## PROGRESS AND ACHIEVEMENTS

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During the 2014 field season, continued water samples were taken to a depth of 50 cm using Sipper Peepers, a second nitrogen mineralization study was completed, the soil was sampled for bulk density, a physiology study was conducted on multiple wetland species planted in the plots, samples that were collected for soil microbe analysis, atmospheric deposition collectors for sulphur and nitrogen compounds were re-installed, decomposition study continued, and a study of net ecosystem productivity under 4 different sedge species was started. At the end of the field season, analysis began in the laboratory. To date the analysis of the water samples collected for base cation concentration, nitrogen mineralization sampling, and atmospheric deposition data have been analyzed. Preliminary data from the physiological and NEP study are also analyzed. A vegetation survey was carried out in July 2014, and plants growing in the fen were identified.

## OUTCOMES AND LESSONS LEARNED

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**Nitrogen:** Nitrogen (N) mineralization is a below-ground microbial-mediated N-cycling process that transforms soil organic matter into the inorganic forms ammonium and nitrate. Because fens are anoxic systems, nitrification rates in fens inherently are low. Thus, net N mineralization is dominated by ammonification in natural fen systems. Net N mineralization (net ammonification + net nitrification) rates were measured at Sandhill fen and across six comparative benchmark fen sites over the month of June. In the 'Wet' plots at Sandhill fen, inorganic N production patterns were similar to N production rates observed at the six benchmark fen sites, and net N mineralization was dominated by ammonification. However, in the 'Dry' plots at Sandhill fen, inorganic N production patterns are functioning like upland systems, and net N mineralization is dominated by nitrification. Overall, for future fen reclamation projects, keeping the fen soil water-saturated is necessary to reduce nitrification potentials.

**Physiology:** Physiological performance of four plant species was monitored in plots across SHF using a CI-340 portable photosynthesis system. The photosynthetic rate of *Carex aquatilis* and *Triglochin maritima* are regressed against soil moisture in the plots of SHF. There was a slight increase in photosynthetic rate with an increase in soil moisture. Both species are performing well in SHF. A Master's thesis will be complete later in 2015 and will include detailed results from four wetland species in SHF as well as natural benchmark sites.

**Vegetation:** A moss survey was conducted by Dale Vitt in August 2014 at SHF, and 21 moss species were identified. Fourteen of the 21 were peatland mosses. Mosses occurred in scattered areas throughout the fen, but not in areas that were or had been inundated for part of the growing season. The vegetation surrounding the 20 plots was surveyed. Two distinct communities were found in the fen: one associated with dry areas and another associated with wet areas. *Calamagrostis canadensis* is a dominant species in dry areas, and *Carex aquatilis* is more abundant in wet areas. The study identified 112 vascular species, divided into two categories: weeds (65 species) and wetland volunteers (47 species). Weeds dominate and wetland volunteer cover is reduced in dry areas compared to wet areas. Survival of wetland species planted in the research plots was also monitored. Most species survived. Some survived well in both wet and dry plots (i.e., *Carex aquatilis* and *Scirpus atrocinctus*). *Carex limosa* and a few other species did not survive well regardless of moisture levels. Still others showed a preference for either wet or dry plots. Please review referenced publications for detailed results.

**Carbon Sink Potential of Species:** Renee Hazen's Master study was initiated in 2014; the goal of this project is to determine which of four wetland species introduced to the fen sequester carbon most efficiently, establishing a carbon sink. The four species selected are *Carex aquatilis*, *Carex canescens*, *Carex hystericina*, and *Scirpus microcarpus*. Preliminary data indicate that there are strong differences in photosynthetic and respiration rates between the four species.

## PRESENTATIONS AND PUBLICATIONS

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Ebbs, S., M. House, L. Glaeser, R. Hazen and D.H. Vitt. 2014. *Plant establishment, community stabilization, and ecosystem development on oil sands soft tailings*. 11<sup>th</sup> Annual Meeting, International Phytotechnologies Society, Heraklion, Crete. Oct. 1-4, 2014.

Hartsock, J., M. House and D.H. Vitt. 2014. *Net nitrogen mineralization: A performance indicator for wetland reclamation*. Soil Science Society of America (SSSA) 2014 International Annual Meeting. Long Beach, CA.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Southern Illinois University

Principal Investigator: Dale Vitt

Name	Institution	Degree	Start Date	Completion Date
Stephen Ebbs	Department of Plant Biology and Center for Ecology, Southern Illinois University,	Co-Principle Investigator	2012	2016
Kelman Wieder	Department of Biology, Villanova University	Co-Principle Investigator	2012	2016

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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The overall goal of this research project is to examine the inter-relationships among tree species and density, understorey 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

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- An inventory of all tree seedlings found in the 78 revegetation plots was performed August 2014 as a follow-up to initial seedling mensuration performed during the 2012 and 2013 field seasons. Root collar diameter, height and crown diameter were recorded on ten target trees for each species. Survival and natural regeneration ingress was determined. Tree seedling performance will be re-measured again in August of 2016 (fifth growing season).
- Soil water matric potential in addition to soil temperature were recorded using Decagon MPS-2 sensors installed 2012 at 10 cm and 20 cm depths from May 2013 to present in each of the revegetation plots.
- Stomatal conductance was measured on one aspen and one pine seedling in the buffer of each planted revegetation plot (June 24/25, July 16/17 and August 21/22, 2014), 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) June 3, June 23/25, July 15, and August 19, 2014.
- An inventory of all tree seedlings found in the 30 slope and aspect plots was performed August 19 and 20 as a follow-up to initial seedling mensuration performed August 2012 as part of Shaun Kulbaba and Alex Goeppel's Masters projects. Root collar diameter and height were recorded on the remaining aspen and pine stocktypes planted on south and north facing slopes and in hydrogel amended plots.
- Plant community association plots were established on both a/b and d ecosite capping materials by Elizabeth Hoffman as part of her Master's project with the aim to determine spatial relationships among desirable forest understorey species and species considered undesirable. Ocular cover estimation of shrub, forb, graminoid, and bryophyte vegetation by species was estimated within the 1,000 0.25 m<sup>2</sup> plots in July 2014. These data will be linked to plant community data collected by Elizabeth at Syncrude's W1 site (reclaimed overburden).

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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Goepfel, A. 2014. *Evaluating jack pine seedling characteristics in response to drought and outplanting*. M.Sc. Thesis, Department of Renewable Resources, University of Alberta, Edmonton, AB.

Hoffman, E. 2014. *Spatial interactions between weeds and forest species in response to donor materials from different forest ecosites*. Ren R 604, Presentation, Edmonton, AB, Mar. 6, 2014.

Hoffman, E. and S.M. Landhäuser. 2014. *Weed population dynamics in response to donor materials from different forest ecosites*. Forestry Industry Lecture Series, Edmonton, AB, Mar. 27, 2014.

Kulbaba, S. 2014. *Evaluating trembling aspen (*Populus tremuloides* Michx.) seedling stock characteristics in response to drought and out-planting on a reclamation site*. M.Sc. Thesis, Department of Renewable Resources, University of Alberta, Edmonton, AB.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Dr. Simon Landhäuser

Industry Collaborators: None

# Sandhill Fen: Geospatial Metadata and Mapping System

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** University of Windsor

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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As part of the Sandhill Fen research watershed project, researchers from a wide variety of disciplines will be collecting data that measure numerous physical, biological, and chemical parameters as part of their research. These data reside in multiple formats at different institutions, making access difficult for Syncrude and other research teams. To address these problems, GLIER's GIS Team at the University of Windsor has developed an integrated geospatial tool that incorporates a metadata and mapping component. Called the Sandhill Fen Metadata and Mapping System, this ISO-compliant system couples GeoNetwork open source with ESRI's ArcGIS - Server and Latitude Geographics' Geocortex software packages to create a unique interactive web-mapping and metadata catalogue. Users are able to edit their metadata online and view Sandhill fen data in a map environment.

The overall purpose of the Sandhill Fen Mapping and Metadata System is to:

- improve access to and integrated use of spatial data and metadata information amongst researchers and Syncrude;
- support decision making of the Sandhill Fen (long-term and short-term);
- promote multidisciplinary approaches to sustainable development of the fen and reclamation strategies, and
- To enhance understanding of the benefits of geographic information.

## PROGRESS AND ACHIEVEMENTS

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For 2014, the University of Windsor GIS team primarily focused on streamlining the process of creating and uploading metadata related to assets found on the Sandhill Fen site for the 2013/2014 sampling period. This included the transitioning from the "flexible user approach", which initially required each researcher to edit and upload their asset information on their own time into the SFMMS, to the "structured approach", where the University of Windsor GIS team acted as the "hub" to help organize and upload each researcher's asset information into the system itself, thus encouraging each researcher to focus on using the system as a data search mechanism only. The implementation of the structured approach included:

- an editable .pdf form was developed using the ISO metadata template with a focus on asset based information;
- an FTP site was set up for data transfer;
- setting up concrete deadlines for metadata and data submission; and

- assessing, editing, converting and uploading information into the SFMMS.

The structured approach was successful and yielded 99 asset based metadata records that were submitted into the SFMMS, along with some reports, images and geospatial/measurement data.

Secondly, the University of Windsor GIS team also added new “tools” via CSharpe, XML, XAML, JAVAscript, HTML, and CSS programming within the mapping application of the SFMMS. These tools included, expanding the map, a database view, drawing tools, print and export map functionality, and aerial history of the site.

## OUTCOMES AND LESSONS LEARNED

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Initial set up and utilization of the system has been the most challenging. Use of the tool is being tracked and will be evaluated against the initial goals in 2015.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Windsor

Principal Investigator: Alice Grgicak Mannion

Industry Collaborators: None

# Sandhill Fen: Hydrogeologic Investigation of Sandhill Fen and Perched Analogues

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

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## 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, Simon Landhäusser's work on vegetation succession and very shallow moisture regimes on hummocks, Sean Carey's work on atmospheric interactions. It also links with Lee Barbour's Industrial Chair for defining landscape hydrology through isotope sampling (LJ0210). Additional work within this program looks at monitoring the hydrologic behavior of a perched fen complex at the Utikuma Region Study Area (LJ0215). 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.

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## PROGRESS AND ACHIEVEMENTS

The 2014 field season largely involved the collection of enough field data to document the initial/baseline hydrogeological conditions in a now unmanaged system. Prior to 2014, water was brought into the study area and managed. We also installed another 15 piezometers. Over 175 piezometers or wells have been installed at over 70 sites throughout the watershed. About 50 of these installations are continuously monitored (i.e., every 4 hours) and all installations are manually measured weekly to bi-weekly. Over 120 shallow access tubes have been installed for manually measuring soil-moisture content profiles. Detailed soil pits have been established at eight hillslope-wetland interface locations to continuously monitor soil-moisture content and tension.

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 modelling efforts. Analysis of field data is ongoing.

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## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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Price, J., K. DeVito, C. Mendoza and R. Petrone. 2014. *Hydrological challenges and opportunities for reconstructing wetland ecosystems after oil-sands mining*. Responsible management of peatlands: Involvement of the industrial sector. Peatland Ecology Research Group 20th Symposium.

Mendoza, C., S. Carey, K. DeVito, S. Landhäusser and J-M. Longal. 2014. *Early water dynamics within a wetland complex constructed on tailings at an oil-sand mine*. Geological Association of America, Vancouver, BC, October 2014.

Mendoza, C. and K. DeVito. 2014. *Ecohydrology applications to ecosystem reconstruction after oil-sand mining*. Geophysical Research Abstracts. Vol.: 16. European Geosciences Union. May. <http://meetingorganizer.copernicus.org/EGU2014/EGU2014-9840.pdf>.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Carl Mendoza

Name	Institution	Degree	Start Date	Completion Date
Kevin DeVito	University of Alberta	Co-Principle Investigator	2012	2016
Jean Michelle Longal	University of Alberta	B.Sc.	2012	2014

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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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

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Field data for the project continued to be collected in summer of 2014. This included the first round of peat depth measurements on 72 peat plots located on clay islands. Collecting peat depths took approximately one week, and there were no problems with the data collection. Summer 2014 marked the second round of *Carex aquatilis* survival and spread data. The number of living stems were counted, and a percent cover recorded.

Preliminary (basic) statistics have been run on both data sets, but additional statistics are still forthcoming. A second field season is planned for data collection on both sets of data.

## DELIVERABLES AND MILESTONES

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This was year two of the three-year program.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Lee Foote

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Mallory Hazell	University of Alberta	M.Sc.	2013	2015

Industry Collaborators: None

# Sandhill Fen: Water and Carbon Balance in the Constructed Fen

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0204

**Academic Institution:** McMaster University and Carleton University

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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

- to measure the ecosystem scale annual water/energy and C balance for the reclaimed fen over a five-year period (2012-2016) based on complete year measurements of all the major inputs and outputs to the system;
- establish the intra-fen variability in NEP and FCH<sub>4</sub> to establish which areas of the fen are more productive (successful) than others and link this to the ecosystem-scale flux (2012-2016);
- characterize the quantity and quality of DOC and POC released from Sandhill Fen through surface and subsurface hydrological pathways (2012-2016);
- monitor changes in DOC and POC quantity and quality across a range of hydrological conditions (2012-2016); and
- 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

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Considerable progress has been made towards estimating the carbon, water and to a less extent salt balance of the watershed. Findings will be discussed process-by-process below:

### WATER BALANCE

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Precipitation (snow) - We have a record of snow accumulation (water equivalent) and melt. There was considerable variability across the fen in 2012/13 compared with 2013/14 along with more snow. Snow surveys complement this record.

Evapotranspiration was measured using the eddy covariance technique at three sites: a tower located in the centre of the wetland area and one to the south of the fen representing a terrestrial surface and in 2014 a tower located between the perched fens. Evapotranspiration measured from June through October indicated greater values from the wetland than the terrestrial surface. There is some intra-year variability that is being investigated and is most likely related to climate and vegetation.

Pump inflows and outflows are being tracked. Shallow water table was measured at approximately 15 sites distributed throughout the fen and upland area.

## SALT DYNAMICS

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There are a large number of sensors measuring salinity and its progression with time along with spatial variability.

To evaluate spatial patterns of cation exchange, SAR is being evaluated throughout the fen.

## CARBON BALANCE

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Vertical CO<sub>2</sub> balances were computed for the fen and terrestrial eddy covariance towers. Over the growing season, all sites have now become carbon sinks as summer production (photosynthesis) is high. Carbon allocation in plants is increasing with time. The north tower (terrestrial site) has moved from being a source of carbon to a sink over three years.

On an annual basis, the fen is still a small net source of carbon to the atmosphere, although this source is rapidly declining and we estimate in the next few years that the fen will become a net carbon sink.

Methane flux was very low as measured at the fen tower during both 2013 and 2014.

In addition to the above, water chemistry was measured at various locations throughout the fen and outlet to improve understanding of the salt balance. Additional work on DOC dynamics is also ongoing.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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Mendoza, C., S.K. Carey, K. DeVito, S. Landhäusser and J-M. Longval. 2014. *Early water dynamics within a wetland complex constructed on tailings at an oil-sand mine*. Presented at Geological Society of America AGM, Vancouver, BC, October 2014.

Nicholls E.M., S.K. Carey, G.B. Drewitt, E.R. Humphreys and M.G. Clark. 2014. *Towards a water balance of a constructed wetland, Fort McMurray, Alberta*. Presented at CGU Annual General Meeting, May 2014.

Thorne, C.E., S.K. Carey and C. Oswald. 2014. *A comparison of nutrient availability in reclaimed wetland soils, Fort McMurray, Alberta*. Presented at CGU Annual General Meeting, May 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: McMaster University and Carleton University

Principal Investigator: Sean Carey

Name	Institution	Degree	Start Date	Completion Date
Elyn Humphries	Carleton University	Professor/PI on project	2012	2016

Industry Collaborators: None

## Soils and Reclamation Materials

# Multiple Years of Biosolids Performance Data and Method Development

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0166

**Academic Institution:** Teck Highland Valley Copper

**Industry Champion:** Teck Resources Limited

## PROJECT SUMMARY

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Teck's Highland Valley Copper (HVC) is one of the largest copper-molybdenum mines in North America. To date, approximately 6200 ha have been disturbed by mining within the area of Highland Valley Copper's Reclamation Permits. To guide reclamation activities for each area of the mine, an end land use plan for the property has been developed. Establishment of forages for cattle grazing, native shrubs and trees for wildlife browse and conifers for wildlife corridors comprise important components of the revegetation goals at the mine site. However the physical and chemical characteristics of mine waste material at Highland Valley Copper represent challenges that might limit the capability of some reclamation areas to achieve the revegetation goals. Some of these challenges include:

- mine waste materials have no organic matter and low fertility;
- mine waste materials typically have a low water holding capacity due to high coarse fragment content and coarse texture;
- elevated concentrations of copper, molybdenum and sulphur in vegetation due to metal uptake from some mine waste materials potentially limit site suitability for grazing and wildlife end land use;
- the mine waste material is alkaline and may negatively impact conifer reforestation success; and
- insufficient suitable overburden materials available for capping all mine disturbances.

Biosolids application represents a reclamation treatment that provides a source of organic matter to amend soil conditions and improves nutrient and water availability. Although biosolids do not initially change the texture of waste materials on reclaimed areas, they may supplement the nutrient and water holding capacity to a level that is sufficient for vegetation establishment. In addition, biosolids may reduce soil pH to a range that is more widely tolerated by plants, and provide soil micro-organisms.

Since 1996 Teck's Highland Valley Copper mine has tested the effectiveness of biosolids application as a potential reclamation treatment on different waste materials, and has assessed the possible benefits and deleterious effects of the application of biosolids to waste areas. The test sites used are located primarily on tailings and overburden-capped waste rock areas of Bethlehem property. Control treatments have been included in the study design to allow for comparison of biosolids treatment with standard reclamation treatments using annual application of chemical fertilizers. To confirm the impacts of biosolids application on vegetation sustainability several years of vegetation monitoring is required. In 2014 monitoring continued at tailings and waste rock dump at HVC as well as new applications to test sites.

## PROGRESS AND ACHIEVEMENTS

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During 2014, Metro Vancouver applied 2,614 wet tonnes (745 dry tonnes) of biosolids to two disturbed areas of the mine site (Trojan Tailings dam and Huestis waste rock dump). Over the past 19 years, Metro Vancouver has applied a total of 404,521 wet tonnes of biosolids on 741 ha of disturbed land at Highland Valley Copper. Biosolids applications on the Trojan Tailings began in 1996 and continued periodically over the years, to different areas of the tailings and dam. Biosolids reclamation conducted in 2014 was limited to a 0.09 ha site. The 2014 Huestis site is a biosolids reapplication site located on an uncapped waste rock dump on Bethlehem West Dump. The site (HUE14A1), a 2.90 ha slope, had previously received a biosolids application in 1997. Due to poor vegetation growth, the site was selected for additional fertilization with biosolids. With the exception of copper and molybdenum, all elements in both pre and post application data sets for 2014 Metro Vancouver Biosolids application sites on the Trojan Tailings dam are within the prescribed limits of the BC Organic Matter Recycling Regulation (OMRR) for agriculture and livestock use. The OMRR does not apply at this mine site; rather, it is referenced as guidance for conducting biosolids applications and is consistent with HVC's end land goals for cattle grazing and wildlife use. However, HVC did receive approval from the Ministry of Environment to exceed the OMRR guidelines for molybdenum and copper due to the background levels of these elements in the area that the biosolids were applied.

In addition to Metro Vancouver biosolids, HVC uses biosolids from the Joint Abbotsford Mission Environmental System (JAMES) plant. Biosolids from JAMES began to be beneficially reused at HVC in 2001. Since that time approximately 90% of the biosolids produced by the plant have been used for reclamation of mining-disturbed land at HVC. Prior to 2014, approximately 105,670 bulk tonnes of JAMES plant biosolids had been used at HVC to help reclaim 128.3 ha of disturbed land. In 2014, 5,299 bulk tonnes were applied and incorporated at two Huestis dump sites, HUEJ14A (upper dump area) and HUEJ14B (lower dump area), with a combined area of 4.42 ha. This brings the total land base reclaimed with JAMES plant biosolids to 132.8 ha and the total amount of biosolids recycled on HVC reclamation sites to 110,969 bulk tonnes.

## OUTCOMES AND LESSONS LEARNED

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This program has enhanced reclamation practices at HVC, waste from Metro Vancouver and JAMES have been diverted to the mine site instead of landfills. The 2014 Metro Vancouver Biosolids application sites on the Trojan Tailings dam are within the prescribed limits of the BC Organic Matter Recycling Regulation (OMRR) for agriculture and livestock use. There will be no further application of JAMES plant biosolids at Teck-Highland Valley Copper for the foreseeable future due to mine expansion which has minimized reclamation requirements temporarily.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Teck's Highland Valley Copper

Principal Investigator: Jaimie Dickson, Environmental Supervisor

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Ruth McDougall	Consulting Agrologist	M.Sc.	2010	2014
Richard Doucette	HVC	Environmental Coordinator	2010	Ongoing
Dave Falcon	HVC	Environment & Community Affairs Coordinator	2010	Ongoing

Industry Collaborators: None

# Nutrient Biogeochemistry 2: Tracking Nutrient Fluxes Through Reconstructed Soils

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0120

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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Following surface mining, land reclamation necessitates the reconstruction of soil-like profiles using salvaged surface soils, organic soils (peat), mineral parent materials, and in some cases mining by-products. Both forest floor soil salvage and placement of peat are used as the coversoil (topsoil) layer in oil sands mine reclamation in the Athabasca Oil Sands Region. The availability of these soil materials varies between leases and with time. 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 reclaimed soils initially relies on coversoil for its nutrient needs, over time these should be replaced by in-situ litterfall and the build-up of a forest floor layer. This project, which represents a collaborative effort between several oil sands operators and Canadian Universities, will directly contribute to ongoing research efforts in land reclamation by characterizing forest floor development and associated biogeochemical processes in chronosequences of reclaimed ecosystems. These characteristics will be compared to the forest floor characteristics developing in recently burned ecosystems, another disturbance 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 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 will be integrated and built upon so that a mechanistic model of C and N fluxes in reclaimed soils can be developed.

