COSIA Land EPA

2017 Mine Site Reclamation Research Report

April 2018

Introduction

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

Please contact the Industry Champion identified for each research project if any additional information is needed. COSIA Land EPA 2017 Mine Site Reclamation Research Report. Calgary, AB: Canadian Natural Resources Limited*; Imperial; Suncor Energy Inc.; Syncrude Canada Ltd.; Teck Resources Limited.

* In 2017, Canadian Natural Resources Limited purchased Shell Canada Energy's Albian Sands operation. All COSIA Land EPA projects previously supported by Shell Canada Energy were transferred to Canadian Natural Resources Limited.

This report is funded by:

Canadian Natural Resources Limited

Imperial

Suncor Energy Inc.

Syncrude Canada Ltd.

Teck Resources Limited

April 2018

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Aurora Soil Capping Study: Program Overview

COSIA Project Number: LJ0201

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

The Aurora Soil Capping Study (ASCS) is a study to address two issues for oil sands mine operators in the Athabasca Oil Sands Region: 1) the effect of naturally-occurring petroleum hydrocarbons (PHCs) in soil reclamation materials and overburden on environmental receptors (e.g., plants, surface water and groundwater), 2) the appropriate use of coarse-textured reclamation materials to create soil moisture and nutrient conditions similar to the predevelopment upland forest conditions in the area, and 3) the appropriate tree species and revegetation strategy for quick establishment of a forest stand and promote development of the understory community. The ASCS is designed specifically for the purpose of addressing these issues, consisting of several, replicated soil cover design treatments with vegetation subplots. Learnings from this work is intended to provide guidance on the appropriate soil cover design and capping depth to mitigate any risks associated with naturally-occurring PHCs, as well as the appropriate vegetation species and revegetation practices to promote the establishment of key vegetation species and their plant community. 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 mine and is situated on the Fort Hills overburden dump. The overburden of Fort Hills dump consists dominantly of lean oil sand (LOS), which contains petroleum hydrocarbons (PHCs) that generally range from <1% to 7% oil in soil. LOS is removed in the mine process to expose the oil sand ore body and is disposed in constructed overburden landforms. Soil materials available for reclamation at the Aurora North mine are generally coarse-textured, glaciofluvial surficial geologic materials. They also contain oil sand materials in variable proportions of the soil matrix, in the form of discrete bands (layers) or aggregated particles of PHCs that can range in size from pebbles to boulders. The oil sand materials present in the soil reclamation material have measurable PHC concentrations; however, their total concentration within the entire soil reclamation matrix is significantly lower than the PHC concentration present in LOS.

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

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

RESEARCH TEAM AND COLLABORATORS

The ASCS has involved a number of research disciplines for study within the project area. A list of these research projects, including the primary investigator and their classification within COSIA are provided in the table below. A more detailed description of the individual projects and their results to date can be found in their accompanying sections of this document. The project Water and Carbon Isotope Methods Development was completed in 2015.

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

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

COSIA Project Number: LJ0099

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 6 of 7 (one-year extension)

PROJECT SUMMARY

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

The objectives of the project are the following:

1. develop a better understanding of the physics associated with water and energy balance in reclamation cover prescriptions containing oil sand materials (aggregated oil sand material [AOSM]) overlying lean oil sand overburden;
2. determine optimal soil cover design options and placement thickness(es) of peat-mineral mix and upland surface soil for soil-moisture, which will result in reclamation soil cover designs equivalent to natural a/b ecosites of the region;
3. evaluate the possibility of separate placement of mineral soil layers (Bm, deeper subsoil lifts) containing AOSM for improving soil water retention and being worthy of consideration for salvaging separately; and
4. develop a water dynamic model for soil cover designs consisting of coarse textured soils containing AOSM over lean oil sand overburden.

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements completed in 2017. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for earlier work completed.

Thermal Properties of Peat: Mineral Mixes

Ying Zhao used a dual-probe heat-pulse (DPHP) method to measure the thermal properties of 84 soil columns, consisting of six peat-mineral soil mixtures, spanning wide ranges of water contents and bulk densities. Generally, the thermal conductivity (λ) of peat soil was about one fifth of the sandy soil under unfrozen and frozen conditions, which subsequently increased with increasing sand content, water content, and bulk density. The extended de Vries model could successfully predict the soil thermal conductivity and thermal capacity under unfrozen and frozen conditions.

Data collection was conducted in the spring of 2017. Two manuscripts were written from this study: one has been submitted to a scientific journal and the other is under review.