## PROGRESS AND ACHIEVEMENTS

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### **Objective 1: Carbon release from forest floor and peat amendments**

This objective was completed by Mark Béasse (M.Sc., supervised by S. Quideau). 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. The first article from Mark's work has been accepted for publication in *Ecological Engineering* for 2015, and is now available on line. A second and final article will be submitted to another peer-reviewed journal in 2015.

### **Objective 2: Key characteristics of fire-disturbed soils and comparison to reconstructed soils**

For her M.Sc. studies, Jill Martin (supervised by D. MacKenzie) selected 11 aspen-white spruce stands recovering from wildfire, with stand ages ranging from two to 125 years. Jill also examined a chronosequence of five reclaimed sites aged four to 27 years since reclamation. Fieldwork consisted of the establishment of sampling transects at each site for routine soil characterization, nutrient availability, and microbial analyses. Jill continued to work towards the completion of her M.Sc. degree in 2014.

### **Objective 3: Organic carbon and nitrogen cycling in boreal forest soils**

Charlotte Norris (Ph.D. co-supervised by S. Quideau and S. Landhäusser) utilized stable isotopes ( $^{13}\text{C}$  and  $^{15}\text{N}$ ) to trace C and N fluxes from new litter to various soil organic matter pools. She generated double labelled ( $^{13}\text{C}$  and  $^{15}\text{N}$ ) 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. Enrichment in  $^{15}\text{N}$  provided a tracer to assess N cycling in the stands, while the  $^{13}\text{C}$  tracer characterized the active segment of the microbial community through compound-specific stable isotope analysis of phospholipid fatty acids (PLFAs). Results were presented at the 2014 Canadian Soil Science Society Meetings, and will be submitted to a refereed journal for publication in early 2015.

Four study sites (located within a 20 km radius on the Syncrude's Mildred Lake Mine Lease) were chosen to quantify and compare N fluxes between reclaimed and natural forest soils: Young Reclaimed, Older Reclaimed, Harvested, and Undisturbed. The Young Reclaimed site was constructed in 1998 and planted with alternating rows of aspen and spruce seedlings, while the Older Reclaimed site was constructed in 1988 and planted to pure aspen. The Harvested site was clearcut in 1992 and has recovered since with natural re-growth of aspen and spruce trees. Lastly, the undisturbed site is a mature healthy aspen dominated stand approximately 80 years old. On each of the four sites three transects of paired mesocosm cylinders were established and sampled at regular intervals to quantify  $^{15}\text{N}$  enrichment in vegetation, microbes, and soils. The last collection occurred in September 2014, and laboratory analyses are ongoing. Both laboratory and data analyses should be completed in the next three months.

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. Compound specific isotopic values ( $^{13}\text{C}$  and  $^2\text{H}$ ) of soil biomarkers will be investigated as a tool to tease apart the origin of soil carbon between the original peat amendment and the newer plant litter material.

A M.Sc. student (Cassandra McKenzie) has been recruited for this project, and she will start her graduate studies in May, 2015.

#### **Objective 4: Effects of faunal communities on forest floor and soil organic matter accumulation**

Jeff Anderson (supervised by C. Prescott) completed his M.Sc. thesis in 2014. For his work he focused on understanding how vegetation planting prescriptions affect soil organic matter accumulation in the mineral section of peat/mineral mix (PMM) reclaimed soils. Together with Meghan Laidlaw, he described and sampled 17 research sites at two oil sands leases. The research sites comprised 20 to 35 year-old reclaimed sites and included four areas planted to grassland, five stands planted to spruce and four stands planted to aspen. In addition, four 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. Soil carbon accumulated quickest in the deciduous sites, intermediate in the grassland sites, and not at all in the spruce sites. The mechanisms by which soil carbon accumulated also differed for each vegetation treatment.

Meghan Laidlaw (supervised by C. Prescott) started her M.Sc. studies in September, 2012. She focuses on soil structure, which plays an important role in creating a stable soil habitat that supports the abundance and diversity of the microbial community, and aids in the storage of carbon and other nutrients essential for plant and microbial growth. She is investigating the abundance, size distribution and carbon content of water-stable aggregates in reclaimed soils under different vegetation treatments, and comparing these results to the naturally fire-disturbed sites in the surrounding area. To identify factors that may be influencing aggregate development within reclamation treatments, and between reclaimed and natural soils, she also measured microbial biomass carbon and nitrogen, coarse- and fine-root biomass, total soil carbon and nitrogen, pH, cation exchange capacity, aeration porosity, bulk density and the availability of specific cations such as Ca and Na.

Meghan is currently finishing statistical data analysis. Her results indicate that water-stable aggregate development was not significantly different between reclaimed and naturally fire-disturbed sites, or within vegetation treatments at reclaimed sites. Soil organic carbon was significantly higher at reclaimed sites compared to natural sites, and moreover, it was distributed differently among soil carbon pools. At reclaimed sites, most organic carbon was found within the free-floating soil organic matter pool, whereas the majority of organic carbon at naturally fire-disturbed sites was either aggregate-associated, or adsorbed to silt and clay surfaces. Meghan presented preliminary results at the Canadian Society of Soil Sciences Annual Meeting in May, 2014. She hopes to defend her thesis in spring 2015.

A third and last part of Objective 4 is to assess mesofaunal diversity at a chronosequence of reclaimed sites. Sites were sampled in 2014, and will need to be resampled in 2015. This objective was originally conducted by Mathew Swallow (Post-Doctoral Fellow), but, since September 2014 Mathew is an assistant professor at Mount Royal University. Consequently, a M.Sc. student will be recruited to complete this objective under Mathew and Sylvie Quideau's co-supervision, to start in May 2015.

#### **Objective 5: Spatial variability in fire- disturbed and reconstructed soils**

Sanatan Das Gupta (co-supervised by D. MacKenzie and S. Quideau) started his Ph.D. studies at the University of Alberta in May 2011. During fall 2013 and winter 2014, data on resin-available nutrients (from Plant Root Simulator-PRS probes), soil microbial properties, stand characteristics (tree location, canopy cover, coarse woody debris, forest floor depth), understory vegetation (species richness, abundance and %cover) were analysed and a draft manuscript was written. An oral presentation was given on the study at the Alberta soil science workshop in Calgary, Alberta in February 2014. During summer and fall 2014, other basic properties of soils (texture and total C

and N) collected from the wildfire sites were analysed, and the manuscript on this study was finalized. One poster was presented at the World Congress of Soil Science in Jeju, South Korea in June 2014. An oral presentation was also given on the final results of this study at the Soil Science Society of America annual workshop in Long Beach, California, USA in November 2014. Sanatan is now working on the final draft of his doctoral thesis. The expected submission of his thesis draft is the first week of February 2015. The tentative timeline for his thesis defense is set during the last week of March 2015.

#### **Objective 6: Microbial communities in reconstructed soils**

Jacynthe Masse (supervised by S. Grayston) started her Ph.D. at the University of British Columbia (UBC) in September 2011. Her overall aim is: 1) measure the gross rates of nitrogen transformations under different vegetation treatments in both reclaimed and naturally-disturbed (fire) sites; and 2) characterize the microbial communities participating in the nitrogen cycle within the same soils. High nitrogen deposition recorded in the oil sands area combined with the high level of nitrate found in reclaimed soils raised concerns about the possibility of reclaimed soils being in early stages of N saturation, although little evidence of net nitrification in reclaimed soils suggested the contrary. To date, results on the behaviour of the nitrogen cycle in the reclaimed sites are contradictory. A systematic study of the nitrogen cycle, in particular rates of gross mineralization, nitrification and denitrification, was needed.

Jacynthe has conducted two years (2012, 2013) of field work at her research sites together with M.Sc. students (Jeff Anderson, Meghan Laidlaw; Objective 4) who worked on the same sites. In 2012, soils and sites were characterized in the field. In 2013, Jacynthe collected soil samples to be used for biological analysis. Gross nitrogen transformation rates were measured using  $^{15}\text{N}$  pool-dilution. Microbial communities participating in the N-cycle were characterized using functional genes amplification and next-generation sequencing techniques. All laboratory analyses are now complete. Results from the gross nitrogen transformation studies showed that reclaimed sites mineralized and immobilized more  $\text{NH}_4^+$  from organic sources than natural sites. In addition, reclaimed sites nitrify and produce more  $\text{NO}_3^-$  than they immobilize, which likely accounts for the significantly higher  $\text{NO}_3^-$  concentrations in reclaimed soils.

Jacynthe is currently auditing a bioinformatics course at the University of Montreal and will be analyzing her sequencing data as part of this course. Once all the data analyses are complete Jacynthe will then explore what factors influence the biogeochemical cycling of nitrogen and the nitrifying microbial communities in reclaimed and naturally disturbed soils. In 2014, Jacynthe presented results of her research at two International conferences, the European Geosciences Union in Vienna and the Canadian Society of Soil Science conference in Banff. Jacynthe gave two presentations on her research to the Belowground Ecosystem Group at UBC in October and November 2014.

Jacynthe has become involved in a variety of science-outreach programs; she is a Director on the executive board of the Pacific Regional Society of Soil Science. She is also on the official sub-committee in charge of developing and testing the new soil order of Canada for the upcoming 4<sup>th</sup> edition of the Canadian soil classification system. In addition, she is currently translating and developing learning activities in French for an award-winning virtual-learning website on soil science developed at UBC and she will be presenting this at the Soil Science Education and Outreach session at the annual meeting of the Canadian Society of Soil Science in Montreal in July 2015. At this same meeting Jacynthe and Sue Grayston are organizing and co-chairing a session on "Beyond tools: what the "omic" world can do for our understanding of soil functioning." Finally, the last year of Jacynthe Ph.D. program will be dedicated to writing her thesis and scientific papers with an anticipated date of completion of August 2015.

### **Objective 7: Development of a mechanistic model for C and N fluxes within reclaimed sites**

Nilusha Welegedara (co-supervised by R. Grant and S. Quideau) started her Ph.D. program in January 2013 and she passed her candidacy exam in December 2014. She joined the land reclamation international graduate school (LRIGS) in September 2014. The main objectives of her research are to understand and model the carbon, water, and nutrient cycling, salt redistribution and productivity in reclaimed landscapes. She is using the *ecosys* model to analyse the structure, processes and functional connections of cycling in the South Bison Hills (SBH) experimental site to better understand regeneration of ecosystem productivity in reclamation landscapes with different cover thicknesses. This understanding is being tested with detailed site measurements of soil water content, soil salinity, soil and plant nutrient status and plant biomass accumulation with more than one decade of recorded data at the study site. She will compare results for ecosystem productivity modelled for these landscapes to that of a natural aspen site to establish the extent to which productivity is being restored through the different reclamation covers at the SBH site.

Nilusha collected soil and plant samples from the natural aspen site (regenerating after fire in 2003) in August, 2014. Plant samples were collected from aspen ( $n = 18$ ) and underground shrubs and bushes ( $n = 18$ ) to analyse foliar nutrient (carbon, nitrogen and phosphorous) status and tree heights, base and DBH diameters and plant density data were measured to calculate plant productivity of this natural reference site. Soil samples were collected from six sampling points up to 1 m at 10 cm intervals ( $n = 60$ ) and they were analysed to determine nutrient status (total carbon, total nitrogen,  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ ), soil physical (bulk density, texture) and chemical properties (pH, anion and cation concentrations, CEC, electrical conductivity). She has developed model input files for the natural aspen site using these measured data and the data collected by Sanatan Das Gupta to simulate water, salinity, nutrient and plant productivity in the site. She is refining her model outputs for hydrological components and electrical conductivity with measured data at South Bison Hills to reduce the gap between measured and modelled values. She presented preliminary results at the American Geophysical Union fall meeting-2014 in San Francisco, California, USA. These results are expected to be submitted to a journal in 2015.

## **OUTCOMES AND LESSONS LEARNED**

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Below are some key outcomes derived from the work conducted under Objectives 1 and 4. Please note that work is still underway for the other objectives, hence outcomes for these objectives are not included in the current annual report.

### **Objective 1: Carbon release from forest floor and peat amendments (M.Sc. projects by Aria Hahn and Mark Béasse)**

- The use of forest floor material in the coversoil of soil reclamation results in a greater percent cover of upland vegetation when compared to the use of peat.
- The use of forest floor material in the coversoil places the soil microbial community on a faster trajectory towards ecosystem recovery when compared to the use of peat.
- There is greater carbon flow from aspen and alder seedlings to their rhizosphere microbial communities when seedlings are grown in forest floor coversoil material as compared to peat coversoil.
- Peat has a greater water holding capacity than forest floor material, but forest floor coversoil fosters a more active microbial community than peat coversoil.
- Combining forest floor material and peat coversoil creates a mixture with a soil microbial community more similar to that of forest floor coversoil material than to peat coversoil.

#### **Objective 4: Effects of faunal communities on forest floor and soil organic matter accumulation (M.Sc. projects by Preston Sorenson and Jeff Anderson)**

- Reclaimed sites contain higher soil organic matter content than their natural analogues.
- Forest floor accumulation at the reclaimed sites occurs faster under aspen than under spruce.
- Forest floor accumulation is associated with changes in soil organic matter composition.
- Organic matter accumulation in the reclaimed mineral soils (0-10 cm) occurs faster under deciduous and grass vegetation than under planted spruce.
- Achieving a canopy cover of 30% appears to be a critical threshold in controlling soil microbial communities.

## PRESENTATIONS AND PUBLICATIONS

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Anderson, J. 2014. *Organic matter accumulation in reclaimed soils beneath different vegetation types in the Athabasca Oil Sands*. M.Sc. Thesis. University of British Columbia, Forest Sciences, 105 pages.

Anderson, J, C.E. Prescott and S.J. Grayston. 2014. *Organic matter accumulation in reclaimed soils beneath different vegetation types in the Athabasca Oil Sands*. Submitted to Plant and Soil.

Das Gupta S., M.D. MacKenzie and S.A. Quideau. 2014. *Aboveground and belowground patterns in pyrogenic boreal aspen ecosystems: what governs nutrient availability?* Alberta Soil Science Workshop, Calgary, AB, Feb. 12-24, 2014.

Das Gupta S., M.D. Mackenzie and S.A. Quideau. 2014. *Aboveground and belowground patterns in pyrogenic boreal aspen ecosystems: what governs nutrient availability?* 20th World Congress of Soil Science, Jeju, South Korea, June 8-13, 2014.

Das Gupta S., M.D. MacKenzie and S.A. Quideau. 2014. *Aboveground and belowground patterns in pyrogenic boreal aspen ecosystems: what governs nutrient availability?* Soil Science Society of America Meetings, Long Beach, CA, Nov. 2-5, 2014.

Das Gupta, S., M.D. Mackenzie and S.A. Quideau. 2014. *Using spatial ecology to examine above and belowground interactions on a reclaimed aspen stand in Northern Alberta*. Submitted to Geoderma.

Laidlaw, M, C. Prescott and S. Grayston. 2014. *The development of soil structure under three vegetation treatments in reclaimed Oil Sands sites*. Canadian Soil Science Society Annual Meetings, Banff, AB. May 4-8, 2014.

Masse J., S. Grayston, C. Prescott and S.A. Quideau. 2014. *Restoring the nitrogen cycle in the boreal forest - a case study from Northern Alberta*. European Geosciences Union General Assembly, Vienna, Austria, April 27 to May 2, 2014.

Masse J., S. Grayston, C. Prescott, S.A. Quideau, and C. Müller. 2014. *Restoring the nitrogen cycle in the boreal forest - a case study from Northern Alberta*. Canadian Soil Science Society Annual Meetings, Banff, AB, May 4-8, 2014.

Masse, J. 2014. *Sneak peek at nitrogen fluxes in restored oil sands soils*. Belowground Ecosystem Group Mini-Symposium, UBC, Vancouver, BC, October 2014.

Norris C.E. and S.A. Quideau. 2014. *Vegetation influence on soil microbial community structure in the western boreal forest*. Canadian Soil Science Society Annual Meetings, Banff, AB, May 4-8, 2014.

Welegedara, N.P.Y., R.F. Grant, S.A. Quideau and E. Lloret. 2014. *Modelling effects of cover material and cover depth on hydrological regime in reclaimed oil sand landscapes in northern Alberta*. American Geophysical Union Fall Meeting, San Francisco, CA, Dec. 14–19, 2014.

## 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	Degree	Start Date	Completion Date
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	Ph.D.	January 2009	September 2013
Jill Martin	University of Alberta	M.Sc.	September 2010	Ongoing
Emily Lloret	University of Alberta	PDF	April 2011	August 2013
Sanatan Das Gupta	University of Alberta	Ph.D.	June 2011	Ongoing
Jacynthe Masse	University of British Columbia	Ph.D.	September 2011	Ongoing
Jeff Anderson	University of British Columbia	M.Sc.	September 2011	April 2014
Meghan Laidlaw	University of British Columbia	M.Sc.	September 2012	Ongoing
Mathew Swallow	University of Alberta	PDF	September 2012	August 2014
Nilusha Welegedara	University of Alberta	Ph.D.	January 2013	Ongoing

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

# Salt Migration and Salinity Exposure to Plants in Reclamation

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0132

**Academic Institution:** University of Alberta

**Industry Champion:** Total E&P Canada Ltd.

## PROJECT SUMMARY

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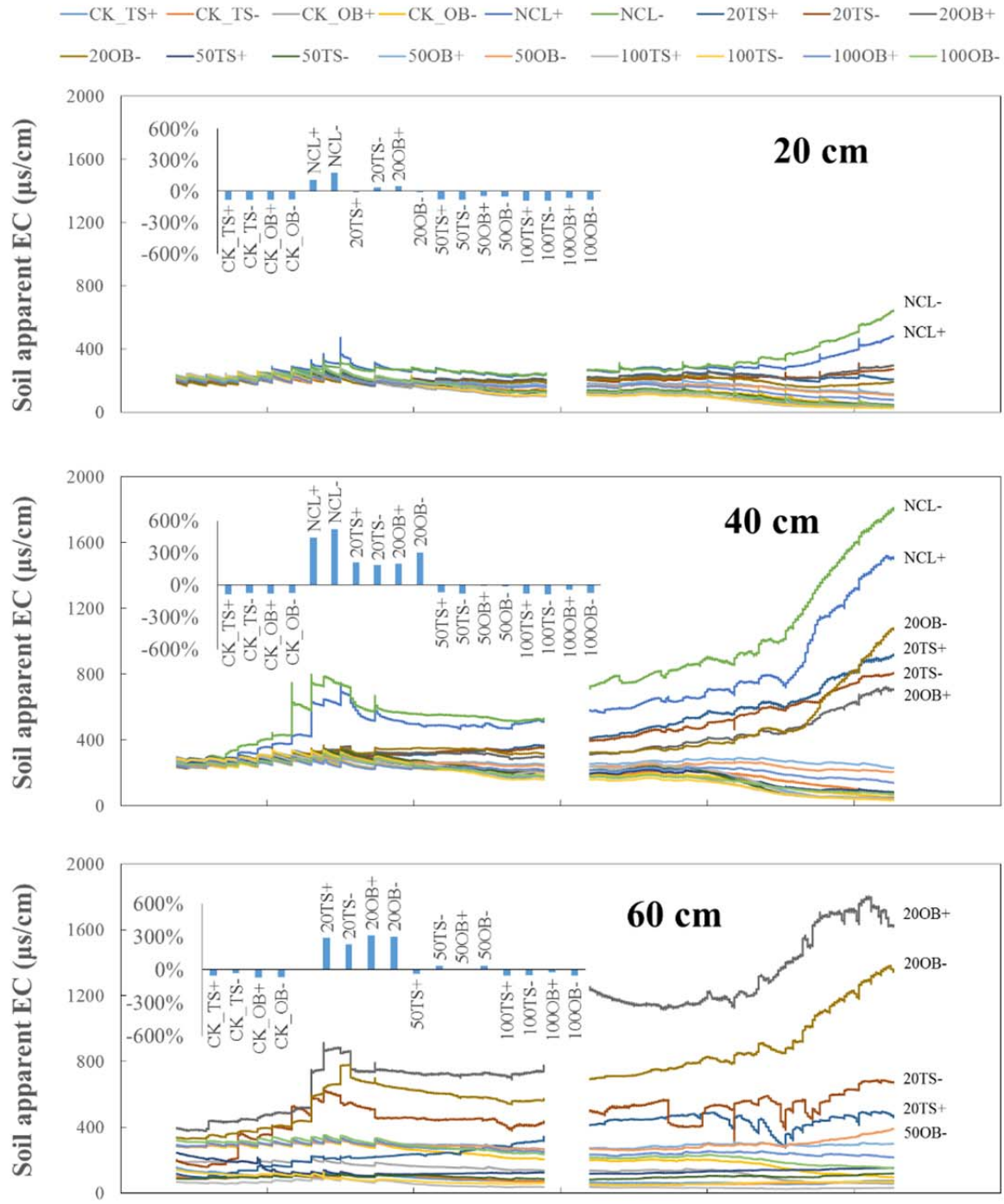
Soil salinity is one of the major issues that can substantially impact the success of oil sands reclamation. Government policy and regulation have proposed two avoidance mechanisms to deal with salts: 1) adapt appropriate landform design that channels all drainage to one location on lease and then deal with salinity at that point; or 2) adapt appropriate capping strategy that provides adequate barrier between tailings/salt affected materials and rooting zone. Salts, which come from a variety of oil sands mining-related sources, can migrate with water within the reclaimed soil depending on the local and regional hydrology and the water balance of a site. Understanding salt migration in capping materials of different texture, under different climatic conditions/water balance scenarios, and with different capping depths will be critical for guiding the reclamation of saline soils. The objectives of this project are to examine the potential pathway of salt migration into the rooting zone to affect plants and address three key questions: 1) how does the texture of common fill (capping) affect salt movement? 2) how does water balance affect salt movement in reconstructed soil profiles? and 3) will a thicker soil capping depth minimize salt intrusion into the rooting zone? This work is largely a laboratory and greenhouse based study, which is the first step in addressing soil salinity issues in oil sands reclamation. This study can be followed by a field-based program and a modelling approach to better understand factors affecting salt migration. Results from this study will provide guidance for preventing salinization in soil profile reconstruction in oil sands reclamation in the future.

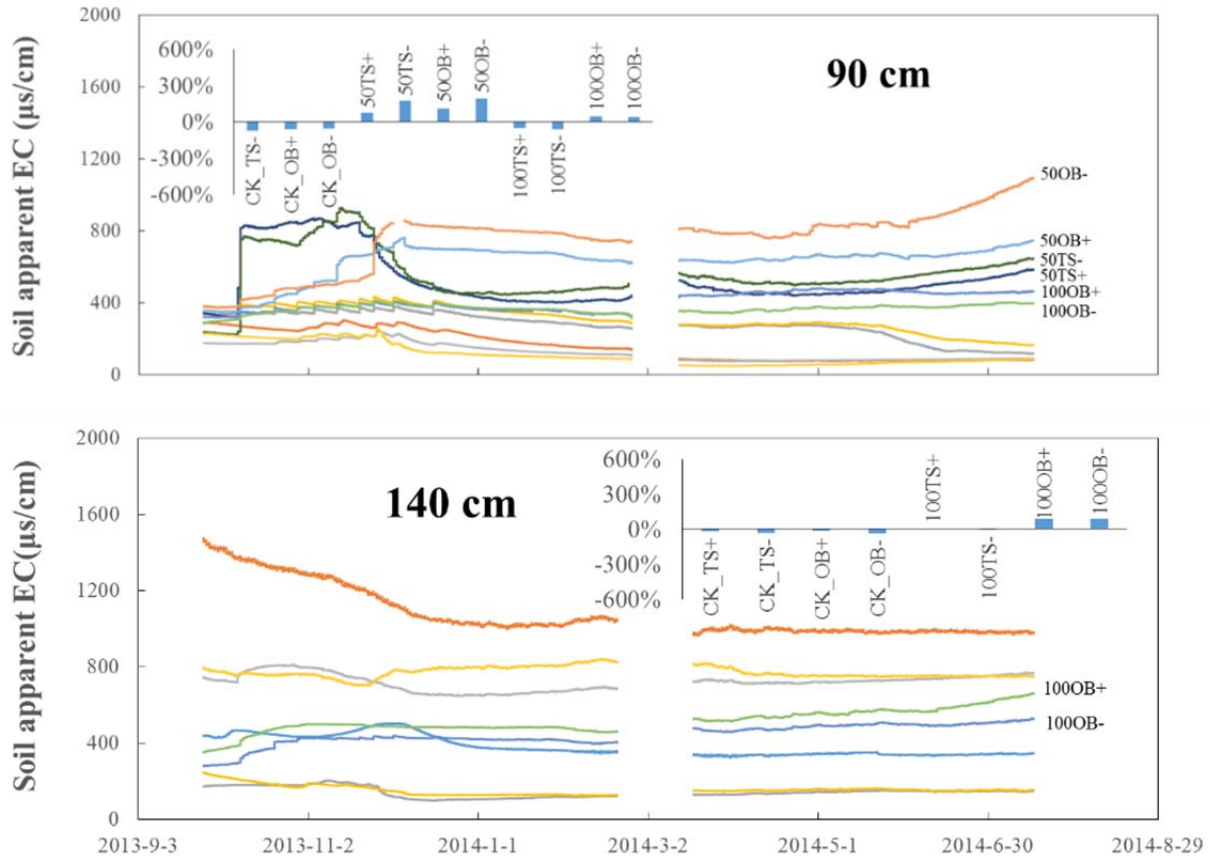
## PROGRESS AND ACHIEVEMENTS

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Soil salinity was recorded by the GS3 probes as soil apparent EC ( $EC_a$ ), which is considered to be strongly related to soil total dissolved solids (TDS), and EC of saturated paste extraction ( $EC_e$ ).

After nine months of operation, clear salinization trends have already been shown in the cover soil (PMM) and capping (TS or OB) layers in some treatments, especially at 40 and 60 cm below the surface of the column (Fig. 1).





**Fig. 1. Temporal variations of soil apparent EC in the cover soil (20 and 40 cm depth) and capping (60, 90, and 140 cm depth) layers under different treatments. The inserts describe the changes as compared to the initial values (October, 2013 – July, 2014)**

Surface (20 cm below the soil surface) and subsurface (40 cm) cover soils generally exhibited similar salinization trends under the various treatments, except that the salinization progressed faster in the subsurface cover soil layer. In the surface cover soil layer, the salinity levels in the profiles without a capping layer (NCL+ and NCL-) not surprisingly had the largest increase, in which soil  $EC_a$  was more than doubled from the initial condition. This was probably due to their shallowest saline water table among all the treatments, in which salt from the saline groundwater can easily get into the cover soil through capillarity. In all treatments without capping material or with a thin layer of capping material (i.e., NCL+, NCL-, 20TS+, 20TS-, 20OB+, 20OB-), soil salinity distinctly increased especially in the second growth period (April to July, 2014). Subsurface cover soils generally showed greater salt accumulation than surface cover soils, when there was no or a thin layer of capping material. Soil  $EC_a$  in the NCL-treatment was 5 times that of the initial  $EC_a$ . This result indicates that if the cover soil is directly placed above a saline groundwater, there will be an immediate salinity risk to the plants.

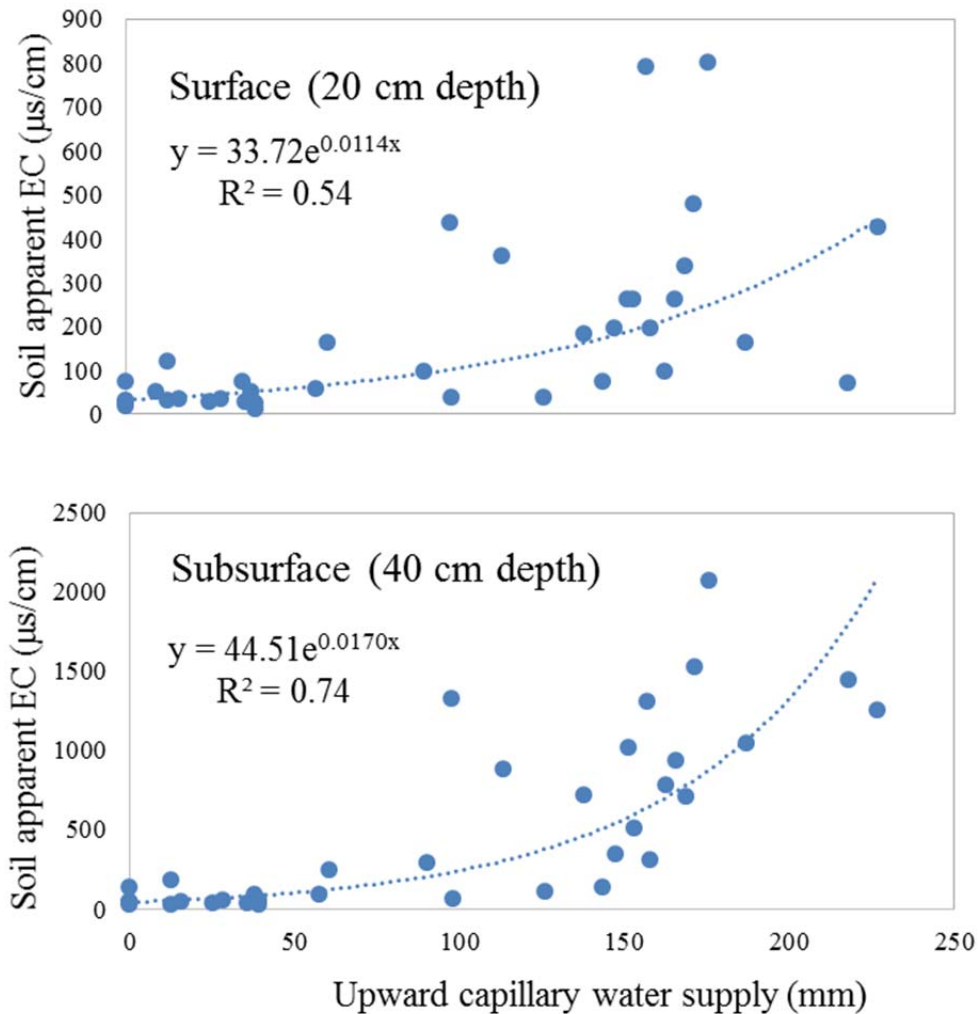
The capping layer is a barrier between the cover soil (rooting zone) and the saline groundwater. The salinity level in the capping layer could eventually influence the salinity level in the cover soil in the long term. In this study, soil salinity in the capping materials below the cover soil-capping material interface (60 cm depth) increased over time in some treatments, similar to that in the subsurface cover soil layer (40 cm depth). At the 60 and 90 cm depths, salinization developed faster in the OB than in the TS material. However, when the capping layer became thicker (100 cm), the unsaturated soil was not easily influenced by the underlying saline groundwater because of a weaker substance exchange between them, as the results at the 140 cm depth have shown.

#### **Treatment effects on capillarity, rooting zone salinity, and plant growth**

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The treatment effects on amount of upward capillary water movement (April to July 2014) and cover soil layer salinity (October 2013 to July 2014) were analyzed using Duncan's multiple range test and Classification and Regression Tree (CART). CART is a data mining method, which divides the dataset using recursive binary partition and displays data in a tree-shaped visual diagram. In the diagram, the hierarchical interaction of the variables and the importance of the factors can be easily ranked.

Upward movement of salt with capillary water has been considered an important cause to the development of rooting zone salinity. In this research, we maintained the saline groundwater level and recorded the amount of saline water added to each column. The amount of saline water added should generally equal to the net upward capillary water amount (gross capillary water - deep percolation), which indicates the intensity of capillarity. Relationships between salinity in the cover soil layer (rooting zone) and the amount of saline water added are shown in Fig. 2. According to the data between April and July 2014, the relationships were better fitted exponentially rather than linearly, and this trend was more pronounced in subsurface than in surface cover soils. This indicates that salinization in reclaimed soils could develop quickly if the reconstructed profile was not properly designed. However, whether such relationships are temporary is unknown, and longer term experiments are needed to investigate the long-term impact of the studied treatments on soil salinity.

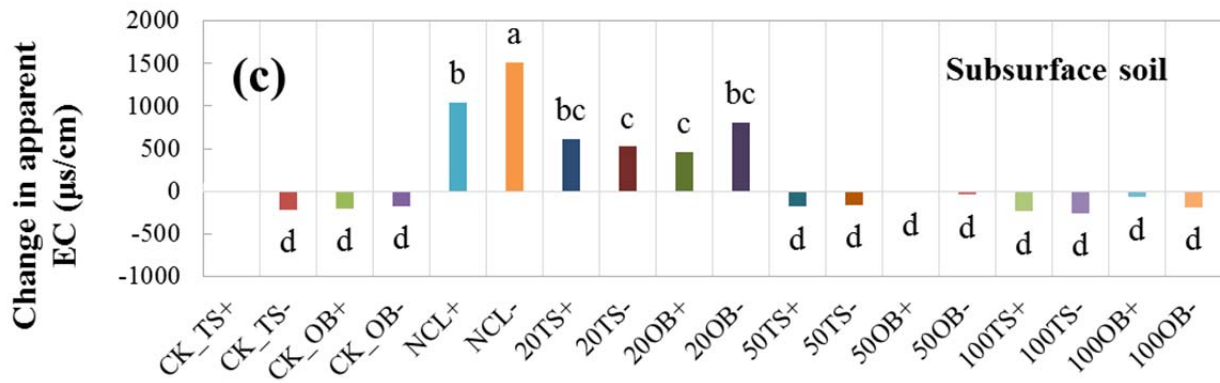
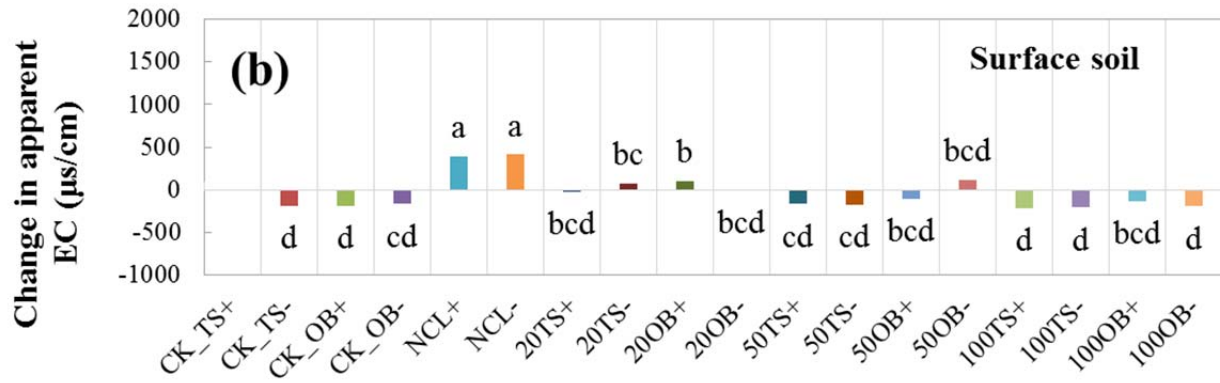
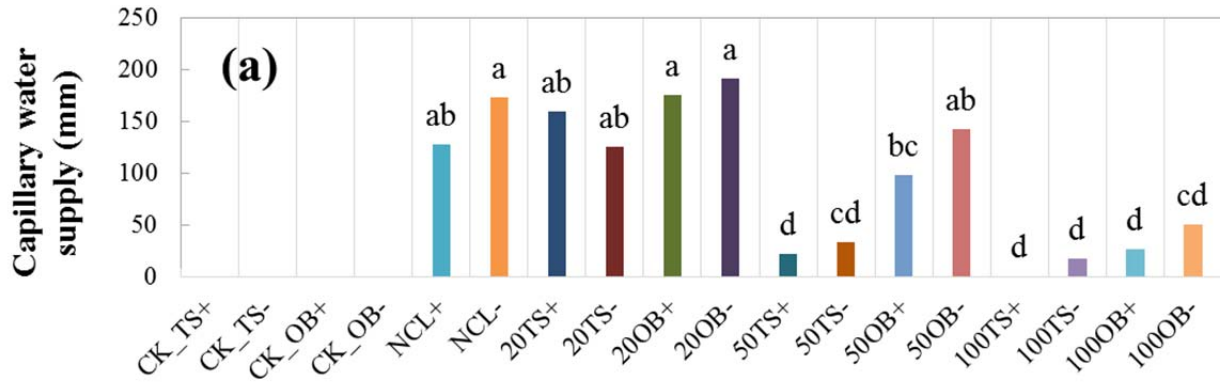


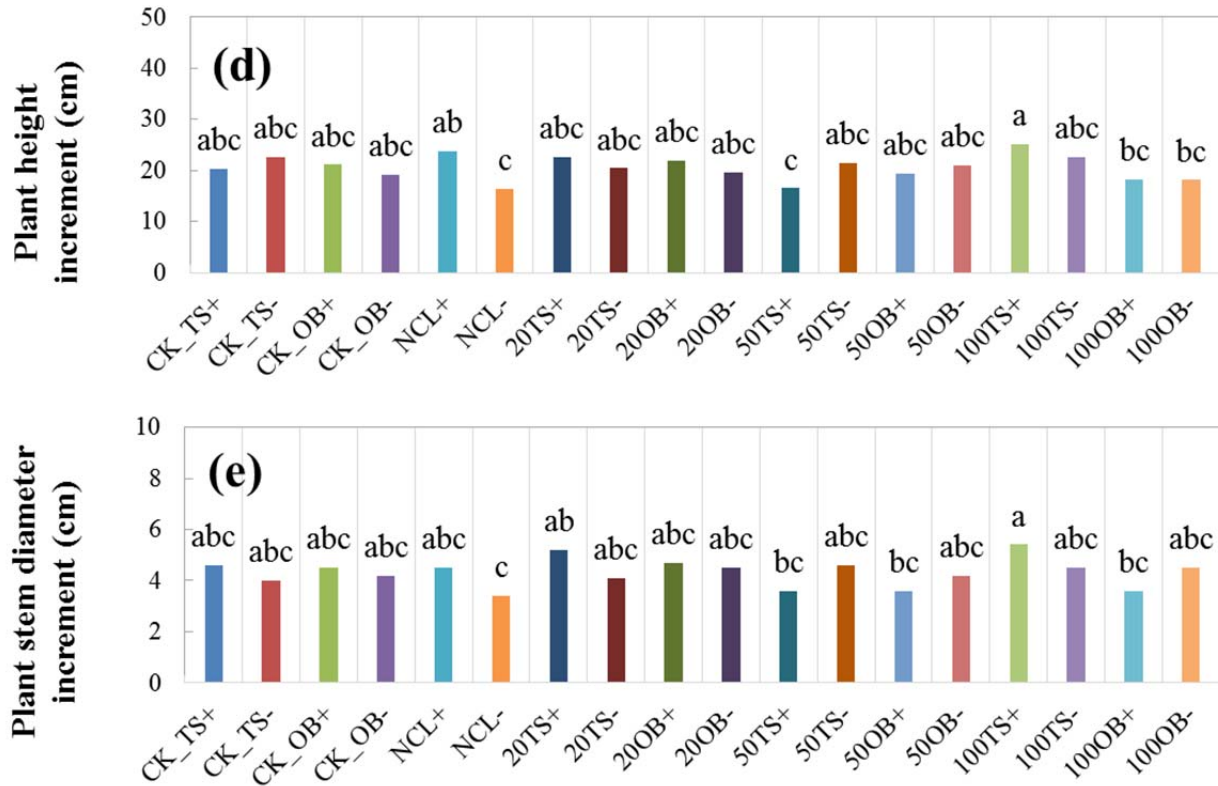
**Fig. 2. Relationships between cover soil salinity and upward capillary water supply from saline groundwater (April - July 2014)**

The largest net upward capillary water supply was found in soil profiles with thin OB capping material (20OB+ and 20OB-), and strong capillary effects also existed in no capping layer (NCL+ and NCL-) and thin TS (20TS+ and 20TS-) treatments (Fig. 3a). The intensive upward movement of saline groundwater means that the potential risk of rooting zone salinization is high. Although it has not affected the salinity in the cover soil layer, it is possible to have it salinized in the longer term. According to the CART result (Fig. 4a), the most significant factor influencing upward capillary water movement was capping thickness (as the root node). The critical thickness for effectively reducing upward capillary water was between 20 and 50 cm. Over the critical thickness, upward movement of saline groundwater through capillarity could be reduced by as much as 73% (162 vs 44 mm), regardless of the type of capping material used and the amount of precipitation (irrigation). However, it doesn't mean the capillary connections in the thick capping treatments were all cut off. There was still significant upward capillary water movement (115.6 mm) even with as much as 1 m of OB capping material (Node 12, Fig. 5a), indicating that the OB material had a strong capillary effect and a large capillary fringe. The water balance treatment did not cause statistically significant differences in the upward movement of capillary water, although less irrigated treatments generally had more upward capillary water supply (Fig. 3a).

The CART results indicate that capping thickness was the most important factor influencing salt migration into both surface and subsurface cover soil layers (as the root nodes) (Fig. 4b and c). Without a capping layer, the surface cover soil tended to accumulate salt; and similarly, with a thin layer of capping material (20 cm), the subsurface cover soil could also have serious salinity problems based on the short-term results from this study. Based on the current data, the critical capping thickness for effectively minimizing salt intrusion into the rooting zone was between 20 cm and 50 cm, which is consistent with the critical thickness for reducing upward capillary water supply. We noticed that when OB was used as the capping material the cover soil was more easily developed salinity in the thin capping treatments and more difficult to be desalinized in the thick capping treatments than when TS was used (Fig. 3b and c). Also considering the intensive capillarity in OB, the capping thickness should be large to minimize the risk of salt intrusion into the cover soil when it is used as the capping material. Water balance treatments have not shown significant effects on surface soil salinization, but it did begin to affect soil salinity in subsurface soils especially in the treatments with no capping (Fig. 3c). We expect that the water balance effect on soil salinity will develop over the longer term.