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

Eric Neil's M.Sc. thesis work investigated the water repellency and hydraulic properties of aggregated oil sand materials (AOSM), at various stages of weathering, collected in subsoil reclamation materials at the Aurora North Mine. Some hydraulic properties of AOSM were examined in order to improve the understanding of the effects of AOSM on the overall soil water dynamics of coarse-textured reclamation soils.

The first study investigated the water repellency (WR) of AOSM in terms of degree (maximum water contact angle [CA]) and persistence (water drop penetration time [WDPT]). AOSM showed considerable variability in water repellency (WR), with CAs ranging from 0° to 129°, where ≥ 75% showed some level of WR (CA > 0). The mean WDPT was 824 seconds (s), with a coefficient of variation (CV) of 221%. Approximately 1/3 of the samples were considered hydrophilic (WDPT ≤ 5 s), less than 1/3 were slightly water repellent (WDPT from 5 to 60 s) and more than 1/3 were strongly to extremely water repellent (WDPT ≥ 60 s). However, despite the apparent WR of these materials as indicated by the CAs and WDPTs, the majority of samples allowed water absorption to commence within 60 seconds of contact with water.

The second study measured the water infiltration rates of AOSM and surrounding soils using a miniaturized infiltrometer. AOSM showed significantly lower infiltration rates in the macropore suction range than the surrounding soil (differences of up to 2 orders of magnitude at equivalent pore suction values). Additionally, it was found that the petroleum hydrocarbon content of AOSM was positively correlated to WR and negatively correlated to water infiltration rate, suggesting that the hydrocarbons within AOSM are producing WR and reducing the flow of water. Furthermore, AOSM experience a decrease in water infiltration not only due to WR, but also from a general reduction in conducting porosity due to the presence of hydrocarbons within the pore structure of the AOSM.

Eric completed a paper that was accepted in 2017 but will be published in 2018. He is scheduled to defend his M.Sc. thesis in February 2018.

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

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

Preliminary data analysis shows that there is hydraulic redistribution of soil-water and that jack pine can take up water from soil below 1 m under drought conditions. Ivanna is currently writing her thesis.

LESSONS LEARNED

Thermal Properties of Peat-Mineral Mixtures Measured by the Dual-Probe Heat Pulse Method

Highlights from Dr. Zhao's study are that the thermal conductivity (λ) of peat soil from the ASCS was about one fifth of that of the coarse textured subsoil of the ASCS under unfrozen and frozen conditions. The extended de Vries (1963) model accurately predicted the soil thermal conductivity and thermal capacity under both unfrozen conditions and frozen conditions. This implies that relative to a sand cover, the peat coversoil of the ASCS may substantially delay the temperature drop in early winter as well as that of the temperature rise in late spring. Furthermore, the de Vries model could be used in modeling the thermal properties of coversoil materials of different peat-mineral mixtures.

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

Highlights from Eric's study are that water repellency (WR) of AOSM collected at the Aurora North Mine operation is prevalent, but water infiltration still occurs within 60 s of contact with water, albeit at a reduced rate compared to the surrounding soil. This implies that AOSMs in subsoil may slow down soil water flow, but it is unlikely that it will create preferential flow as is the case in many hydrophobic soils. Furthermore, AOSMs in soil layers placed directly below the root zone may increase water retention time in the root zone, by decreasing the infiltration rates below the root zone.

LITERATURE CITED

de Vries, D.A. 1963. The thermal properties of soils. In R.W. van Wijk (ed.) Physics of plant environment. North Holland, Amsterdam, p. 210-235.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in this reporting period.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

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

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Trent Pernitsky	University of Saskatchewan	M.Sc.	2011	2015
Meghan Rosso	University of Saskatchewan	M.Sc.	2012	2016
Henry Chau	University of Saskatchewan	Ph.D.	2008	2014
Lindsay Tallon	University of Saskatchewan	Ph.D.	2010	2014
Min Li	University of Saskatchewan	Ph.D.	2011	2016
Eric Neil	University of Saskatchewan	M.Sc.	2013	2018
Wei Hu	University of Saskatchewan	Post-Doctoral Fellow	2013	2015
Mark Sigouin	University of Saskatchewan	M.Sc.	2013	2016
Ivanna Faucher	University of Saskatchewan	M.Sc.	2014	Ongoing
Brianna Zoerb	University of Saskatchewan	B.Sc.	2012	2016
Ying Zhao	University of Saskatchewan	Visiting Professor	2016	2017