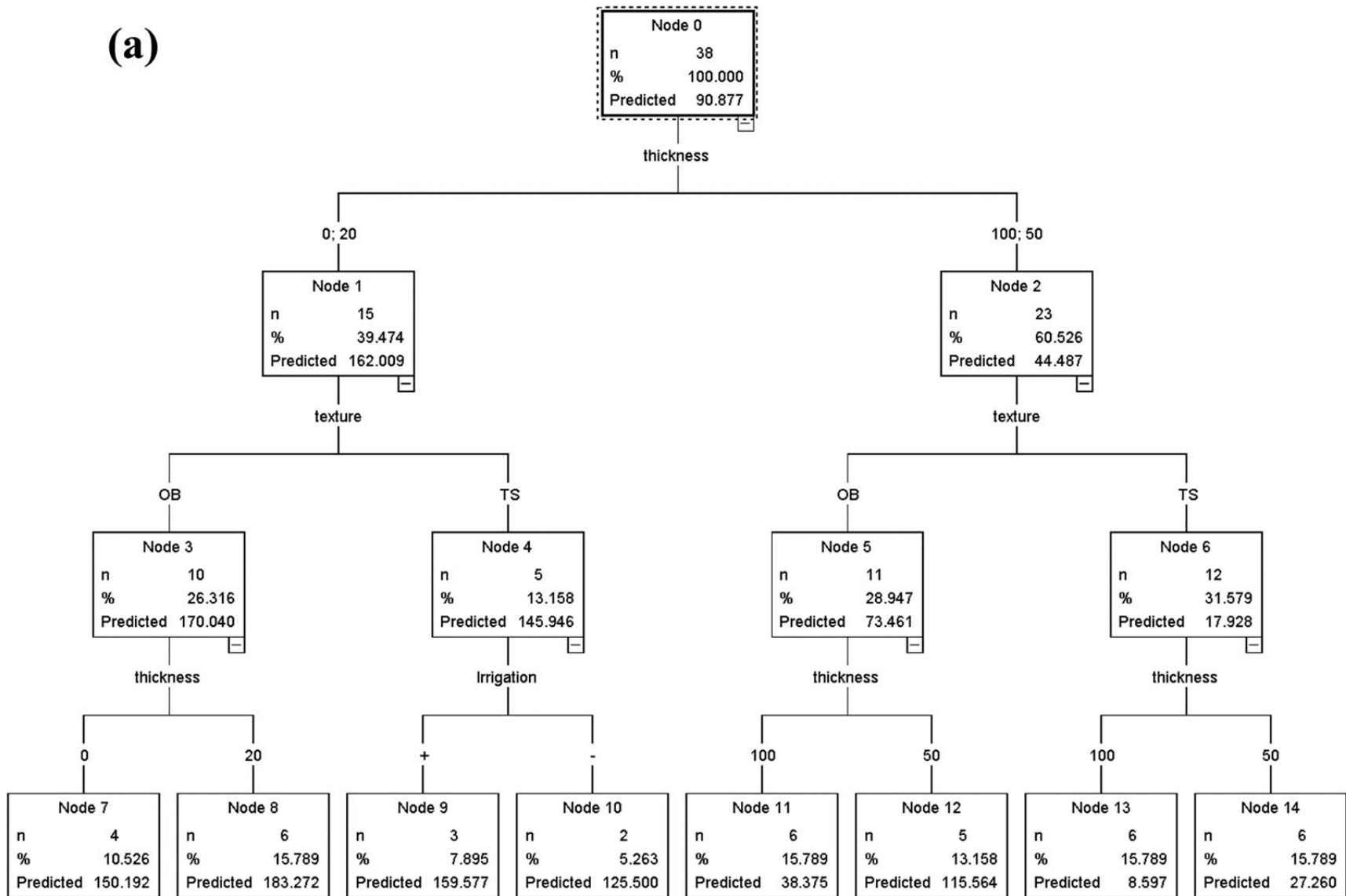
We also compared plant growth (height and stem diameter increment) among treatments (Fig. 3d and e). There were no statistically significant differences among the treatments. We also expect the treatment effects on plant growth to develop over the longer term. The differentiation in plant growth responses among the treatments should corroborate the results from the soil salinity study and should assist in our decision making in selecting the best capping thickness and capping material.



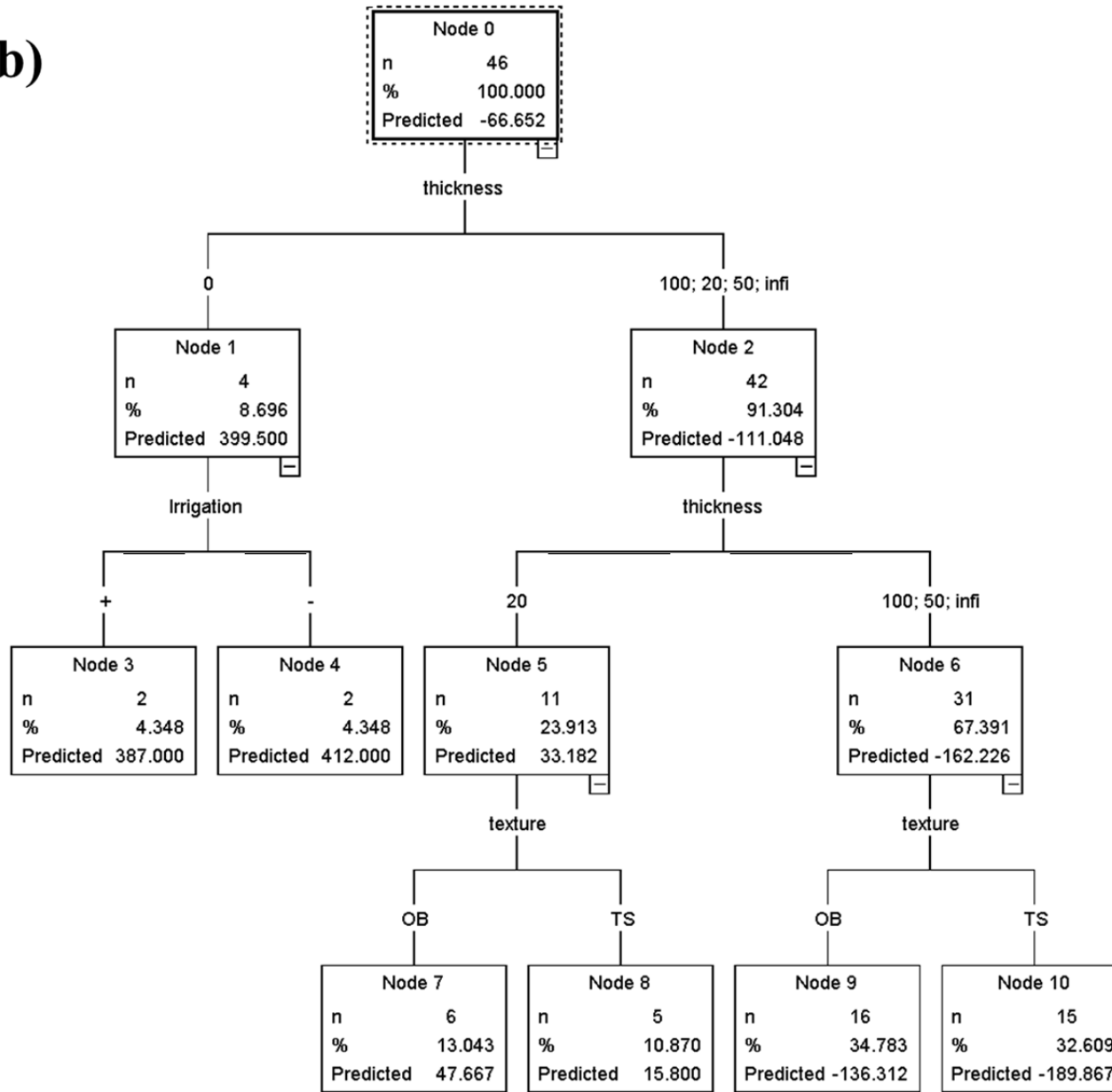


**Fig. 3. Treatment effects on upward capillary water movement, changes in apparent EC in the cover soil, and plant increment. Analyzed by Duncan's multiple range test. Different lowercase letters in the same histogram indicate significant difference ( $P < 0.01$ ). Upward capillary water movement data was from April to July 2014, and plant growth data was from October 2013 to May 2014.**

(a)



(b)



(c)

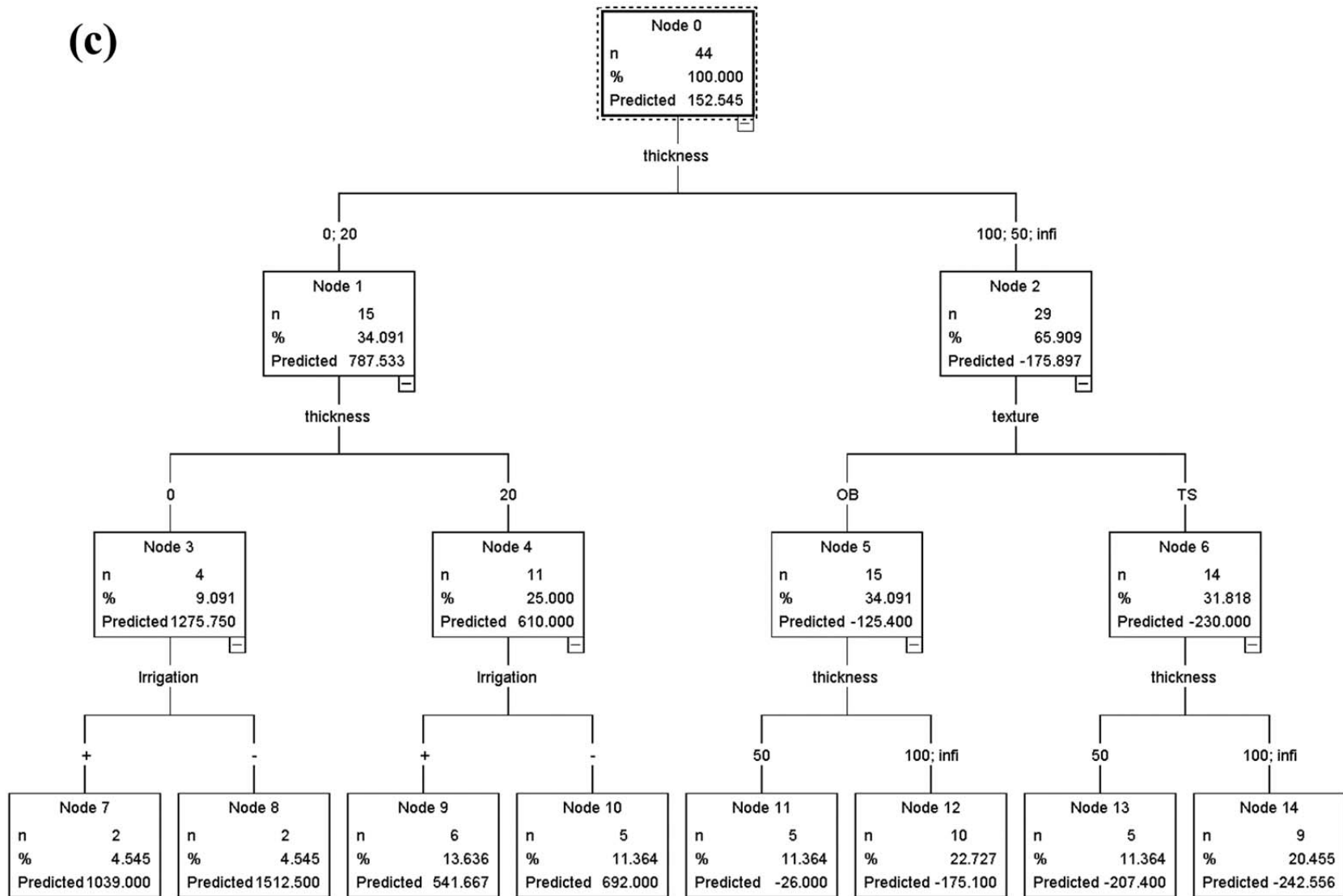


Fig. 4. Classification tree analysis of the treatments on capillary water supply and nutrient layer salinization. a) The classification tree model of upward capillary water supply (mm), b) the classification tree model of  $EC_a$  ( $\mu S/cm$ ) change in surface cover soil, and c) the classification tree model of  $EC_a$  ( $\mu S/cm$ ) change in subsurface cover soil.

## OUTCOMES AND LESSONS LEARNED

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- Capping thickness is the most important factor for soil salinization, and it can affect cover soil salinity in a short period. When OB is used as the capping material, the cover soil is more easily salinized than when TS is used. Water balance only began to affect cover soil salinity.
- Upward capillary water supply from the saline groundwater has strong relationship with cover soil salinity. A critical capping thickness for effectively reducing capillarity and minimizing salt intrusion into the rooting zone was found between 20 cm and 50 cm.
- The result shows its necessity of a longer term research. In a longer term experiment, more treatment effects on cover soil salinity and the direct responses of plants to salinity stress will be observed; and the relationship between soil water dynamic and cover soil salinity will be more clearly understood.

## PRESENTATIONS AND PUBLICATIONS

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Li, X.P., S.X. Chang and F. Salifu. 2014. *Soil texture and layering effects on water and salt dynamics in the presence of a water table: a review*. Environmental Reviews. 22: 41-50.

Li, X.P., S.X. Chang, K.F. Salifu, B. Drozdowski and M. Duan. 2014. *Salt migration and salinity exposure to plants in reclamation*. Canadian Society of Soil Science Annual Meeting, Banff, AB, May 4-8, 2014.

Li, X.P., S.X. Chang, K.F. Salifu, B. Drozdowski and M. Duan. 2014. *Salt migration and salinity exposure to plants in reclamation*. World Congress of Soil Science, Jeju, Korea, June 8-13, 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Scott Chang

Name	Institution	Degree	Start Date	Completion Date
Xiaopeng Li	University of Alberta	Postdoc	October 2012	October 2014
Min Duan	University of Alberta	Ph.D. student	January 2013	October 2014
Bin Ma	University of Alberta	Postdoc	September 2014	September 2015
Bonnie Drozdowski	Alberta Innovates-Technology Futures	Researcher	October 2012	September 2015

Industry Collaborators: None

# Revegetation

# Environmental Influences of Salinity Resistance in Forest Plants

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0133

**Academic Institution:** University of Alberta

**Industry Champion:** Total E&P Canada Ltd.

## PROJECT SUMMARY

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Oil sand's mining involves a complete removal and reconstruction of landforms in sensitive boreal ecosystems in northeastern Alberta. Land reclamation and revegetation efforts following oil sands mining are challenging due to the severity of land disturbance and the properties of oil sands tailings. It is hypothesized that soils in many reclamation areas could be affected by high pH, limited nutrient supply, hypoxia, and elevated salt levels.

Some boreal plants are known to be sensitive to salt; however, it is unclear how they respond to salinity in the presence of other unfavorable soil factors which often accompany salinity in reclamation sites. This information is essential to ensure successful revegetation of oil sands mining areas. It is also important to develop understanding of the processes contributing to plant recovery from salt stress and learn how to recognize the critical stages beyond which severe injury is irreversible and vegetation survival is threatened.

In the present project, we examine the effects of root zone pH, soil oxygen availability and mineral nutrition on salt resistance and sodium uptake in important oil sands reclamation tree species. We also study the processes of recovery from salt exposure and determine whether tissue sodium concentration could be used as a more reliable parameter than soil salinity level for monitoring and predicting salinity effects on vegetation. Since salt avoidance and salt sequestration are the most effective salt tolerance mechanisms in plants, the expected consequences of increased sodium uptake include significant increases in mortality and decreases in growth rates of reclamation plants. It has been well documented that salt injury is triggered once sodium levels in shoots reach a certain threshold level. Therefore, if elevated tissue sodium levels are found to correlate with plant injury and mortality, they could be used as a more effective monitoring tool for mitigation and management of salinity-affected sites than the soil salinity data alone. Since plant responses to tissue sodium accumulation may be influenced by site conditions, it is necessary to examine how environmental factors such as soil pH, hypoxia, and mineral nutrition affect this relationship.

The principal objective of the present study is to generate fundamental knowledge which is required to develop protocols for successful reclamation of oil sand areas affected by salinity that is accompanied by other unfavorable soil factors. The knowledge generated by this project will also help improve basic understanding of the processes which plants use to resist these detrimental soil factors. The study will examine the following hypotheses:

1. sodium tissue levels correlate with plant injury and mortality;
2. high and neutral pH aggravate the effects of salinity by increasing shoot sodium uptake and the magnitude of this effect varies between plant species;

3. elevated calcium levels reduce sodium uptake and alleviate salt effects in plants due to the stabilizing effect on root aquaporins, 4) Mineral deficiencies aggravate the effects of salt;
4. effective long-term recovery mechanisms in trees from salt stress include both Na<sup>+</sup> sequestration in vacuoles and leaf abscission by deciduous trees; and
5. hypoxia increases the apoplastic transport of water and ions in roots resulting in a greater uptake and accumulation of Na<sup>+</sup> in shoots and acceleration of salt injury.

## PROGRESS AND ACHIEVEMENTS

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- Experimental set ups were built and tested for Studies 1, 2, and 5.
- Experiments for Study 1 were carried out. In 2014, experiments were completed for aspen, green alder, jack pine, white spruce, balsam poplar and tamarack. Data collection was completed by December 2014 and included: net photosynthesis, transpiration, biomass, chlorophyll content and elemental analysis (chloride, nitrogen, sodium, macro- and microelements). Data analysis is in progress.
- The experiments for Study 5 were carried out with trembling aspen, white spruce and jack pine. The treatments included full (control) and reduced nutrient concentrations of nitrogen, phosphorus, potassium, manganese, and iron in plants subjected to 0 (control) and 60 mM NaCl. The measurements included gas exchange (photosynthesis and transpiration), leaf chlorophyll concentrations and different growth parameters. Data analysis is in progress.

## OUTCOMES AND LESSONS LEARNED

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Balsam poplar showed similar growth, photosynthetic and transpiration rates when grown at pH 5 and 7. However, over 20% mortality was observed in plants grown at pH 9. Surviving plants at pH 9 exhibited decreases in photosynthesis, transpiration, and growth rates. Balsam poplar was highly sensitive to NaCl treatment. Adding 60 mM NaCl caused 100% mortality in all pH treatments. At pH 5 and 7, 30 mM NaCl treatments induced 35% and 30% mortality, respectively. Surviving plants exhibited decreases in photosynthesis, transpiration and growth rates.

Tamarack grown in elevated NaCl and high pH exhibited decreases in growth rates, photosynthesis and transpiration. Both stresses caused increases in the root to shoot biomass ratio, which was also the trend exhibited by aspen and green alder. Interestingly, elevating the pH caused plants to be more sensitive to NaCl treatments as plants held at pH 7 and 9 + 30 mM NaCl had decreased growth, photosynthesis and transpiration rates compared to plants grown at pH 5 + 30 mM NaCl. However, tamarack appeared to be relatively tolerant to elevated pH and NaCl and 10% mortality was only observed in the pH 9 with 60 mM NaCl treatment.

In white spruce, elevated NaCl caused decreased photosynthesis and transpiration rates whereas elevated pH had little effect. A significant interaction was observed for total needle chlorophyll concentrations. Plants maintained at pH 5 and 7 with 60 mM NaCl exhibited significant decreases in chlorophyll concentrations compared to controls whereas plants maintained at pH 9 with 30 and 60 mM NaCl exhibited significant decreases. This suggests that plants maintained at pH 9 were more sensitive to NaCl stress compared to plants maintained at the lower pH. Interestingly, no differences were observed in the total biomass and shoot to root weight ratios between treatments. Furthermore, there was no seedling mortality during the duration of the experiment. These results are likely a reflection of the slow growth and high pH tolerance that are characteristic of white spruce.

In trembling aspen, both elevated pH and NaCl treatments caused significant decreases in whole plant photosynthetic rates. However, it appeared that whole plant transpiration was less sensitive to pH 7 treatment compared with photosynthesis. All treatments exhibited a significant decline in leaf chlorophyll concentrations compared to controls. Furthermore, a significant interaction between pH and salinity was detected. This suggests that both elevated pH and NaCl caused total chlorophyll content to decrease. A significant interaction between pH and salinity was detected for total biomass in aspen. No difference in biomass was detected between pH 5.0 mM and pH 7.0 mM. However, plants maintained at pH 9.0 mM exhibited a significant decline in total biomass as well as increased mortality, suggesting that elevated pH alone was sufficient to stunt plant growth and induce mortality.

The preliminary results of the completed mineral nutrition experiment confirm the sensitivity of trembling aspen seedlings to salinity. However, no significant negative effects were observed in terms of growth and gas exchange when salt treatments were accompanied by the reduced nitrogen, potassium, iron, manganese and phosphorus nutrition.

## PRESENTATIONS AND PUBLICATIONS

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Lauer N. 2014. *Evaluating the tolerance of selected boreal forest trees to elevated pH and salinity*. REN R 480, University of Alberta, Edmonton, AB, Nov. 24, 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Janusz Zwiazek

Name	Institution	Degree	Start Date	Completion Date
Samantha Olivier	University of Alberta	Ph.D.	January 1, 2014	-
Nathan Lauer	University of Alberta	Ph.D.	September 1, 2013	-
M. Alejandra Equiza	University of Alberta	Ph.D.	September 1, 2013	-
Francis Salifu	TOTAL E&P Canada Ltd.	Ph.D.	September 1, 2013	November 30, 2014
Scott Chang	University of Alberta	Ph.D.	September 1, 2013	-

Industry Collaborators: None

# A Forest Fertilization Trial in a Mildred Lake Jack Pine Stand

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0209

**Academic Institution:** University of British Columbia

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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This study includes application of fertilization in a controlled experiment in a reclaimed 19-year old (at start of study) jack pine stand that has reached canopy closure. The soil cover design is a single strip salvage of peat and underlying fine textured mineral material and a single strip of placement at a 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 composition. Results from this study were used to design fertilizer treatments for the main study. Fertilizer treatments included NPS and NPKS + Cu and Mg micronutrients. 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 block 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 tree growth and measurable soil parameters. A journal article highlighting correlations between organic matter and closely associated soil properties with tree growth (Farnden et al. 2013) has been produced.

## PROGRESS AND ACHIEVEMENTS

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

## DELIVERABLES AND MILESTONES

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This project is entering year five of five.

## OUTCOMES AND LESSONS LEARNED

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The screening trial indicating a likely growth response to a combination of N, P and S based on first year foliar mass increases. Results from the main trial are not yet published.

The additional trial that was imposed 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.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of British Columbia

Principal Investigator: Bruce Larson

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

Industry Collaborators: None

## LITERATURE CITED

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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.

# Improving Seed Longevity of Native Shrubs During Storage for Reclamation of Oil Sands Mines

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0195

**Academic Institution:** University of Saskatchewan

**Industry Champion:** Shell Canada Energy

## PROJECT SUMMARY

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Native shrub species are an important component of boreal forests. For successful reclamation, a steady and predictable supply of seeds of native shrubs is needed. However, native shrubs seed set is unpredictable and seeds lose viability rapidly after harvest. The objective of this research is to identify optimal storage conditions so a steady supply of shrub seeds for reclamation would be possible. Specific objectives are to:

- study the effects of pre-storage treatments and storage conditions on seed viability, germinability and seedling vigour of selected species;
- predict viability loss using seed longevity models; and
- understand the biochemical and molecular basis of seed aging.