Aurora Soil Capping Study: Hydrocarbon Degradation and Mobility

COSIA Project Number: LJ0219

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 7 of 7 (Final summary)

PROJECT SUMMARY

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

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

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

PROGRESS AND ACHIEVEMENTS

In 2011, Kyle Scale began a M.Sc. that was extended to a Ph.D. program. His study focused on the temporal and spatial variability in gas flux and methane oxidation potential of reconstructed soils of the ASCS. The study evaluated gas production and oxidation for a range of LOS PHC concentrations to evaluate the soil gas environment of a range of soil cover designs on LOS and its potential implications to plant growth. 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, oxidation and advection/diffusion were evaluated to develop a numerical predictive and explanatory model to estimate the risk of gas-related toxicity to plant growth in the closure reclamation landscape.

In 2017, Kyle Scale's PhD thesis was finalised and successfully defended in July. Kyle was awarded a Doctoral Degree in Environmental Engineering in October, 2017.

Following review by the industry partners, two manuscripts were submitted for publication in 2017 (in addition to the two that had previously been submitted). One was accepted and the other remains in review. A paper reported in 2016 as published online ahead of print has now been formally published in Volume 4, No 6 of *Env. Geotechnics*.

LESSONS LEARNED

The lessons learned from completed study are outlined below.

- Differences in soil cover design in the uppermost 0.1-0.3 m did not significantly alter the O_2 pore-gas concentration in the intermediary layer of subsoil or in the LOS at a depth of 0.5 m below ground surface.
- Bulk density was found to be correlated to O_2 and CO_2 pore-gasses in the uppermost horizon of LOS. Rates of CH_4 oxidation appear to have been elevated at lower LOS bulk densities based on reduced pore-gas concentrations of O_2 and elevated pore-gas concentrations of CO_2. On the other hand, rates of CH_4 oxidation appear to have been restricted at higher LOS bulk density based on elevated pore-gas concentrations of O_2 and reduced pore-gas concentrations of CO_2.
- Based on the reclamation soil and LOS overburden of this study, the results suggest a thicker soil capping thickness (≥1 m) over LOS overburden may require a bulk density <1.5 Mg/m^3 in order to maintain sufficient pore-gas O_2 concentrations in the plant-rooting zone of the soil reclamation cover, while allowing sufficient oxidation of CH_4 in the uppermost horizon of the LOS. If a thinner soil cover (≤1 m) is placed, a bulk density >1.5 Mg/m^3 (bulk density of study ranged from 1.5-1.8 Mg/m^3) may be necessary to maintain sufficient pore-gas O_2 concentrations in the plant-rooting zone of the soil covers, while allowing sufficient oxidation of CH_4 in the uppermost horizon of the LOS.
- Volumetric water content also plays an important role in the oxidation of pore-gas CH_4. This study found the capability of the LOS to oxidize pore-gas CH_4 may be limited when the volumetric water content of the LOS is approximately less than 15% and greater than 24%.
- Based on the study findings, the design of the soil cover system appears to be less impactful to pore-gas dynamics than the characteristics (i.e., bulk density) of the LOS overburden landform.

PRESENTATIONS AND PUBLICATIONS

Published Theses:

Scale, K.O., 2017. Pore-gas dynamics in overburden and reclamation soil covers. Ph.D. thesis, Department of Civil, Geological & Environmental Engineering, University of Saskatchewan.

Journal Publications:

Scale, K.O. and Fleming I.R. 2017. The Role of Pore-gas Dynamics in Guiding Reclamation Practices. *Environmental Geotechnics*. Accepted July 2017. Will be available online at ice/jenge.

Scale, K.O. and Fleming I.R. 2017. Pore-gas Dynamics in Overburden and Reclamation Soil Covers. *Environmental Geotechnics*, pp.1–15, Published online: Oct. 2017 https://doi.org/10.1680/jenge.17.00016

Scale, K.O., Korbas, T.S. and Fleming, I.R. (2017) Degradation and Mobility of Petroleum Hydrocarbons in Oil Sands Waste. *Environmental Geotechnics*, 4(6), pp. 402–414. (Reported 2016 as published online ahead of press).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Ian Fleming

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Tomasz Korbas	University of Saskatchewan	M.Sc.	2010	2013
Kyle Scale	University of Saskatchewan	Ph.D.	2011	2017

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

COSIA Project Number: LJ0100

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 5 of 6 (one-year extension)

PROJECT SUMMARY

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

Through improved access to soil resources, tree species may depend on symbiotic microbes such as ectomycorrhizal (EM) fungi for establishment, increased growth or survival. EM fungi differ widely in their influence on tree hosts such that shifts in the composition of EM fungal communities may have important consequences for tree and stand productivity. The importance of EM fungi on above- and below-ground plant growth and the role that vegetation and soil play in EM fungi development is poorly understood in the natural and reclaimed environment.