Eleven native shrub species including *Vaccinium myrtilloides*, *Vaccinium vitis-idaea*, *Amelanchier alnifolia*, *Shepherdia canadensis*, *Cornus sericea* ssp. *sericea*, *Alnus viridis* ssp. *crispa*, *Viburnum edule*, *Prunus pensylvanica*, *Rosa woodsii*, *Arctostaphylos uva-ursi*, and *Prunus virginiana* were selected.

Seed longevity varied greatly among species and collections. Because of the deep dormancy in most of these species, sustaining seed longevity is possible given appropriate storage conditions. High seed moisture content during seed storage can cause rapid loss of viability during storage. Seed viability did not change significantly between seed moisture content within the range of 3% to 8% during storage up to three years, indicating seed viability of these species can be sustained if they are sufficiently dried before storage. In some species/collections, however, lower seed moisture content benefited seed quality. Seeds stored in N<sub>2</sub> did not seem to affect seed viability but more data are needed for a definite conclusion. There was a trend that N<sub>2</sub> gas reduced seed deterioration at high storage temperature but reduced seedling vigour in some species/collections. The negative effect of room temperature (22.5°C) compared to sub-zero temperature was reflected in decreased final germination percentage before a reduction in viability could be detected. Rapid loss in seed viability after artificial ageing was detected in germination percentage and leakage but less reliable by Tetrazolium tests. Late Embryogenesis Abundant proteins increased with aging and the detection of which using western blot was more effective than Sodium Dodecyl Sulfate - Polyacrylamide Gel Electrophoresis.

## DELIVERABLES AND MILESTONES

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Ms. Y Wang will defend her M.Sc. thesis in February 2015.

## OUTCOMES AND LESSONS LEARNED

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- Seed dormancy breaking treatments vary among species and collections, and may be different from those reported in literature. New information was submitted to COSIA for the update of species factsheets.
- Be cautious when using TZ for seed viability tests of rapidly aged seeds because viability may be overestimated.

## PRESENTATIONS AND PUBLICATIONS

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Wang, Y., Y. Wei, Y. Bai and R. Chibbar. 2014. *Application of artificial aging techniques on shrub seeds*. The 11th ISSS Conference on Seed Biology, Changsha, China, September 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Saskatchewan

Principal Investigator: Yuguang Bai

Name	Institution	Degree	Start Date	Completion Date
Yimeng Wang	University of Saskatchewan	M.Sc.	September 2010	Defence on February 12, 2015
Yongsheng Wei	University of Saskatchewan	PDF	January 2010	In progress
Lixue Wang	China Agricultural University	Visiting Ph.D. Student	November 2010	November 2011
Jushan Liu	NE Normal University	Visiting Ph.D. Student	June 2010	July 2011
Maya Zhang	University of Saskatchewan	Research Assistant	January 2011	August 2011
Rashim Bibi	University of Saskatchewan	Research Assistant	January 2012	In progress
Nicolas Poulin	University of Saskatchewan	Summer Student	May 2012	August 2012
Fengqin Jia	Yili Normal Univ.	Visiting Ph.D. Student	January 2013	December 2013
Tao Liu	University of Saskatchewan	Research Assistant	September 2013	December 2013
Marika Cameron	University of Saskatchewan	Summer Student	September 2014	In progress

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

# Industrial Research Chair in Forest Land Reclamation

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**Project Type:** EPA led Study

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LE0012

**Academic Institution:** University of Alberta

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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Resource extraction is a major component of the Albertan and Canadian economy but the associated surface mining severely disrupts forest ecosystems, especially in the Western Boreal Forest. The pressing objective of 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 the rapid re-development of a tree canopy to create conditions that initiate and sustain abiotic and biotic processes characteristic of a functioning forest ecosystem.

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 which hastened the development of a closed tree canopy. Building on this, the renewal IRC program proposes to examine critical issues related to growth constraints, such as limited soil nutrients and high competition, during stand initiation and development. In addition, it will explore the use of different topographical features to promote more spatially diverse site conditions resulting in more diverse plant communities.

To provide the 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
- development and testing of planning tools.

## PROGRESS AND ACHIEVEMENTS

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- **Accelerating forest establishment:** To expedite initial forest establishment (stand initiation and early growth), the IRC program will investigate 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.
  - We developed new aspen seedlings stocktypes for competitive sites (grass) and are currently testing them in the field. A M.Sc. student (Kyle Le) has been recruited to execute the study. A large scale field study at Highvale (TransAlta) is currently being setup to test the arrangement and usage of different amendments for successful tree establishment on nutrient-limited sites. The process of recruitment of one or two graduate students (M.Sc.) for these projects is underway. A second large scale study to test the feasibility of enhanced meso- and micro-topography for vegetation and seedling establishment is currently being established at Shell's oil sands mine. One M.Sc. student (Kate Melnik) has been recruited to explore the vegetation response while another M.Sc. student will explore the seedling performance in relation to topographical position on these sites. The preliminary work to determine if a study to test the effectiveness of specific formulated fertilizers for specific site conditions could be developed has been completed (M.Sc. Jana Bockstette) and a study to explore these applications will be developed.
- **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 are dominated by undesirable species impacting stand development. The renewed IRC program will explore stand management strategies (e.g., intervention practices) that could facilitate and improve forest canopy and understory development in older reclamation sites.
  - Parts of these studies will be setup in the 2015 field season. Older reclamation sites will be selected to explore different vegetation management approaches to accelerate these reclamation areas to more closed canopy conditions. A M.Sc. (Carolyn King) and a Ph.D. student (Morgane Merlin) have been recruited for these studies. Another study is currently being executed (M.Sc. Caren Jones) that explores the influence of overstorey plants on the early developmental trajectories of understory plant communities. 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, and soil development and soil-water availability of these reclaimed forests. The renewal of the IRC will explore soil water availability and water-use as main drivers of forest stand performance on reclamation sites.
  - In a study that was established in the summer of 2014 (PDF Jeff Kelly) we explored the relationships between water use (sapflow) of aspen and spruce canopy trees and investigate how it is influenced by capping material thickness and rooting depth. This will be repeated in 2015 to get a more complete data set to correlate sapflow data with other climatic and edaphic data collected by Syncrude, other colleagues and their research groups on the same site. Morgane Merlin (Ph.D.) will also be involved in some of the water transport studies to explore water movement through aspen root sections.

## DELIVERABLES AND MILESTONES

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This project is in year one of five.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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Results from work completed under the first IRC have been included. Presentations and papers are not always solely related to the projects reported here; however, the chair position includes other research related to forest reclamation.

Bijman, A., S.E. Macdonald, S.M. Landhäusser and K. Pritsch. 2014. *Influence of Shelter on Germination of Native Grasses and Forbs*. 4th HAI Science Forum, Edmonton, AB, Sep. 29, 2014.

Bockstette, J and S.M. Landhäusser. 2014a. *Reforestation of mine spoils – biochar a soil amendment for land reclamation*. FILS, Edmonton, AB, March 2014.

Bockstette, J. and S.M. Landhäusser. 2014b. *Reclaiming mine sites with poor surface soils*. 4th HAI Science Forum, Edmonton, AB, Sep. 29, 2014.

Bockstette, S., S.M. Landhäusser, B.D. Pinno and M.F. Dyck. 2014a. *Mechanical alleviation of soil compaction – Impact on root distribution and growth performance of trembling aspen seedlings*. 4th HAI Science Forum, Edmonton, AB, Sep. 29, 2014.

Bockstette, S., S.M. Landhäusser, B.D. Pinno and M.F. Dyck. 2014b. *Ecophysiology of trembling aspen in response to root-zone conditions and competition on reclaimed mine soil*. American Geophysical Union, San Francisco, CA, December 2014.

Brown, S.M., R.M. Petrone, L. Chasmer, C.A. Mendoza, M.S. Lazerjan, S.M. Landhäusser, U. Silins, J. Leach and K.J. DeVito. 2014. *Atmospheric and soil moisture controls on evapotranspiration from above and within a Western Boreal Plain aspen forest*. Hydrological Processes 28: 4449-4462. (Imp Fact: 2.696).

Dyck, M.F., P. Sabbagh, S. Bockstette, S.M. Landhäusser and B.D. Pinno. 2014. *Improving root-zone soil properties for trembling aspen in a reconstructed mine-site soil*. American Geophysical Union San Francisco, CA, December 2014.

Gaster, J.R.E., J. Karst and S.M. Landhäusser. 2014. *Carbon and nutrient dynamics underlying interactions between aspen and ectomycorrhizal fungi*. Peter Biology Conference, Edmonton, AB, February 2014.

Hankin, S., J. Karst and S.M. Landhäusser. 2014a. *Impact of capping material selection on the recovery of ectomycorrhizal fungi and seedling growth of forest reclamation sites*. RE Peter Biology Conference, Edmonton, AB, February 2014.

Hankin, S., J. Karst and S.M. Landhäusser. 2014b. *Ectomycorrhizal fungal inoculum potential of surface reclamation materials in oil sands mining*. Ecological Society of America AGM, Sacramento, CA, August 2014.

Hoffman, E., S.M. Landhäusser and S.M. Macdonald. 2014. *Weed population dynamics in response to donor materials from different forest ecosites*. FILS, Edmonton, AB, March 2014.

Hupperts, S., J. Karst and S.M. Landhäusser. 2014. *Role of ectomycorrhizal fungi in forest restoration following oil sands reclamation*. R.E. Peter Biology Conference, Edmonton, AB, February, 2014.

- Karst, J. and S.M. Landhäusser. 2014. *Low soil temperatures increase carbon reserves in Picea mariana and Pinus contorta*. Annals of Forest Science 71: 371-380. (Imp Fact: 1.536).
- Kelly, J., P. Chow and S.M. Landhäusser. 2014. *Nursery production of high quality aspen seedlings: Alternative techniques in the forest reclamation and restoration process*. Conference on Ecological and Ecosystem Restoration, New Orleans, LA, July 2013.
- Landhäusser, S.M. 2014. *Assessing and manipulating planting stock quality in Populus*. International Poplar Symposium VI (IPS VI) meeting, Vancouver, BC, July 2014.
- Landhäusser, S.M. 2014. *Fitness for purpose: Tree seedling quality in forest restoration*. Conference on Ecological and Ecosystem Restoration (CEER), New Orleans, LA, July 2014.
- Landhäusser, S.M. 2014. *Root system reserve status, a potential barometer of carbon limitations in trees?* European Geophysical Union General Assembly, Vienna, Austria, May 2014.
- Landhäusser, S.M. and E.T. Wiley. 2014. *Does NSC storage increase survival under herbivory?* Ecological Society of America, Sacramento, CA, August 2014.
- Mendoza, C., S. Carey, K. DeVito, S.M. Landhäusser and J-M. Longval. 2014. *Early water dynamics within a wetland complex constructed on tailings at an oil-sand mine*. Geological Society of America conference, Vancouver, BC, October 2014.
- Najar, A., S.M. Landhäusser, J.G.A. Whitehill, P. Bonello and N. Erbilgin. 2014. *Reserves accumulated in non-photosynthetic organs during the previous growing season drive plant defenses and growth in aspen in the subsequent growing season*. Journal of Chemical Ecology 40: 21-30. (Imp Fact: 2.239).
- Pinno, B.D., S.M. Landhäusser, P.S. Chow, S.A. Quideau and M.D. MacKenzie. 2014. *Nutrient uptake and growth of fireweed (Chamerion angustifolium) on reclamation soils*. Canadian Journal of Forest Research 44: 1-7. (Imp Fact: 1.657).
- Ramnarine, S., M.F. Dyck and S.M. Landhäusser. 2014. *Review of standard practices in Oil Sands Exploration (OSE) forest reclamation on coarse-textured soils*. FILS, Edmonton, AB, March 2014.
- Rogers, P.C., S.M. Landhäusser, B.D. Pinno and R.J. Ryel. 2014. *A functional framework for improved management of Western North American aspen (Populus tremuloides Michx.)*. Forest Science 60: 345-359. (Imp Fact: 1.523).
- Saunders, M., E. Belair, S. Clark, S.M. Landhäusser and M. Jenkins. 2014. *Fire ecology of American chestnut regeneration*. IUFRO World Forestry Congress, Salt Lake City, UT, October 2014.
- Schoonmaker, A.L., V.J. Lieffers and S.M. Landhäusser. 2014. *Uniform versus Asymmetric Shading Mediates Crown Recession in Conifers*. PLOS ONE Volume: 9 Issue: 8 Article Number: e104187 (Online only) (Imp Fact: 3.534).
- Schott, K.M., J. Karst and S.M. Landhäusser. 2014. *The role of microsite conditions in restoring trembling aspen (Populus tremuloides Michx) from seed*. Restoration Ecology 22: 292-295. (Imp Fact: 1.991).

Wachowski, J., S.M. Landhäusser and V.J. Lieffers. 2014. *Depth of root placement, root size and carbon reserves determine reproduction success of aspen root fragments*. Forest Ecology and Management 313: 83-90. (Imp Fact: 2.667).

Wiley, E.T., B. Rogers, R. Hodgkinson, P. Chow and S.M. Landhäusser. 2014. *Non-structural carbohydrate dynamics of dying lodgepole pines following mountain pine beetle attack*. Ecological Society of America AGM, Sacramento, CA, August 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution	Degree	Start Date	Completion Date
*Alexander Goeppel <sup>(a)</sup>	University of Alberta	M.Sc.	2012	2014
*Alia Snively <sup>(a)</sup>	University of Alberta	M.Sc.	2012	2014
*Shaun Kulbaba <sup>(a)</sup>	University of Alberta	M.Sc.	2012	2014
Jana Bockstette	University of Alberta	M.Sc.	2013	
Caren Jones	University of Alberta	M.Sc.	2013	
Kyle Le	University of Alberta	M.Sc.	2014	
Katherine Melnik	University of Alberta	M.Sc.	2014	
Jeff Kelly <sup>(a)</sup>	University of Alberta	PDF	2013	

<sup>(a)</sup> Students that were directly involved in previous IRC-related research.

Industry Collaborators: 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.

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0202

**Academic Institution:** Alberta-Pacific Forest Industries Inc.

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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The main objective of this research is to identify and select balsam poplar clones from the Alberta-Pacific 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 levels on reclaimed oil sands mine sites.

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

A total of 35 clones selected from AI-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% process affected water treatment and were chosen as the 'salt tolerant treatment group' and 10 of the remaining clones that did not exhibit salt tolerance were chosen as a control group.

Three discrete trials were established: one on the south shore of Base Mine Lake, one in the southeast corner of Sandhill Fen and one on sand islands "A" and "B" within Sandhill Fen. All three were laid out as a randomized block design with single tree plots. The first two of these trials utilize four ramets of each of 35 AI-Pac clones and 60 Syncrude control trees planted in three replicates (for a total of 200 trees in each replicate).

On the sand islands, there was one tree of each of the 35 AI-Pac clones and 25 Syncrude control trees planted in each of six replicates. Each replicate had a total of 60 trees (10 trees x 6 trees) with three replicates 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 Kingfisher Fen.

## PROGRESS AND ACHIEVEMENTS

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The initial controlled experiment was established on the south shore of Base Mine Lake and in Sandhill Fen in October, 2014.

## DELIVERABLES AND MILESTONES

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This project is in year one of five. An establishment report has been produced.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Alberta-Pacific Forest Industries Inc.

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

Industry Collaborators: None

## Native Plant Establishment

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0053

**Academic Institution:** Wild Rose Consulting, Inc.

**Industry Champion:** Imperial and Syncrude Canada Ltd.

### PROJECT SUMMARY

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In an ongoing effort to include native plants in revegetation efforts in oil sands reclamation, Wild Rose Consulting Inc. (WRC) was contracted in 2000 to study propagation and establishment of specific local plants on reclamation sites at Syncrude. The project was extended for a further four years in 2003 to allow the monitoring period of field trials to include at least five growing seasons and to add several new species in the project, particularly wetland plants that may be best established through vegetative means. In late 2006, the project was further refined and expanded with additional funds from the five other mining operators in the region. This allowed more rigorous testing of the potential of direct sowing as a means of establishment over a larger area and with many new species.

The primary objective was to determine the feasibility of establishing native plant species (from seed) on reclaimed sites in the oil sands disturbances of northeastern Alberta. Two seeding times (spring and fall) were compared and, for species that produce fleshy fruit, sowing cleaned seeds was compared with sowing intact whole fruit. A secondary goal was to provide pertinent harvest, seed cleaning, seed and fruit metrics, and cultural information that will facilitate the inclusion of these species in industrial revegetation operations.

List of Species under study:

• <i>Alnus viridis</i>	green alder	• <i>Lonicera caerulea</i>	blue fly honeysuckle
• <i>Alnus incana</i>	river alder	• <i>Maianthemum canadense</i>	wild lily-of-the-valley
• <i>Amelanchier alnifolia</i>	saskatoon berry	• <i>Mitella nuda</i>	bishop's cap
• <i>Anemone multifida</i>	cut-leaf anemone	• <i>Prunus pensylvanica</i>	pin cherry
• <i>Anemone patens</i>	prairie crocus	• <i>Prunus virginiana</i>	chokecherry
• <i>Apocynum androsemifolium</i>	spreading dogbane	• <i>Rhododendron groenlandicum</i>	Labrador tea
• <i>Aralia nudicaulis</i>	wild sasparilla	• <i>Rosa acicularis</i>	prickly rose
• <i>Arctostaphylos uva-ursi</i>	Kinnikinnick	• <i>Rubus idaeus</i>	red raspberry
• <i>Betula papyrifera</i>	paper birch	• <i>Rumex aquaticus</i>	western dock
• <i>Bromus ciliatus</i>	fringed brome grass	• <i>Schizachne purpurescens</i>	false melic grass
• <i>Campanula rotundifolia</i>	Harebell	• <i>Shepherdia canadensis</i>	Canada buffalo berry
• <i>Castilleja raupii</i>	purple paintbrush	• <i>Sibbaldiopsis tridentata</i>	shrubby fivefingers
• <i>Cornus canadensis</i>	Bunchberry	• <i>Solidago canadensis</i>	Canada goldenrod
• <i>Cornus sericeus</i>	red-osier dogwood	• <i>Solidago simplex</i>	mountain goldenrod
• <i>Cypripedium acaule</i>	stemless ladyslipper	• <i>Symphoricarpos albus</i>	snowberry
• <i>Dasiphora floribunda</i>	shrubby cinquefoil	• <i>Symphyotrichum laeve</i>	smooth aster
• <i>Fragaria virginiana</i>	wild strawberry	• <i>Trientalis borealis</i>	northern starflower
• <i>Geocaulon lividum</i>	bastard toadflax	• <i>Vaccinium myrtilloides</i>	blueberry
• <i>Hesperostipa curteseta</i>	western porcupine grass	• <i>Vaccinium vitis-idaea</i>	lingonberry
• <i>Lilium philadelphicum</i>	western wood lily	• <i>Viburnum edule</i>	lowbush cranberry
		• <i>Vicia americana</i>	American vetch

In 2012, a study originally supported by CEMA, was transferred to this project. This study compared direct-seeding with out-planting nursery stock of five priority shrubs including: *Arctostaphylos uva-ursi*, *Shepherdia canadensis*, *Vaccinium myrtilloides*, *Vaccinium vitis-idaea* and *Viburnum edule*.

## PROGRESS AND ACHIEVEMENTS

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### Specific Results from Field Trials

A total of 41 species were sown, and of those 28 emerged. Four species, *Bromus ciliatus*, *Castilleja raupii*, *Hesperostipa curtiseta* and *Rosa acicularis*, are spreading naturally. Flowering heads of several species were also observed: *Campanula rotundifolia*, *Dasiphora fruticosa* (formerly *floribunda*), *Solidago canadensis*, *S. simplex* and *Symphyotrichum laeve* although no new plants from seed have been observed. *Fragaria virginiana*, although not flowering, is producing runners and spreading vegetatively on all three sites. Most emerging species were found on all three sites and many emerged in similar percentages from both spring and fall planted seeds: *Alnus viridis*, *Anemone multifida*, *Betula papyrifera*, *Campanula rotundifolia*, *Castilleja raupii*, *Hesperostipa curtiseta*, *Schizachne purpurascens*, *Sibbaldiopsis triendata* *Solidago canadensis* and *Vicia americana*. Difference in emergence between seasons and/or propagule type was observed for several species. A greater proportion of *Amelanchier alnifolia*, *Cornus sericea*, *Prunus pensylvanica*, *Rosa acicularis* and *Symphoricarpos albus* emerged from seed rather than from fruit. In contrast, *Shepherdia canadensis* and *Viburnum edule* had better emergence from whole fruit.

*Anemone patens* and *Solidago simplex* seedlings were more likely to emerge after spring sowing whereas *Bromus ciliatus* and *Dasiphora fruticosa* seedlings tended to emerge from fall sown seed. Spring sown clean seed demonstrated the best emergence for *Prunus virginiana*. *Arctostaphylos uva-ursi* and *Rubus idaeus* seedlings were most likely to emerge from fall sown clean seed. Three fruited species, *Cornus canadensis*, *Fragaria virginiana* and *Maianthemum canadense*, have statistically equivalent emergence from clean seed or whole fruit regardless of sowing season. Of the 13 species that have yet to emerge, some are known to require multiple growing seasons to overcome dormancies.

The five shrub species in the previous CEMA study established well, except where a significant competitive cover limited their access to light, nutrients and water.

## DELIVERABLES AND MILESTONES

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In 2007 and 2008, an experimental design was drafted and three locations were selected for field trials. Individual plots were staked. Seeds and fruits of 41 native species were harvested from natural habitats, cleaned and prepared for seeding. Work with *in vitro* germination and seed and fruit measures continue to fill information gaps.

In 2010, all three experimental plots were sown in spring and fall. Harvest of five species was replicated for sowing in 2011 and 2012. These were of species for which seeds were unavailable in 2009.

The final sowing was completed in 2012 and included *Lonicera caerulea*, *Schizachne purpurescens*, *Campanula rotundifolia* and *Maianthemum canadense*. All plots were monitored for growth and development in 2013 and a final report was prepared in 2014. A paper for publication has been submitted to the Native Plants Journal. It has yet to be accepted for publication but we continue to pursue this end.

## OUTCOMES AND LESSONS LEARNED

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Many boreal forb and shrub species can effectively establish by direct seeding. Emergence was relatively low and this method will be most cost effective for species that produce sufficient seeds or those for which seed can be multiplied under agronomic conditions.

Establishment of shrubs from nursery stock can be severely restricted by competition from larger, faster growing species.

Pertinent harvest, seed cleaning, seed and fruit metrics and cultural information that will facilitate the inclusion of these species in industrial revegetation operations was gleaned from this work and has been published (2013) on the OSRIN website.

## PRESENTATIONS AND PUBLICATIONS

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Smreciu, A., K. Gould and S. Wood. 2014. *Establishment of Native Boreal Plant Species on Reclaimed Oil Sands Mining Disturbances*. Final Report. Prepared for COSIA (Canada's Oil Sands Innovation Alliance). 51 pp + appendices.

Smreciu, A. and K. Gould. (in prep). *Field emergence of native boreal forest species on reclaimed sites in north eastern Alberta*. Native Plants Journal.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Wild Rose Consulting, Inc.

Principal Investigator: A. Smreciu, M.Sc.

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Kim Gould	Wild Rose Consulting, Inc	Not Applicable	Not Applicable	Not Applicable

Industry Collaborators: Canadian Natural Resources Limited; Shell Canada Energy and Suncor Energy Inc.

# Nutrient Loading of Seedlings to Improve Growth and Land Reclamation Success

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0141

**Academic Institution:** University of Alberta

**Industry Champion:** Total E&P Canada Ltd.

## PROJECT SUMMARY

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This is the second phase of a project to study fertilization dose response in seedlings of three tree species on reclamation sites in the Athabasca Oil Sands Region. In the first phase of the project, a method was successfully developed to load aspen, white spruce and jack pine seedlings with nutrients in the nursery for potential planting on oil sands reclamation areas and in the second phase, these seedlings are tested in the field for their growth performance.

Seedlings, once loaded with nutrients in the nursery, have greater nutrient reserves that can be used by seedlings in early establishment after out-planting in the field. Nutrient-loaded seedlings are expected to have higher nutrient re-translocation from old tissues as compared to conventionally-produced seedlings that potentially increases new tissue growth. Improved new tissue growth favors early establishment of roots' contact to soil, the roots then can exploit nutrients and moisture more effectively from soils that can enhance survival and early growth of seedlings. Because of the greater nutrient reserves in nutrient-loaded seedlings, they have better abilities to compete with understorey vegetation for nutrients and moisture. The benefit of the nutrient loading technique can be more beneficial in reclaimed soils which have inherent characteristics such as nutrient deficiency, drought and weed competition that limit plants' growth. This part of the project is examining the efficiency of nutrient-loaded seedlings to re-translocate nutrients from sink to new growth and evaluating the survival and growth performance of these seedlings in nutrient poor and weedy environments in oil sands reclamation.

## PROGRESS AND ACHIEVEMENTS

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The first year experiment of this phase of the project is still ongoing. The experiment was started in June 2014 with out-planting of nutrient-loaded and conventionally-produced seedlings of aspen, white spruce and jack pine in a reclaimed site. The seedlings were planted in two (conventional vs. nutrient-loaded) by two (with weeds or with weeds removed) factorial randomized complete block design. The main experiment is in a peat-mineral soil mix (PMM) site with all three species and a supplementary experiment with the same design is conducted in a LFH site with only aspen. Seedling samples were collected and tested for their initial nutrient concentration and biomass before the seedlings were deployed for out-planting.

To test for their growth in the field, morphological data (height, root collar diameter [RCD], foliage size, root size and root depth) and component dry mass data were collected. Analysis of nutrient concentrations in seedlings to

examine the potential of nutrient-loaded and conventionally-produced seedlings to re-translocate nutrients from old tissue to new growth is still ongoing. Soil samples were collected and tested for physical and chemical characterization. Soil temperature and moisture content were measured periodically. To quantify the competitive stress of seedlings for nutrients from competing vegetation in the field, understory vegetation cover, their biomass and nutrient concentrations were analyzed.

From the available data, there is no significant difference in soil nutrients including total carbon (TC), total nitrogen (TN), C:N ratio and available nitrogen in all sites except C:N in the 10 to 30 cm in white spruce plots and nitrate in 10 to 30 cm in aspen LFH plots. Other soil characteristics such as pH, electrical conductivity (EC) and bulk density were not significantly different in all treatments. Weeds had significant effect on soil moisture content in June (in white spruce and jack pine plot) and September (in aspen plots).

Jack pine seedlings exhibit significant positive effect of nutrient loading on growth parameters such as height, RCD and component dry mass while the effect of weed on growth of these seedlings is not significant. Aspen seedlings on the PMM site also show similar results. However, nutrient loading shows little effect on the growth of aspen seedlings on the LFH site. For foliage size, nutrient-loaded seedlings of aspen on the PMM site had greater leaf area than that of conventionally-produced seedlings. In contrast, weeds show significant effect on leaf area of aspen seedlings on the LFH site. Nutrient loading increased new needle area by 112% in jack pine relative to conventional fertilization.

## OUTCOMES AND LESSONS LEARNED

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The field trial has been successfully established and sampling in summer 2014 has been completed.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Dr. Scott Chang

Name	Institution	Degree	Start Date	Completion Date
Prem Pokharel	University of Alberta	M.Sc.	January 2014	December 2015
Stephanie Ibsen	University of Alberta	M.Sc., Research Assistant	2014	2016
Kangyi Lou	University of Alberta	M.Sc., Research Assistant	2014	2015
Phil Auer	University of Alberta	B.Sc., Research Assistant	2014	2014

Industry Collaborators: Imperial; Shell Canada Energy and Suncor Energy Inc.

# Oil Sands Vegetation Cooperative

**Project Type:** EPA led Study

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LE0014

**Academic Institution:** Wild Rose Consulting, Inc. (WRC)

**Industry Champion:** Imperial and Shell Canada Energy

## 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 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) region. Key deliverables of the OSVC in 2014 were the development of a Member’s Handbook and a Strategic Plan that included a 10-year projection of seed requirements for the mineable oils sands, an initial knowledge gap analysis and a SWOT analysis. A cross-company record keeping system was also developed such that industry could have a current listing of available seeds from the bank.

## PROGRESS AND ACHIEVEMENTS

In 2014, the OSVC harvested, extracted and registered the following:

For the Cold Lake region (COLK) 17 seed lots representing eight species (328 L total) (representing one seed zone).

For the Mineable Oil sands (NAOS) 75 seed lots representing 22 species (444 L total) (representing four seed zones)

**Table 1. Species Harvested**

COLK	NAOS	NAOS
<i>Alnus viridis</i> green alder	<i>Acorus americanus</i> ratroot	<i>Cornus sericea</i> dogwood
<i>Arctostaphylos uva-ursi</i> bearberry	<i>Alnus incana</i> river alder	<i>Corylus cornuta</i> beaked hazelnut
<i>Cornus sericea</i> dogwood	<i>Alnus viridis</i> green alder	<i>Dasiphora fruticosa</i> shrubby cinquefoil
<i>Rhododendron groenlandicum</i> Labrador tea	<i>Amelanchier alnifolia</i> Saskatoon	<i>Primula pauciflora</i> saline shooting star
<i>Rosa acicularis</i> prickly rose	<i>Anthoxanthum nitens</i> sweetgrass	<i>Prunus pensylvanica</i> pin cherry
<i>Vaccinium myrtilloides</i> dwarf blueberry	<i>Arctostaphylos uva-ursi</i> bearberry	<i>Prunus virginiana</i> chokecherry
<i>Vaccinium vitis-idaea</i> lingonberry	<i>Betula papyrifera</i> paper birch	<i>Shepherdia canadensis</i> buffaloberry
<i>Viburnum edule</i> lowbush cranberry	<i>Betula pumila</i> bog birch	<i>Triglochin maritima</i> seaside arrowgrass
	<i>Carex aquatilis</i> water sedge	<i>Vaccinium myrtilloides</i> dwarf blueberry
	<i>Carex atherodes</i> beaked sedge	<i>Vaccinium vitis-idaea</i> lingonberry
	<i>Carex utriculata</i> NWT sedge	<i>Viburnum edule</i> low-bush cranberry

## DELIVERABLES AND MILESTONES

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WRC worked closely with harvesters and extractors to ensure seed quality and registration of seed lots. A kick-off meeting was held in the spring with harvesters, where harvest sheets were distributed for all species to be harvested in 2014. The collaborators reviewed and discussed seed zones, collection permits and chain of custody for seedlots. The meeting opened a line of communication among harvesters and WRC and harvesters shared some of their successes and impediments.

WRC met with members at three meetings throughout the year to discuss progress on all aspects of the project and included short presentations regarding projects that are being undertaken by individuals and industry.

COLK was set up and aligned with the existing OSVC system for harvest and banking; SAOS has yet to be integrated.

A Members Handbook was prepared and distributed to members.

A strategic plan was prepared and included a 10-year projection of seed requirements for the mineable oil sands. It is expected that the NAOS, primarily mining operations, will require over two million plants by 2025; this indicates that an escalation of harvest efforts is necessary. Projections for the in-situ groups have not been completed due to a lack of available information. The Knowledge Gap Analysis (KGA) was scaled back to an internal process (a decision made by the members) with a plan to analyse the data and prepare a more comprehensive KGA for external distribution. A SWOT analysis was prepared.

A cross company record keeping database was developed and is being updated biannually.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu

Name	Institution	Degree	Start Date	Completion Date
Kimberly Gould	Wild Rose Consulting, Inc.	Not Applicable	Not Applicable	Not Applicable

Industry Collaborators: BP Canada; Canadian Natural Resources Limited; Cenovus Energy Inc.; ConocoPhillips Canada Resources Corp.; Devon Canada Corporation; Nexen; Statoil Canada Ltd.; Suncor Energy Inc.; Syncrude Canada Ltd.; Teck Resources Limited; and Total E&P Canada Ltd.

# Point Intercept Vegetation Monitoring

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Work Completed

**COSIA Project Number:** LJ0168

**Academic Institution:** Teck Resources Limited.

**Industry Champion:** Teck Resources Limited

## PROJECT SUMMARY

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Teck's Red Dog Mine in Alaska uses point-intercept survey methodology to measure composition, relative cover, frequency of occurrence and species diversity. The objective of this monitoring effort is to provide for a means to precisely and consistently evaluate the effectiveness of dust control efforts as expressed by vegetation community health primarily through two key measures: 1) moss and lichen cover; and 2) vascular plant cover and composition. A 1-m long "laser point bar" consisting of a bar with 10 specialized low energy lasers at 10-cm intervals, is used to determine "hits" of vegetation, litter, bare soils, or rock. This method employs a more accurate, defensible and faster approach than the manual point intercepts survey method.

## PROGRESS AND ACHIEVEMENTS

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Since the implementation of this method at Teck's Red Dog mine in Alaska, monitoring of reclamation performance has improved, by providing more precise data. Density of data has increased about three times for the same effort (from about 5,000 points to about 150,000 points per two weeks' effort). The survey provides baseline vegetation, moss and lichen cover values to facilitate long-term monitoring of representative sites (both with and without perceived impacts) within a 4,000 m radius of the mine and within 2,000 m downwind of the DMTS road and port facilities. The monitoring survey is designed to document improvements, or the lack thereof, to local floral communities in response to dust suppression mitigation measures implemented by Red Dog operations.

## DELIVERABLES AND MILESTONES

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Red Dog will continue to use this method and has switched to a three year cycle to match moss sampling that ties into the fugitive dust monitoring.

## OUTCOMES AND LESSONS LEARNED

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A survey of this type provides an accurate range of acceptable cover values that could then aid an assessment of mitigation measure veracity/effectiveness and provide additional suggestions for remediation or recovery goals. As part of this effort, those monitoring points that seem to be well outside the impact footprint could be utilized to supplement this database. Future surveys of the long-term monitoring points would be undertaken during the summer thereby facilitating a more rapid initial analysis other than static. This effort would provide relatively quick feedback on the effectiveness of recent dust control mitigation measures and may provide an initial assessment of the recovery, stabilization, or continued decline of affected areas.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Teck's Red Dog Mine

Principal Investigator: Chris Eckert, Senior Environmental Coordinator

Name	Institution	Degree	Start Date	Completion Date
Wayne Hall	Teck's Red Dog Mine	Manager Community and Public Relations	2010	2014
Jeff Clark	Teck's Red Dog Mine	Environment Superintendent	2010	2014

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0203

**Academic Institution:** Natural Resources Canada

**Industry Champion:** Syncrude Canada Ltd.

## PROJECT SUMMARY

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In Alberta oil sands reclamation, the presence of oil sands process-affected water (OSPW) can be problematic. 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. From a human perspective in a reclamation context, willows are often deployed early in 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. Approximately 3000 willow container seedlings were grown from cuttings during the summer of 2013, hardened off and cold stored for planting in spring of 2014. 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

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The trial was planted on the south shore of Base Mine Lake in the late spring of 2014, with limited assessments in fall of 2014.

## DELIVERABLES AND MILESTONES

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This project is in year one of three. An establishment report will be produced in April 2015.

## OUTCOMES AND LESSONS LEARNED

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

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Natural Resources Canada

Principal Investigator: Richard Krygier

Industry Collaborators: None

# Terrestrial Mesocosm as a Model System for Evaluating Ecological Responses to OSPW Exposure

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0135

**Academic Institution:** Alberta Innovates Technology Futures

**Industry Champion:** Total E&P Canada Ltd.

## PROJECT SUMMARY

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The long-term tolerance of boreal plants to oil sands process water (OSPW) exposure via seepage is not well understood. The objective of this study was to quantify targets and thresholds of native boreal woody and grass species, common to the Athabasca oil sands region, to OSPW in a dose-response greenhouse trial.

**Hypothesis: OSPW components (e.g., naphthenic acids, salinity, etc.) may cause toxic effects in plants, thus hindering reclamation.**

Plant response in 410-day-old plants was evaluated for six potted upland plant species (including trees, shrubs, forbs and grasses) in a randomized block design experiment. Grouped plants were watered in trays for a period of eight weeks using 0 (control) to 100% OSPW to simulate seepage exposure in the rooting zone. A negative response in shoot length was observed for *B. ciliatus* and *C. angustifolium* (fire weed); a 189 mm (20%) and 438 mm (60%) reduction in shoot length was measured for plants exposed to 100% OSPW in comparison to the control plants, respectively. For *P. banksiana* (Jack pine), an increase in shoot length (corresponding to increased plant vigour) was measured for plants exposed to 20% OSPW, suggesting that OSPW may provide adequate nutrient supply supporting plant growth to a point of sufficiency at this concentration.

Effects from OSPW exposure were most notable in root biomass. Reductions in root biomass were observed for all plant species with increasing OSPW concentrations. Notable decreases in root biomass were measured for *B. ciliatus* (fringed brome grass) (80%), *C. angustifolium* (53%); and *P. tremuloides* (trembling aspen) (50%) when exposed to 100% OSPW, in comparison to the controls.

Although plant growth response differed among species exposed to 0% to 100% OSPW, no plant mortality was observed after eight weeks of exposure. This study suggests that plants may use different physiological mechanisms to cope with stress, as observed through the varying responses in morphology. Therefore, diverse plant communities dominated by plants most tolerant to OSPW exposure could be considered in future reclamation scenarios. The photosynthetic yield results suggested that plants may be able to recover from the effects of short term influxes of OSPW into the root zone.

## PROGRESS AND ACHIEVEMENTS

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In summer of 2013, a field pilot mesocosm was installed and operated for a year to elucidate understanding of the fate and transport of oil sands process-affected water (OSPW) through reclaimed soils within the terrestrial ecosystems residing in the Athabasca Oil Sands Region. Two mesocosms were constructed to verify the methodology of the experimental set-up, evaluate the feasibility and effectiveness of the hydraulic head method for OSPW delivery, determine the natural seasonal effects from precipitation, freezing and snow cover and instrumentation and operation of the pilot-scale systems.

## DELIVERABLES AND MILESTONES

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- Completed the construction and validation of two terrestrial pilot mesocosm operated year-round
- Plant tolerance results were presented at the 9th Annual Mine Closure Conference (S. Africa)
- Attenuation of naphthenic acid in soils pore water and plant tissue. Samples are ready, chemical analysis remains.

## OUTCOMES AND LESSONS LEARNED

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Uplands plants are more tolerant to OSPW than originally thought as all plants survived even in 100% OSPW. The soil medium may have played a role in buffering the effects from OSPW. Using a soil medium in the study is more reflective of reclamation prescriptions.

## PRESENTATIONS AND PUBLICATIONS

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Woosaree, J. and F. Salifu. 2014. *Terrestrial Mesocosm for Evaluating Ecological Response to OSPW Exposure*. The 9th International Conference on Mine Closure in Johannesburg, South Africa. Sep. 30 to Oct. 4, 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Scott Chang

Name	Institution	Degree	Start Date	Completion Date
Jay Woosaree	Alberta Innovates Technology Futures	Not Applicable	Not Applicable	Not Applicable
Christina Small	Alberta Innovates Technology Futures	Not Applicable	Not Applicable	Not Applicable
Toby Turner	Alberta Innovates Technology Futures	Not Applicable	Not Applicable	Not Applicable

Industry Collaborators: None

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

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0007

**Academic Institution:** Canadian Forest Service

**Industry Champion:** Canadian Natural Resources Limited

## PROJECT SUMMARY

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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 seeding potential. The greenhouse studies can be used to test the impacts of specific soil and site properties, including potential future reclamation methodologies (i.e., compaction effects), on aspen seedling establishment. The field studies will build upon 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.

## OUTCOMES AND LESSONS LEARNED

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Soil type was the major controller of aspen seedling establishment in both the greenhouse and field trials but the soil with the best establishment was different between studies. In the greenhouse best establishment was on forest floor – mineral mix while in the field the best establishment was on peat – mineral mix. This indicates that soil is not the only driver of aspen establishment. Competition and differences in soil moisture are likely also important.

In terms of specific soil properties, aspen establishment was negatively related to soil compaction but positively related to soil moisture holding capacity and surface roughness.

## PRESENTATIONS AND PUBLICATIONS

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Pinno, B.D. and R.C. Errington. 2014. *Maximizing natural deciduous tree seedling establishment on a reclaimed oil sands site*. Ecological Restoration. In Press.

Pinno, B.D., A. Lewis and R.C. Errington. 2014. *Patterns of tree and plant community development on a reclaimed oil sands mine in northern Alberta*. Oral presentation abstract submitted to American Society of Mining and Reclamation Annual Meeting, Oklahoma City, Oklahoma, USA, June, 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Co-Principal Investigator: Richard Krygier

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Abby Lewis	University of Northern British Columbia	B.Sc. Forestry – summer student and undergrad thesis project	May 2013	August 2013
Jesse Labatiuk	University of Alberta	B.Sc. Reclamation – summer student	May 2013	August 2013
Edith Li	CFS	Research Technician	May 2013	August 2013
Natalia Startsev	CFS	Research Technician	May 2013	March 2014

Industry Collaborators: None

# Understorey Plant Community Development on Reclaimed and Natural Sites

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0005

**Academic Institution:** Canadian Forest Service

**Industry Champion:** Canadian Natural Resources Limited

## PROJECT SUMMARY

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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 understorey 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 and upland forest floor – mineral mix are currently being used as surface layers 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 CNRL 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 weeding on vegetation development and then compare vegetation development on the reclaimed sites to nearby natural stands using the Reference Condition Approach. The result of this study will be to make recommendations to improve reclamation practices that optimize long term vegetation development.

## DELIVERABLES AND MILESTONES

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Three field seasons of data collection have been completed, with two more field seasons planned. The research expanded from RA1 to include WA2.

An annual research report was delivered in February 2015 which included data on plant community development, tree establishment and growth, and soil properties from RA1, WA2 and nearby natural sites.

## OUTCOMES AND LESSONS LEARNED

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- Plant communities were clearly differentiated on the basis of year (time since establishment) and soil type (peat – mineral mix, forest floor – mineral mix, natural).
- The greatest change over time was from the first growing season to the second with plant communities not changing significantly between the second and third growing seasons.
- The greatest distinction between plant communities due to soil types was found between natural and reclaimed soils. Within reclaimed soils, there were secondary differences between the plant communities occurring on forest floor – and peat – mineral mixes. Within the natural sites, plant communities in mature sites were significantly different from those in stands affected by the 2011 Richardson Forest Fire.

## PRESENTATIONS AND PUBLICATIONS

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Errington, R.C. and B.D. Pinno. *Initial plant community development in reclaimed and natural boreal forest.* Manuscript in preparation.

Pinno, B.D., A. Lewis and R.C. Errington. 2014. *Patterns of tree and plant community development on a reclaimed oil sands mine in northern Alberta.* Oral presentation abstract submitted to American Society of Mining and Reclamation Annual Meeting, Oklahoma City, OK, June, 2014.