At the Aurora Soil Capping Study, a number of soil cover design treatments and planted tree species are available to evaluate the effect of soil and vegetation on EM fungi presence, and conversely, if they have an effect on vegetation growth. The objectives are to investigate the effects and potential of different soil cover and capping depth treatments on:

1. tree establishment and growth, including rooting behavior;
2. plant communities; and
3. the composition of ectomycorrhizal fungal communities and their role in vegetation growth.

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

PROGRESS AND ACHIEVEMENTS

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

Jana Bockstette (M.Sc. candidate) has led growth measurements of all trees in the capping treatments between 2012 and 2014. Jana continued to write her thesis in 2017 and plans to defend in the coming year.

Shauna Stack (M.Sc. candidate 2016) has continued the annual tree measurements and is synthesizing the entire growth data set (2012-2016) for her thesis. In 2017, she started to compile and analyze the tree growth data to relate them to edaphic and climatic variable that were measured over the same period. Early analysis indicates that aspen and pine grow taller in the treatments with forest floor material than treatments with peat or no coversoil material. Spruce trees have shown minimal differences in their response to different capping materials. In addition, the arrangement of the different capping materials, tree composition and tree density also affected seedling growth. In 2017, an additional study was created that studies the impact of fertilizer addition on seedling growth on peat. This study is based on preliminary work by Jana Bockstette, which showed that tree seedlings could benefit from a specific addition of phosphorous and potassium when growing on peat.

Simon Bockstette who explored rooting behavior of trees as a function of capping material and the configuration of their placement, successfully completed and defended his PhD thesis in 2017.

Objective 2: Effects of capping treatments on plant communities

Caren Jones (M.Sc.) successfully published her work on plant recolonization from patches of salvaged forest floor material, which was executed on this research site. The manuscript was published in the journal Applied Vegetation Science.

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

Natalie Scott completed and successfully defended her thesis in 2017.

Dr. Greg Pec finished his PDF position in 2017. He summarized and synthesized the longer-term results of the early ectomycorrhizal fungal community development on this reclamation site. This manuscript is currently prepared for publication in the journal, Ecosystems.

LESSONS LEARNED

Below are some key outcomes from the study work completed in 2017.

- Ectomycorrhizal (EM) fungi show strong preference for particular species of trees, with a lag in response to different coversoils used in reclamation. Early forest floor material soil placement retains some of the EM fungal community that was present before salvage (determined by comparing with undisturbed reference soil sites). Conversely, peat derived from a non-upland environment (water-saturated bogs and fens) does not contain EM fungi that is associated with an upland soil environment, and thus, contains an assemblage that is less like natural upland soils than forest floor coversoil.
- The composition of an EM fungal community on a given tree species is not influenced by whether trees are planted as single species or mixed-stands. In other words, the species richness and composition of EM fungal communities in mixed-species stands is a result of additive effects, a combination of the EM fungi of single species stands. There are no synergistic effects of tree species diversity on EM fungal communities, at least in early-successional stands.

- Planting a mixture of tree species can result in belowground over-yielding (i.e. mixed species stands have more root biomass than single species stands at the same age and density), but this response appears to be dependent on the coversoil type and the associated growing conditions. Likely, the over-yielding is the result of reduced belowground competition due to phenological rooting differences among species. However, this effect could not be observed in a soil type (peat) that had conditions that were unfavourable to early seedling growth (excessive soil moisture and low soil temperatures), which delayed starts to the growing season.

PRESENTATIONS AND PUBLICATIONS

Published Theses:

Bockstette, S. 2017. Roots in reconstructed soils – how land reclamation practices affect the development of tree root systems. PhD Thesis, 122 pages, University of Alberta.

Scott, N. 2017. Role of host identity, stand composition, soil type, and disturbance severity in structuring ectomycorrhizal communities in the boreal forest. MSc Thesis, 133 pages, University of Alberta.