Lewis, A. 2014. *Effects of forest floor application on an oil sand mine reclamation area, Alberta, Canada.* Undergraduate thesis NRES 422, University of Northern British Columbia, Prince George, BC.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution	Degree	Start Date	Completion Date
Abby Lewis	University of Northern British Columbia	B.Sc. Forestry – summer student and undergrad thesis project	May 2013	August 2013
Jesse Labatiuk	University of Alberta	B.Sc. Reclamation – summer student	May 2013	August 2013
Rebecca McMurray	BCIT	B.Sc. Ecosystem Restoration – summer student	May 2014	August 2014
Jeff Hogberg	University of Alberta	M.Sc. – summer student then graduate student	May 2014	Present
Edith Li	CFS	Research Technician	April 2014	Present

Industry Collaborators: Suncor Energy Inc.

## Wildlife Research and Monitoring

# Horizon Oil Sands Early Successional Wildlife Monitoring Program

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0186

**Academic Institution:** Canadian Natural Resources Limited

**Industry Champion:** Canadian Natural Resources Limited

## PROJECT SUMMARY

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Canadian Natural Resources Limited is implementing an early successional wildlife monitoring program on their Horizon Lease in the Athabasca Oil Sands Region of Alberta. The objectives of this program are to:

- assess the return and re-establishment of early successional wildlife species on reclaimed terrestrial systems on the Horizon Oil Sands;
- assess early successional wildlife use on reclaimed land relative to a naturally disturbed control and mature reference point;
- collect wildlife monitoring data to meet commitments related to wildlife and wildlife habitat reclamation;
- assess the terrestrial / riparian productivity of areas like Horizon Lake; and
- contribute to the state of knowledge regarding the efficacy of upland habitat reclamation in the Athabasca Oil Sands Region as it pertains to wildlife.

To meet these objectives, wildlife monitoring data are being collected from recently (2011) reclaimed habitats (N=8), from burned sites of similar age (N=2) and from mature forest sites (N=2) representing the desired end point of reclamation. Focal taxa include songbirds, small mammals, amphibians, bats, and winter-active wildlife. Data are collected via songbird surveys, small mammal live-trapping, visual encounter surveys for amphibians, autonomous recording units, snow-tracking and incidental observations. Vegetation data are collected from all sampling locations to correlate wildlife presence and abundance with habitat features developing on reclaimed land and existing in mature forests.

## Deliverables and Milestones

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This project is in year four of five.

### OUTCOMES AND LESSONS LEARNED

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The wildlife monitoring program on Canadian Natural's Horizon Oil Sands is a multi-species monitoring program. The data collected are intended to assess reclamation efficacy and answer questions about future landscape potential arising from reclamation. Two approaches to monitoring are used: 1) systematic surveys for select taxa (songbirds, small mammals, bats, amphibians); and 2) incidental wildlife observations for all species. Remote-sensing equipment (autonomous recording units and remote cameras) are used to document difficult to study organisms (e.g., bats) and species not targeted by dedicated surveys (e.g., large mammals). Systematic survey data are used to assess trends in focal taxa over time and all data are pooled to derive an estimate of species richness relative at the lease and treatment (i.e., reclamation) level.

Field sampling on reclaimed wildlife habitat commenced in 2012, one year following reclamation. Additional sampling occurred in 2013 and 2014 and spanned all seasons. Sampling has increased since 2012 from six sites to 12 in 2014. The results of monitoring to date confirm that wildlife use of Canadian Natural's Horizon Oil Sands lease is extensive. For example, in 2013, 133 species of wildlife [mammals (n=27), birds (n=103), and amphibians (n=3)] and 279 species of vascular and non-vascular plants [lichens (n = 65), liverworts (n = 8), moss (n = 35), and vascular plants (n = 171)] were documented from all locations sampled. While not yet fully tabulated for 2014, data collected this year are consistent with 2013 and indicate that specific species of wildlife are starting to use reclaimed habitats, although differences between reclaimed habitat and mature forests exist, which is expected. The species associated with reclaimed habitats are typical of early seral grass and herb-dominated habitats and include deer mouse (*Peromyscus maniculatus*), meadow vole (*Microtus pennsylvanicus*), and southern red-backed vole (*Myodes gapperi*). The bird fauna using reclaimed habitats was dominated by four species of sparrow (Lincoln's sparrow [*Melospiza lincolnii*], Le Conte's sparrow [*Ammodramus leconteii*], clay-coloured sparrow [*Spizella pallida*], and savannah sparrow [*Passerculus sandwichensis*]), species that are typically associated with early seral grass and herb dominated habitats. Preliminary analyses distinguish between wildlife communities using reclamation sites, burned reference habitats, and mature forest. More data are likely to better define the wildlife communities currently using each of the types of sites being sampled on the lease.

### PRESENTATIONS AND PUBLICATIONS

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An internal annual report was produced in 2014, but no publications were released.

### RESEARCH TEAM AND COLLABORATORS

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Institution: N/A

Principal Investigator: Virgil Hawkes

Industry Collaborators: None

# Using Bighorn Sheep from Mined Land to Re-Establish Herds in Historic Ranges

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0161

**Academic Institution:** Teck Resources Limited

**Industry Champion:** Teck Resources Limited

## PROJECT SUMMARY

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[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED] The main focus of this program is to examine bighorn sheep distribution, movement and habitat selection within CRO and to help restore bighorn sheep in different areas of North America. The reclaimed landscapes are used primarily as winter range by bighorn sheep, but other activities such as lambing, rutting and summer use also occur. The bighorn's anti-predator strategy involves visual detection of predators at distance and response by running to escape cover (cliffs or cliff-like terrain). Most observations of bighorn sheep in CRO have been within 300 m of escape terrain, and none have been observed beyond 700 m of escape terrain. Escape terrain at the CRO mines is provided by benched highwall or footwall. Quality forage is provided by the variety of grasses and legumes used in the revegetation program. Other habitat requirements such as mineral licks, lambing locations and rutting habitat are provided by seepage on pit walls, benched highwalls and large flat areas near escape terrain on the reclaimed landscapes. Considering the behaviour and habitat requirements of bighorn sheep in conjunction with an operating coal mine and reclamation process, [REDACTED] including reallocating portions of the healthy and expanding population from CRO to the USA to re-establish historic herds.

## PROGRESS AND ACHIEVEMENTS

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In 2014, 2 bighorn sheep were captured at Teck's Cardinal River Luscar Mine and transported to the state of North Dakota in the United States. The North Dakota Department of Wildlife had applied to Alberta Environment and Sustainable Resource Development, which granted the request to relocate sheep to North Dakota. Another 25 bighorn sheep are scheduled to be captured and transported to South Dakota in 2015.

## DELIVERABLES AND MILESTONES

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The bighorn sheep population has increased (2.8% per year) near the Luscar Creek Mine and 9% near the Gregg River Mine since 1985, despite the removal of 316 female bighorn sheep for export during this same time. Population growth rates are expected to slow down as the amount of new reclamation directly benefiting bighorn sheep decreases.

## OUTCOMES AND LESSONS LEARNED

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As reclamation proceeds, the bighorn sheep population responds to newly planted grassland adjacent to pit walls. Toward the end of the life of the mine, reclamation primarily occurs in areas designated as forest, or not associated with pit walls, making areas less attractive or unusable by bighorn sheep. Once all the area adjacent to highwalls left for escape terrain have been planted, it is expected that the bighorn sheep population will reach its maximum size. Depending on the amount and location of reclamation every year, or series of years, the bighorn population could rise in a “stepped” fashion, reaching successive plateaus until reclamation is completed.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Teck’s Cardinal River Operations

Principal Investigator: Larry Matwie, Environmental Officer

Name	Institution	Degree	Start Date	Completion Date
Beth MacCallum	Bighorn Wildlife Technologies	P.Biol	2013	2014
Cyndi Van Alphen	CRO	Officer	2013	2014
Randall Leblanc	CRO	Officer	2013	2014
Mike Chodyka	CRO	Officer	2013	2014
Shane Reay	CRO	Officer	2013	2014

Industry Collaborators: Bighorn sheep captures on the mine for export are carried out with the cooperation of the provincial and state wildlife agencies, and by the help of many volunteers from other agencies (i.e., Jasper National Park, Alberta Solicitor General), and local conservation groups.

# Wildlife Habitat Effectiveness and Connectivity Program

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**Project Type:** Joint Industry Project (JIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0144

**Academic Institution:** University of Alberta

**Industry Champion:** Shell Canada Energy

## PROJECT SUMMARY

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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

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### MOOSE TRACKING COMPONENT HIGHLIGHTS

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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 Sustainable Resource Development (ESRD) and a revised version is being drafted. Due to ongoing discussions with ESRD with respect to the presentation and interpretation of results, 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

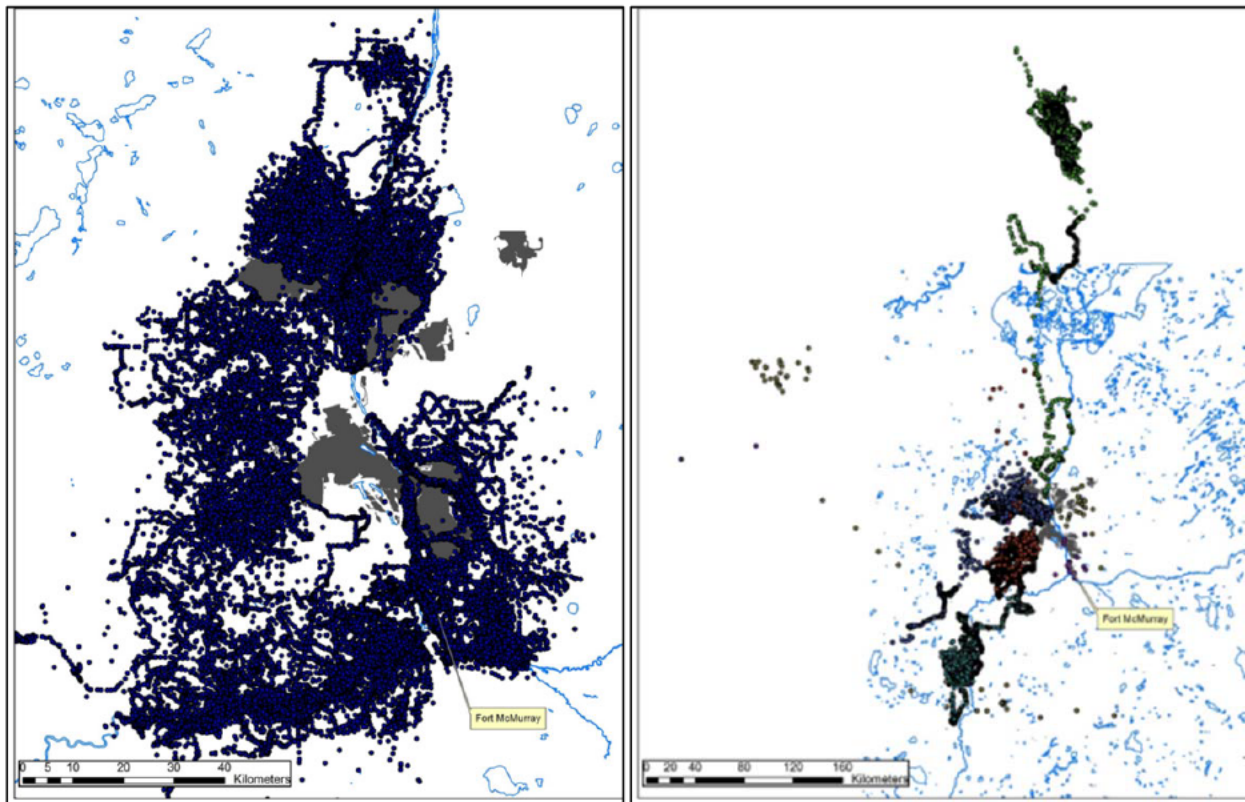
out of river valleys on a seasonal basis. We found strong evidence that moose avoided areas within 250 m around mines.

### WOLF TRACKING COMPONENT HIGHLIGHTS

The wolf tracking field components were concluded in 2014. 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 (Figure 1a). Six of the radio collared individuals dispersed from the study area (39,002 locations; Figure 1b).



a)

b)

Figure 1a/b: All resident (a) and dispersal (b) wolf locations collected by GPS radio collars in 2012-2014.

Wolves selected mainly cranberry understorey, fen, dogwood and shrubland dominated habitats (Figure 2) and avoided bog, mine and lake habitats (Figure 3).

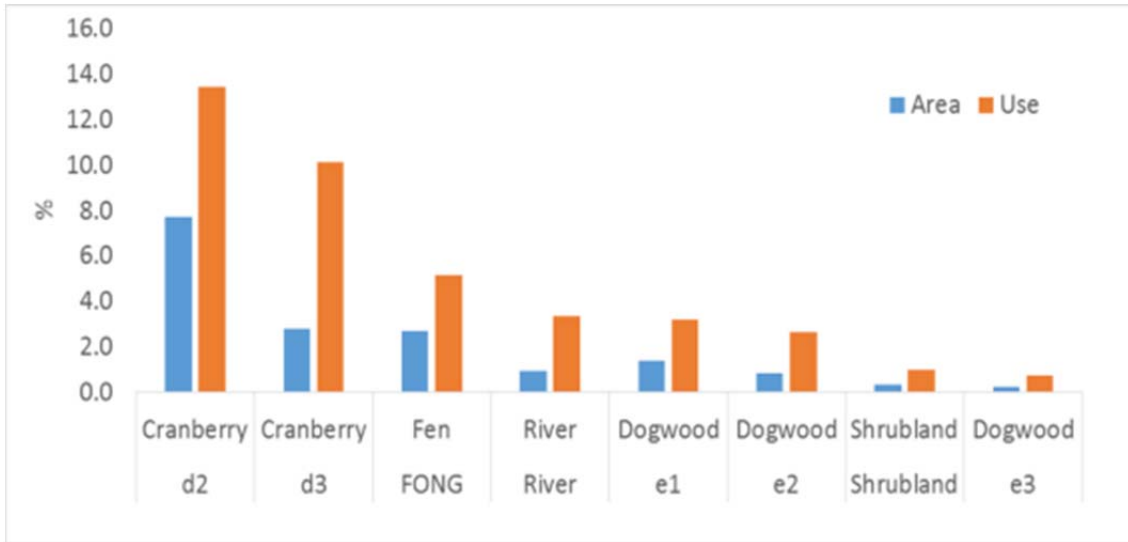


Figure 2: Habitat types used more than available by wolves in 2012-2014 in the WHEC study area

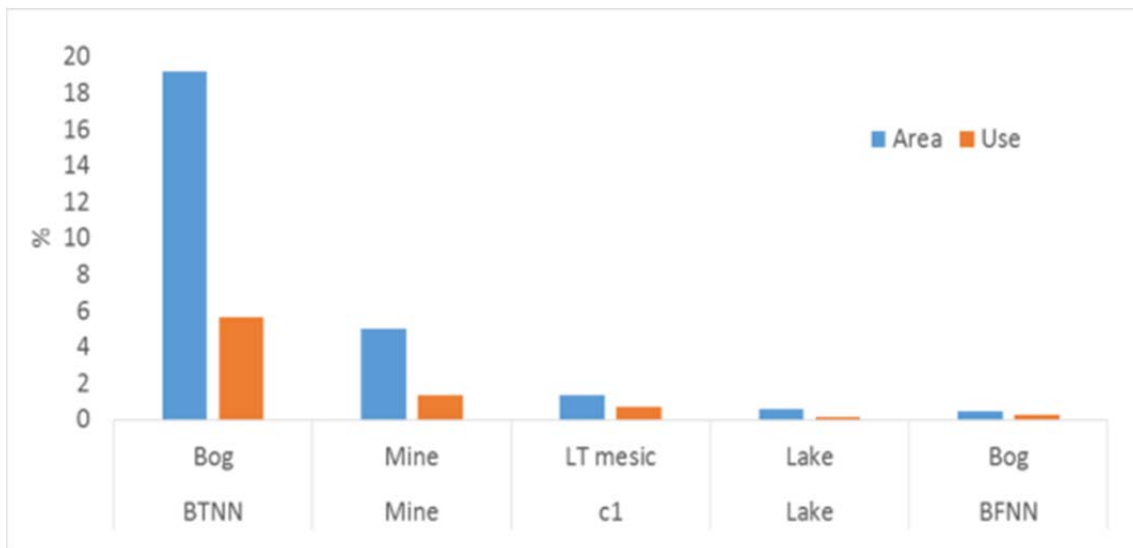
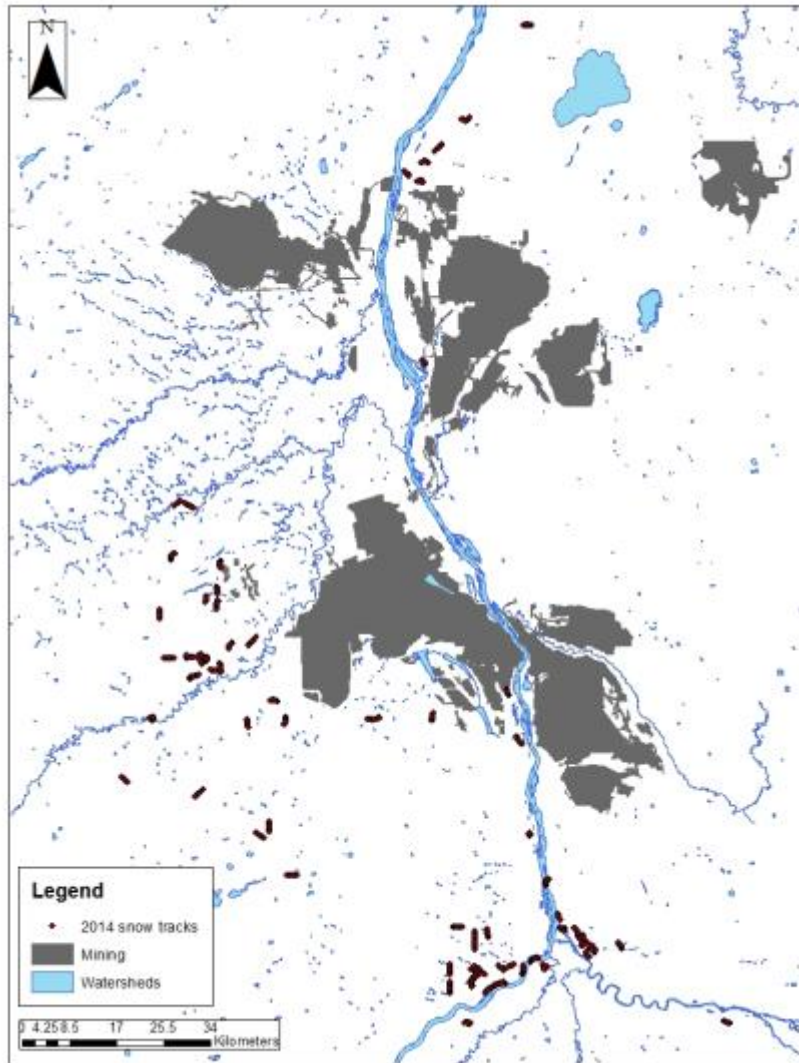


Figure 3: Habitat types used less than available by wolves in 2012-2014 in the WHEC study area.

### 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 (Figure 4).



**Figure 4: 2014 wolf snow tracking locations.**

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 5). 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.

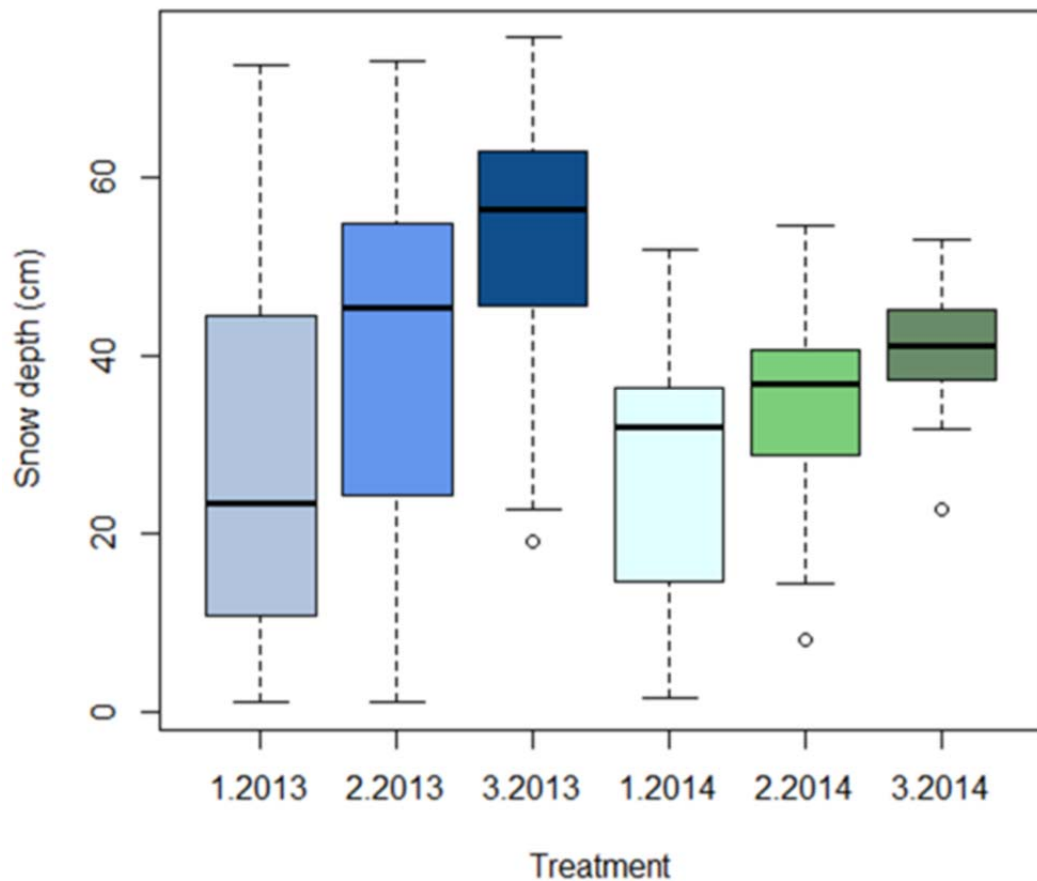
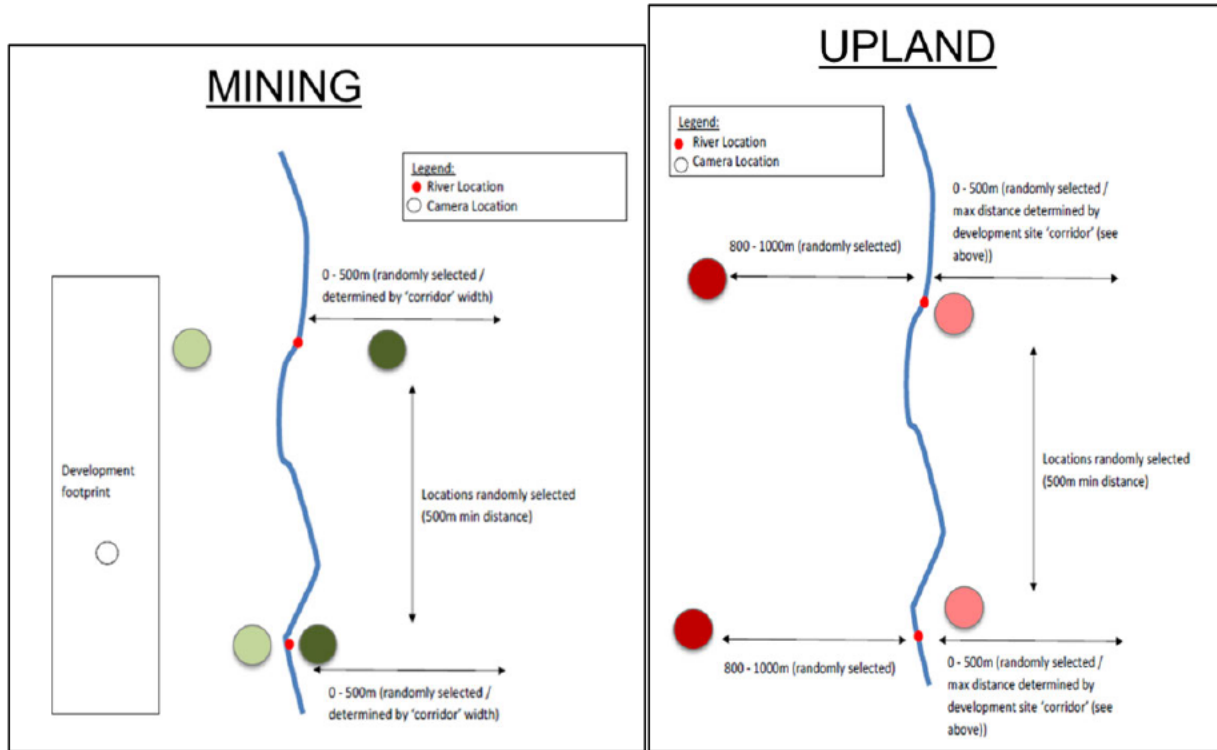


Figure 5: Snow depth measured on (1), 1m off (2) and 10m off (3) wolf tracks in 2013 and 2014.

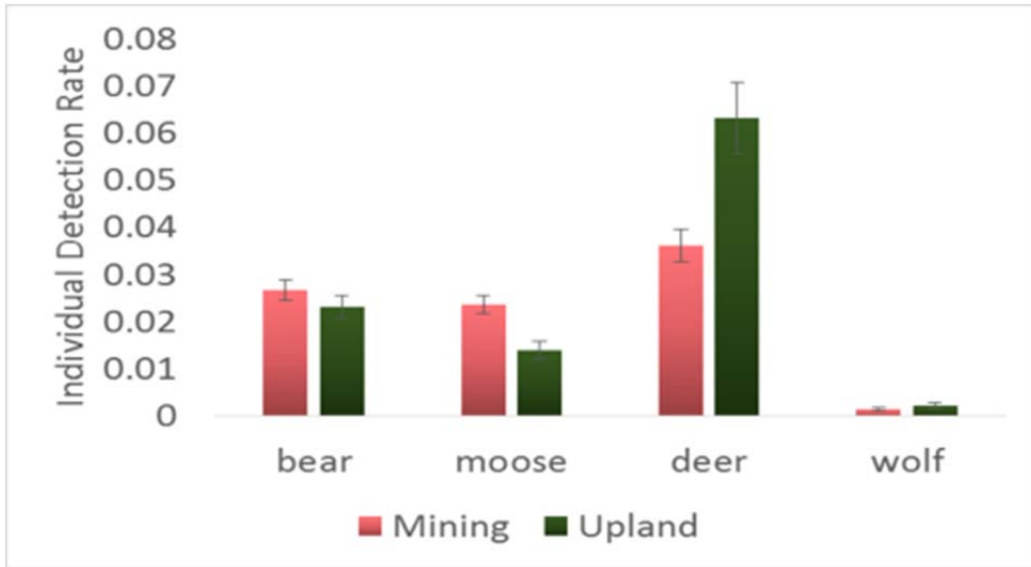
#### REMOTE CAMERA COMPONENT HIGHLIGHTS

The fifth year of the camera monitoring project was completed in 2014. Monitoring was conducted (identical to previous years) between May and July of 2014. Along the Athabasca River and five tributaries (Muskeg, Ells, McKay, Steepbank and Clearwater Rivers) 110 cameras were moved to monitor 235 locations for a two week period. Cameras were paired in 'Mining' and 'Upland' configurations (Figure 6). 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 close (Upland) and developed and non-developed (DND) treatment groups. The proportion of cameras with at least one detection per species per treatment group was calculated.



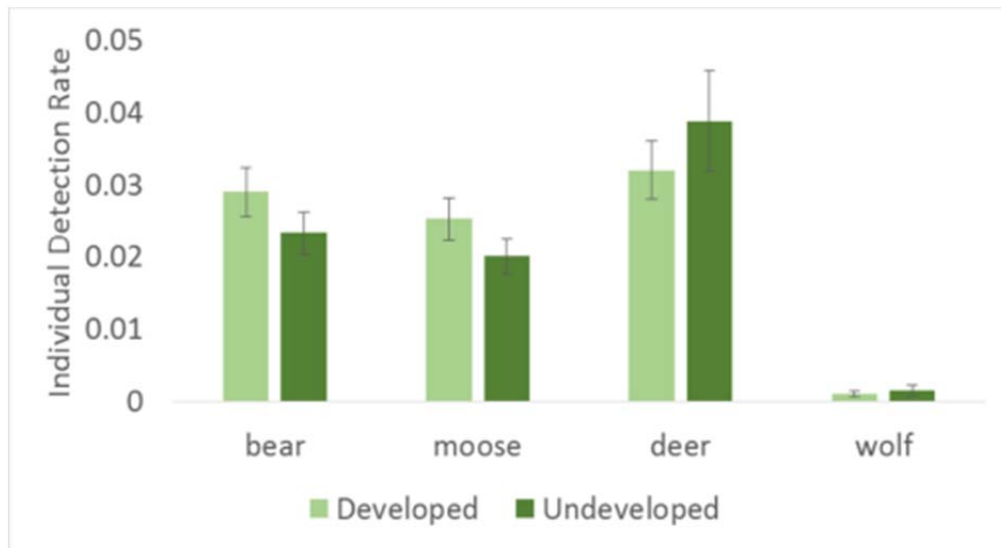
**Figure 6: Schematic of 'mining' and 'upland' camera pair design.**

Summing all five years (2010 – 2014) of the camera project, a total of 187,619 images were collected at 1,063 camera locations. Top species detected on the cameras overall were: moose (20,575 images), white-tailed deer (13,550 images), black bear (8,142 images) and wolf (402 images). Comparing all 'Mining' with all 'Upland' cameras we observed more detections of bear and moose within mining and more detections of deer and wolves in the uplands (Figure 7).



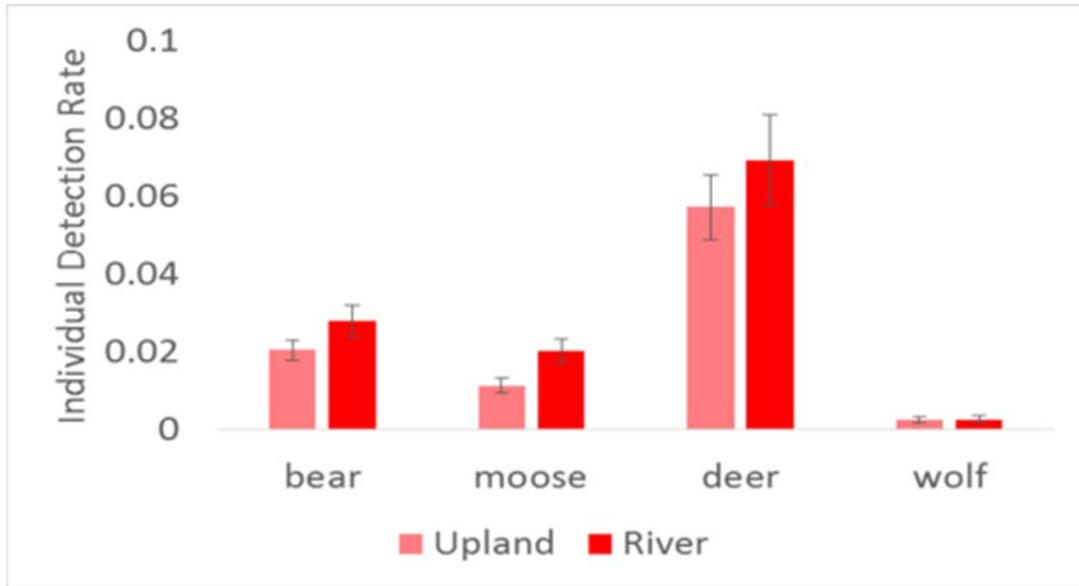
**Figure 7: Individual detection rates of bear, moose, deer and wolf of all cameras deployed in Mining and Upland treatments.**

Within mining bear and moose were detected more often in habitat on the developed side of the river; this trend was reversed for deer and wolf (Figure 8).



**Figure 8: Individual detection rates of bear, moose, deer and wolf of cameras deployed on the developed and undeveloped side of rivers within Mining activity**

In the upland control cameras, all species preferred habitat closer to the river, compared to upland habitat (Figure 9).



**Figure 9: Individual detection rates of bear, moose, deer and wolf of cameras deployed close to a river and in the uplands, away from Mining activity.**

## OUTCOMES AND LESSONS LEARNED

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Data have been provided above and several papers are expected to be published in 2015.

## PRESENTATIONS AND PUBLICATIONS

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### Reports:

Three internal reports have been prepared and are currently in review:

- Moose 2010 – 2012 Summary Report;
- Wolf Final Report; and
- Camera 2010 – 2014 Summary Report.

### Publications:

Publications are expected on the following topics in 2015:

- moose habitat use and selection in a highly industrialized environment;
- examining wolves' fine-scale selection for snow conditions using snow tracking data; and
- the energetic implications of travelling through snow.

## RESEARCH TEAM AND COLLABORATORS

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Institution: University of Alberta

Principal Investigator: Stan Boutin

Name	Institution	Degree	Start Date	Completion Date
Amanda Droghini	University of Alberta	M.Sc.	Fall 2013	2015
Eric Neilson	University of Alberta	Ph.D.	Spring 2013	2016
Emily Chow	University of Alberta	B.Sc.		2015
Brynlee Thomas	University of Victoria	B.Sc.		2015

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

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# Wildlife Observation Database

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Work Completed

**COSIA Project Number:** LJ0163

**Academic Institution:** Teck Resources Limited

**Industry Champion:** Teck Resources Limited

## PROJECT SUMMARY

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Teck Resources Limited developed a database to monitor rare and/or unusual wildlife sightings and report wildlife mortalities for their Coal operations. The intent of the database is to capture locational data, species information, and habitat features that could be used to inform management decisions for mine plans (e.g., if a grizzly den was identified, the information would be shared with the Mining Engineering to develop an avoidance or mitigation plan, to prevent or limit disturbance of the den). Mortalities are tracked anecdotally, but could be used in future management plans, if for example, a section of a road showed an exceptionally high number of vehicle collisions, mitigation plans could then be developed to lessen the impact. The database does not track elk, deer or sheep unless they are injured, deceased or rare at a particular site. Typically these species are abundant at Teck's coal operations. All mine employees and visitors contribute to the database by filling out a wildlife observation form or by directly calling the mine's environmental personnel.

## PROGRESS AND ACHIEVEMENTS

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The database has been up and running since 2009. It is an ongoing project that will continue for many years as part of operations.

## OUTCOMES AND LESSONS LEARNED

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The database is storing important locational and species information. The information is currently being used for a portion of the Wildlife Baseline Assessment for Teck's Environmental Impact Assessment applications.

## PRESENTATIONS AND PUBLICATIONS

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Internal presentations have been made during Teck Environmental Conferences, but there were no external presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Teck's Elkview Operations

Principal Investigator: Lanny Amos, Environmental Officer

<b>Name</b>	<b>Institution</b>	<b>Degree</b>	<b>Start Date</b>	<b>Completion Date</b>
Dan Vasiga	Teck Coal - SPO	Data Management Lead	2009	2011
Tim Chala	Teck Coal - LCO	Environmental Officer	2009	Ongoing

Industry Collaborators: None

# Environmental Research and Monitoring

# Horizon Lake Monitoring

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Program Underway

**COSIA Project Number:** LJ0011

**Academic Institution:** Canadian Natural Resources Limited

**Industry Champion:** Canadian Natural Resources Limited

## PROJECT SUMMARY

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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, hereafter referred to as Horizon Lake, development 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

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### FISH POPULATION

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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. Arctic grayling were captured in Horizon Lake in 2013 and were also captured in the Tar River. In total, 10,997 fish were caught during fish sampling efforts in 2013. Forage fish species comprised 86% of the total 2013 catch.

The sampling in 2010 and 2011 identified the apparent decline of brook stickleback and finescale dace in Horizon Lake. This decline was not apparent in 2012 or 2013 for brook stickleback and this may be attributed to the increase in aquatic vegetation in the littoral zones of the lake. The finescale dace population appears to currently be limited in the lake and the resulting catch numbers are low. Lake chub catch numbers, although high compared

to other forage fish species, have been steadily declining since first captured in 2009. The decline in lake chub catch numbers may be a result of the increase in fathead minnow utilizing similar habitat. The increase in the proportion of species, such as white sucker and longnose sucker, in the lake likely indicates the community structure is still stabilizing. Continued sampling should indicate if these trends continue. Slimy sculpin and arctic grayling were sampled throughout the lake but the catch numbers are still low for these species. Large bodied fish continue to be scanned and implanted with PIT tags and recaptures of these tagged fish is increasing.

### **FISH ABUNDANCE AND PRODUCTION ESTIMATE**

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Hydroacoustic surveys conducted in 2013 were utilized to make fish abundance and production estimates. Based on the four species considered in the analysis due to their abundance in the lake (fathead minnow, lake chub, longnose sucker and white sucker, the estimated fish production in Horizon Lake ranged from 1,900,351 g/yr to 2,279,940 g/yr. The majority of the production for all surveys was from sucker species. The production:biomass (P:B) ratio was 0.24 for all four surveys, which is on the low end of published ratios but within the reported range. Parameters used for the production estimates in 2013 were the same used for the production estimate calculated from the mark recapture abundance estimates in 2012. Hydroacoustic surveys and mark recapture programs are continuing to be utilized to determine fish abundance and production estimates.

### **WATER QUALITY**

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Temperature profiles in Horizon Lake in 2013 indicated high variability, between 7°C at the bottom and 25°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 current fish species. Field measurements of pH from the vertical profile data indicate variability in pH in the water column ranging from 7.2 and 8.5, which are within the tolerance ranges of the lake community of fish. Dissolved oxygen (DO) concentrations indicated that DO is not limiting within the upper 5 m of the lake for any of the fish species anticipated to populate 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.

Through the 2008 to 2013 monitoring period, total alkalinity, DOC and total dissolved solids (TDS) were higher during winter and decreased during the open water season. The total suspended solids (TSS) values in 2013 were higher during the spring compared to previous years. In 2013, total phosphorus concentrations were also higher during spring, reflecting the higher TSS concentrations caused by high flows. Total nitrogen concentrations remained similar throughout 2013. Chlorophyll *a* concentrations were higher in the summer, with the peak concentration in August. This is 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 2013 was generally similar to previous years, with the exception of the spring peaks in concentrations of TSS and associated parameters (nutrients and some metals), low variation in total nitrogen concentration, and lower concentrations of TDS and other ions during the open water season.

### **SEDIMENT QUALITY**

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Sediment samples are collected every other year and were not collected in 2013. Based on 2012 samples, the sediment layer in Horizon Lake is continuing to develop. Sediments collected from Horizon Lake consisted mostly of silt and TOC concentrations were low compared to natural lakes in the region. Concentrations of all other parameters tested were below sediment quality guidelines in 2012.

## PLANKTON

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Phytoplankton abundance, biomass and richness estimated in 2013 showed typical seasonal patterns with higher values in August and lower values in May and October. Cryptophytes and cyanobacteria were the dominant phytoplankton group by abundance and biomass, depending on the month.

In general, cyanobacteria has accounted for the largest biomass of phytoplankton over the past six years, and tends to peak in August or September. Abundance and biomass of other groups has varied in importance from month-to-month and among years.

Zooplankton abundance and biomass has varied monthly and annually, with no persistent seasonal or temporal trends. Biomass and abundance in 2013 were similar to all years except for 2012, when rotifers, cyclopoids, and ciliates were present in high numbers. Taxonomic richness in 2013 was similar compared to previous years. Overall, rotifers and cyclopoid copepods alternated in co-dominance of the zooplankton assemblage over the last six years; however, cyclopoids have decreased in number since the start of the study, while rotifers have increased.

Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both spatially and temporally. Throughout the six years of monitoring at Horizon Lake, this natural variability has been partially observed as fluctuations in phytoplankton and zooplankton species diversity and community composition. Despite the variability, data show that the community is becoming more diverse. The fluctuating dynamics in phytoplankton community composition are likely caused by short-term changes in nutrient composition and other physical parameters (e.g., fluctuations in water depth, wind mixing, and temperature) within the lake. As grazers on phytoplankton, zooplankton will not only respond directly to the changes in the phytoplankton community, but will also influence several aspects of the phytoplankton community.

## BENTHIC INVERTEBRATES

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The benthic invertebrate community in Horizon Lake was characterized by low density and richness in 2013, as expected, although both density and taxonomic richness have increased at several sites compared to the start of the study. By 2013, the lake bottom had accumulated a layer of sediment that was similar to 2012, but thicker than those encountered during previous years. However, the sediment layer was still relatively thin, which limited the available habitat and food for the benthic community. As in 2011 and 2012, the benthic community in open-water and near-shore areas was dominated by midges and aquatic worms in 2013; 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. This result suggests that aquatic worm populations are becoming established in mid-lake bottom sediments.

## AQUATIC MACROPHYTES

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The macrophyte community in Horizon Lake has continued to expand since the 2010 survey. Natural colonization of macrophytes has contributed to the greatest component of the expansion. The transplanted or introduced species are doing well and expanding throughout the littoral areas of the lake. Of the naturally colonized aquatic vegetation observed in Horizon Lake during the 2012 lake survey, submergent vegetation dominated the plant assemblage. The species that have naturally colonized the lake, and those planted, are sufficient to provide the developing fish community in Horizon Lake with suitable habitat. Further development of the macrophyte community in Horizon Lake should continue to develop naturally over the next several years.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Canadian Natural Resources Limited

Principal Investigator: Not Applicable

Industry Collaborators: None

# Swamp Reclamation in the Oil Sands Region: Investigation into Swamp Reclamation and Revegetation

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**Project Type:** Single Industry Project (SIP)

**EPA:** Land

**Status:** Idea

**COSIA Project Number:** LJ0114

**Academic Institution:** Native Plant Solutions – Ducks Unlimited Canada

**Industry Champion:** Suncor Energy Inc.

## PROJECT SUMMARY

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The project is the second phase of an investigation into swamp reclamation in the Oil Sands Region. The first phase was an in-depth review of swamp ecology, hydrology and reclamation, and an analysis of the knowledge gaps that impede our 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 inform the reclamation of swamp wetlands by the oil sands industry through the investigation of vegetation, soils, hydrology and landform elements in natural conifer swamps in the region. The three- year study begins in 2016 with the installation of groundwater wells and piezometers which will inform understanding of swamp hydrology including the position of water tables, the vertical and horizontal movements of groundwater, 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. Microtopography (hummocks and hollows) of the sites will also be studied.

In the summer of 2017 soils will be classified and described within each site, and the variability of chemical and physical soil characteristics within and between swamp study sites will be examined. Reclaimed wetland sites will also be studied to help identify those hydrological, chemical and physical variables important for reclamation of swamp processes. Groundwater, soils and vegetation in reclaimed sites will be compared to similar parameters in natural conifer swamps to determine which characteristics are most important for re-establishing swamp processes.

## PROGRESS AND ACHIEVEMENTS

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Potential study sites were identified remotely by GIS analysis in 2014. Twenty of the identified sites were accessed in August 2014 by helicopter survey. Sites were assessed and selected based on swamp characteristics, site accessibility, position in the landscape and connection to other wetland types.

## DELIVERABLES AND MILESTONES

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An internal report providing the details of the 2014 site reconnaissance trip was produced.

## OUTCOMES AND LESSONS LEARNED

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No outcomes or lessons have been learned so far on this project.

## PRESENTATIONS AND PUBLICATIONS

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There were no presentations or publications in 2014.

## RESEARCH TEAM AND COLLABORATORS

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Institution: Native Plant Solutions/ Ducks Unlimited Canada

Principal Investigator: Lisette Ross

Industry Collaborators: None