Journal Publications:

Jones, C.E. and S.M. Landhäusser. 2017. Plant recolonization of reclamation areas from patches of salvaged forest floor material [online]. Applied Vegetation Science. Doi:10.1111/avsc/12350.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser and Justine Karst

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Simon Bockstette	University of Alberta	PhD	2011	2017
Jana Bockstette	University of Alberta	M.Sc.	2013	ongoing
Caren Jones	University of Alberta	M.Sc.	2013	2016
Stefan Hupperts	University of Alberta	M.Sc.	2014	2016
Natalie Scott	University of Alberta	M.Sc.	2015	ongoing
Shauna Stack	University of Alberta	M.Sc.	2016	ongoing
Greg Pec	University of Alberta	Postdoctoral fellow	2016	
Jake Gaster	University of Alberta	M.Sc.	2012	2015
Shanon Hankin	University of Alberta	M.Sc.	2012	2015
Ashley Hart	University of Alberta	Summer Assistant		
Trevor de Zeeuw	University of Alberta	Summer Assistant		
Robert Hetmanski	University of Alberta	Summer Assistant		
Fran Leishman	University of Alberta	Field Technician		
Pak Chow	University of Alberta	Lab Technician		

In collaboration with the Industrial Research Chair in Forest Land Reclamation, University of Alberta.

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

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Collaborators: Alberta Innovates

Status: Year 4 of 5 (one-year extension)

PROJECT SUMMARY

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

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

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

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements from the 2017 work conducted under Objective 2. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for Objective 1. Objective 3 is ongoing and results will be reported in future update(s).

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

Potential nutrient release of carbon (C), nitrogen (N), and phosphorus (P), through mineralization was measured for two coversoil types (forest floor material [FFM] and peat), which are used at the Aurora Soil Capping Study. On a per kilogram of soil basis, the two materials released comparable amounts of N (111 to 118 mgN kg^{-1}). However, when results were normalized based on each material's organic C content, N release was six times greater for FFM than for Peat. This outcome is in accordance with results of previous studies. In addition, overall C mineralization and P release rates were over one order of magnitude higher with FFM than with Peat. However, when compared to N, P release seemed to be controlled more by abiotic processes than by organic matter mineralization. While the

FFM material overall released more N and P, it also degraded faster. Based on these results, it appears Peat may provide a smaller release of N during early vegetation growth and soil nutrient cycling establishment, but a more stable release over the long-term.

A nutrient sorption experiment was also conducted in order to evaluate the ability of different soil reclamation materials and substrates to chemically retain ammonium, nitrate and phosphate. Five materials involved in the ASCS were considered in this experiment: Peat, FFM, blended B/C subsoil horizons (“SUB”), lean oil sand (“LOS”) and tailing sand (“TS”). Results showed that Peat, SUB and LOS were able to significantly immobilize phosphate, while FFM and TS had virtually no sorption capacity. Results with mineral N did not show clear patterns, but suggested overall that the actual sorption of N compounds on each material was negligible compared to biological processes involved in N biogeochemical cycling.

LESSONS LEARNED

Below are some key outcomes from the work conducted under Objective 2. Please see earlier COSIA Land EPA Mine Site Reclamation Research Reports for previous learnings. Objective 3 is ongoing and outcomes are not included in the current report.

- In this study, the forest floor coversoil released comparatively more P than N when compared to the peat material. The ratio of N to P release rates was 15 for the forest floor coversoil, and was > 250 for the peat. Such a wide N/P ratio for the peat material may result in plant P deficiency in the early years post-reclamation, in the absence of some other form of nutrient addition either by land management (e.g., fertilization) or normal soil processes (e.g., lowering of pH through weathering and leaching of base cations, or release of organic acids in root exudates).
- Overall, results clearly showed a higher C, N and P release from the forest floor material than the peat material (when normalized on each material’s organic C content). Because coversoil materials salvaged for reclamation can vary in their organic matter content, it is also important to document nutrient release rates as a function of total soil weight. In our study, the forest floor material had a much higher organic matter content than the peat, and both materials released similar amounts of N as a function of soil weight. Reporting release rates both ways is recommended in order to compare results from different studies.

PRESENTATIONS AND PUBLICATIONS

Journal Publications:

Quideau, S.A., C. Norris, F. Rees, M. Dyck, N. Samadi, and S.W. Oh. 2017. Carbon, nitrogen and phosphorus release from peat and forest floor-based cover soils used during oil sands reclamation. Canadian Journal of Soil Science 97: 757–768.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

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

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
William Barnes	University of Alberta	M.Sc.	2013	2016
Najmeh Samadi	University of Alberta	PhD	2013	2015
Frédéric Rees	University of Alberta	PDF		
Pierre-Emmanuel Rogee	Université de Lorraine	B.Sc.	2016	2016
Sylyanne Foo	University of Alberta	B.Sc.	2016	2017
Shelby Buckley	University of Alberta	B.Sc.	2017	Ongoing

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

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 5 of 6 (one-year extension)

PROJECT SUMMARY

Vegetation and community development in reclaimed soils is dependent on nutrient pools, forms, and their availability for uptake. In large part, this is related to soil profile characteristics and the soil microbial community. Re-establishment of key vegetation species and communities present in the pre-disturbance landscape will require soil cover designs with similar soil nutrient conditions as undisturbed soils of the area.

A range of soil cover designs varying in material type and placement depth are being investigated at the Aurora Soil Capping Study (ASCS) to understand how the following soil nutrient priority areas are related to land reclamation of lean oil sand overburden using soil materials available in the mine leases of the area:

1. The ability to reclaim to some of the drier ecosites of the region including jack pine and aspen stands on coarse textured materials (a/b ecosites);
2. The effect of using salvaged soil material containing naturally occurring hydrocarbon materials on nutrient availability; and
3. The effect of different soil capping depths and soil cover types over lean oil sand overburden on plant growth and nutrient availability.

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

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

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

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

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

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

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

Study 3 – Using spatial pattern analysis of soil-plant relations to determine the success of land reclamation

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

Research Question 2 – Are there ways to tie recognition of spatial patterns into tracking successional trajectories and therefore defining land reclamation success?

Study 4 – Effect of mixing peat and sub-soil on nutrient and microbial dynamics

Research Question 1 - Does mixing peat and subsoil affect soil biogeochemical performance?

Research Question 2 - Does mixing Peat and subsoil affect microbial structure and function?

In order to compare and test the reclamation treatments investigated in the study a range of benchmark conditions have been added to the studies. This includes boreal forest stands of different ages and community characteristics, as well as sites recovering from disturbances such as wildfire or human disturbance (e.g., harvesting). This study will understand and compare their site characteristics, potential to recover (for disturbed sites) and if they are appropriate analogues for comparison to specific oil sands reclamation situations (focusing on soil biogeochemical processes).

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements for 2017. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports previously completed activities.

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

Jeff Hogberg (M.Sc.) completed processing and analysis of nutrient supply results in different nutrient pools from two different oil sands reclamation sites. He also created and tested two different multivariate analysis techniques to develop a similarity index for assessing reclaimed sites relative to other reclaimed sites and to natural reference sites. Jeff finished his thesis in January 2017 and a manuscript is currently under review.

Study 3 – Using spatial pattern analysis of soil plant relations to determine the success of land reclamation

Sebastian Dietrich (Ph.D. Candidate) submitted 2 publications for review in 2017, one of which was published, and one is still pending revisions. He is currently writing up his third and fourth manuscripts for publication. Sebastian is expected to finish in 2018.

Study 4 – Effect of mixing peat and sub-soil on nutrient and microbial dynamics

Will Kirby (M.Sc.) evaluated the effect of variable proportions of peat and mineral soil admixing, ranging from entirely peat to mineral subsoil to determine if similar function (soil respiration, biodiversity, carbon substrate use, carbon fixation) could be achieved compared to forest floor (upland surface soil). Next generation sequencing was performed on bulk soil samples from replicated soil treatments to examine fungal and bacterial community structure and diversity. Will finished in January 2017 and a manuscript is currently in review.

LESSONS LEARNED

The following are key outcomes of the activities completed in 2017:

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

There was no difference in early aspen and jack pine growth with similar coversoil depth but varying subsoil capping thickness (treatments of 30 cm peat coversoil underlain by 30, 70 and 120 cm of subsoil). Early aspen growth on the forest floor treatment (20 cm coversoil over 130 cm subsoil) was significantly greater than the peat treatments with 70 and 120 cm subsoil treatments and not significantly different than the shallow peat treatment (30 cm subsoil). The shallow peat and forest floor treatments had similar aspen growth as a reference comparison site with eary regrowth after fire. Pine growth for the all peat treatments and the forest floor treatment was not significantly different.

A similarity index using principal component analysis was performed to compare peat and forest floor coversoil soil nutrients, bioavailable nutrients and foliar concentrations. The results determined that early reclamation coversoils dominated by peat were dissimilar from forest floor coversoil and references. Specifically peat coversoil has greater soil N, K, S, Ca, and foliar Ca (aspen only), as well as lower foliar P, Mg and Mn.

Study 3 – Using spatial pattern analysis of soil-plant relations to determine the success of land reclamation

The greenhouse study using ASCS soil reclamation materials showed that admixing peat with subsoil had a positive effect on tree growth. This is possibly the result of higher phosphorus and potassium concentrations, as they significantly increased with increases in the mineral proportion. Additionally, adding peat biochar affected nutrient availability, but there was no significant response in tree growth.

Study 4 – Effect of mixing peat and sub-soil on nutrient and microbial dynamics

Gene sequencing revealed that early reclamation peat-mineral mix coversoil from the ASCS containing any proportion of peat had a microbial community assemblage that was more similar in diversity and phylogeny to pure peat. Although 50:50 peat to subsoil mixtures did display some functional similarity with the upland forest floor coversoil in terms of nutrients.

PRESENTATIONS AND PUBLICATIONS

Journal Articles

Dietrich, S.T., M.D. MacKenzie, J. P. Battigelli, and J. R. Enterina. 2017. Building a better soil for upland surface mine reclamation in northern Alberta: Admixing peat, subsoil, and peat biochar in a greenhouse study with aspen. Canadian Journal of Soil Science:1-14.

Published Theses

Hogberg, Jefferey. 2017. An alternate indicator for nutrient supply as part of ecosystem function, a component of reclamation success in the Athabasca oil sands region. M.Sc. University of Alberta. 115 pages.

Kirby, William. 2017. Rebuilding the boreal: analyzing the replicability of the bacterial community structure and soil functioning of forest floor mineral mix with peat subsoil admixtures. M.Sc. University of Alberta. 92 pages.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: M Derek MacKenzie

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Sawyer Desaulniers	University of Alberta	Field Technician		
Nicole Filipow	University of Alberta	Field Technician		
Arezoo Amini	University of Alberta	Lab Technician		
Maksat Igdyrov	University of Alberta	Field Technician		
Mark Howell	University of Alberta	M.Sc.	2012	2015
Sebastian Dietrich	University of Alberta	PhD	2014	On-going
Nduka Ikpo	University of Alberta	Lab Manager		
Jeff Hogberg	University of Alberta	M.Sc.	2015	2017
William Kirby	University of Alberta	M.Sc.	2015	2017
Monica Shandal	University of Alberta	Lab Technician		
Sylyanne Foo	University of Alberta	Lab Technician		
Patrick Neuberger	University of Alberta	Lab Technician		
Jhon Enterina	University of Alberta	Lab manager		
Jeff Battigelli	University of Alberta	Research Associate		
Shirin Zahraei	University of Alberta	Lab Manager		

Research Collaborators: Brad Pinno, University of Alberta

South Bison Hill Instrumented Research Watershed (Clearwater Overburden) Soil Capping Research Synthesis

COSIA Project Number: LJ0293 and LJ0312

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Year 1 of 1

PROJECT SUMMARY

In 1999, Syncrude Canada Ltd. (Syncrude) initiated the South Bison Hill Instrumented Research Watershed (SBHRW) study. This is a multi-disciplinary study to evaluate the performance of various reclamation capping thicknesses for saline/sodic (Clearwater Formation) overburden at Syncrude's Mildred Lake Mine. The study is located in South Bison Hills (SBH), which is a reclaimed Clearwater overburden landform. Originally the study included three one-hectare reclamation plots to test soil capping thicknesses of 35, 50 and 100 cm. It was later expanded as reclamation in the surrounding area was completed to more than 50 hectares of the landform in order to capture a broader range of research questions related to forest stand dynamics and wetland development. The larger study area included an additional plateau area of the landform, other slopes and aspects, as well as designed and opportunistic wetlands. Research and monitoring has taken place at SBHRW since the completion of reclamation.

South Bison Hill Soil Capping Research Synthesis

IIn 2012, Syncrude established a multi-disciplinary research team to synthesize existing data, collect additional data and conduct modelling to evaluate the current and future upland reclamation performance of different capping thicknesses on SBHRW.

The objective of the study was to determine the appropriate soil capping thickness that will achieve targeted vegetation growth/performance, while recognizing the potential of salt and sodium ingress from the overburden into the overlying reclamation cover.

Several reports, across a range of disciplines, were produced to support the high-level objective of the study and they were collated into a synthesis document. The synthesis document incorporated the results of the individual studies, as well as a risk assessment to identify potential performance risks associated with plant growth using a range of soil cover thicknesses.

Comparison of Overstory Response and Root Dynamics on Reclaimed South Bison Hill and Reference Sites

Following the synthesis document, supplemental overstory response and root studies were completed to better understand root dynamics at SBH in relation to a range of undisturbed, upland boreal forest sites in the local area. The specific objectives of the study were the following:

1. To compare tree site indices at SBH to boreal forests developed on two different soils with similar soil texture that are believed to represent lower and higher soil quality for tree growth.

   a. A Solonetzic Order soil with salinity, sodicity and structure limitations representing a lower quality soil; and
   b. A Luvisolic Order soil representing a higher quality soil that is a typical upland soil type for the region.

2. Measure and compare the rooting characteristics at SBH, non-mine Solonetz soil and non-mine Luvisol soil in the following ways:
   a. Root distributions (biomass and depth), and
   b. Root identification using DNA-based analysis.

This root study is a separate COSIA project (LJ0312), however it is part of the more comprehensive SBHRW program.

PROGRESS AND ACHIEVEMENTS

South Bison Hill Soil Capping Research Synthesis

The synthesis report details the construction and reclamation history at South Bison Hill, key results of the individual studies performed for the synthesis and a risk assessment evaluating the risk and capability of different capping thicknesses. The supporting individual studies are included as appendices in the synthesis report. The list of reports and a short summary describing the work performed for each study is provided below.

- *Syncrude Canada Ltd. South Bison Hill Soil Capping Research Synthesis*
    - Synthesis report detailing the construction and reclamation history at South Bison Hill, key results of the individual studies performed for the synthesis (including reports as appendices) and a risk assessment evaluating the risk and capability of different capping thicknesses.
- *Appendix A – South Bison Hill 2012 Research Synthesis – Root Sampling and Salinity Sampling Field Programs – Methodology and Results*
    - Field methodology details for root and soil sample collection and soil capping thickness summary for study inspection points.
- *Appendix B – A 10 Year Assessment of Evapotranspiration and Net Ecosystem Exchange from South Bison Hill*
    - Compilation of 10 years of measurements at SBH using the eddy covariance technique which measures growing season evapotranspiration and net ecosystem exchange to evaluate vegetation development and temporal patterns at SBH and compare those to other disturbed and undisturbed boreal forest aspen and mixed stands.
- *Appendix C – South Bison Hill research synthesis – vegetation overstory response to reclamation cover depth*
    - Measurement of tree growth performance to date at SBH to determine the response of tree growth with variable reclamation capping thickness. Comparison of tree growth across a range of capping thicknesses present at SBH with the range of natural variation present in the boreal forest region.
- *Appendix D –South Bison Hill 2012 Research Synthesis Root Distributions*
    - Quantifies root biomass distributions across the range of capping thicknesses present at SBH to determine if rooting patterns and depth at SBH are similar to boreal forest soils. Determining if root systems are impeded by Clearwater overburden and if the distributions indicate a minimum cover thickness requirement for root development.
- *Appendix E – Syncrude Canada Ltd. South Bison Hill Research Synthesis – 2012 South Bison Hill Salinity Study*
    - Evaluation of soil salinity and sodicity profiles at SBH to determine if upward salt and sodium migration has taken place at SBH. The effect of soil capping thickness on the magnitude of upward salt and sodium is evaluated by assessing concentrations across a range of soil capping thicknesses. Incorporates previous soil sampling campaigns at SBH to evaluate the changes of upward salt and sodium over time.

- *Appendix F – Numerical Modelling of the Long-Term Water Dynamics and the Impact of Soil Cover Depth on Transpiration from Reclamation Soil Covers over Shale Overburden*
    - o Model evaluating the sensitivity of water storage and potential evapotranspiration across a range of soil capping thicknesses and leaf area indexes (growth potential), applying the 60-year climate data record of the region.

Comparison of Overstory Response and Root Dynamics on Reclaimed South Bison Hill and Reference Sites

Field studies for the supplemental overstory response and root studies were completed in 2013 and reports were generated. The list of reports, and a short summary describing the key findings of each study, is provided below.

- *South Bison Hill Capping Study and Selected Natural Sites – 2013 Root and Soil Sampling Field Program – Methodology and Results (NorthWind Land Resources Inc., 2014)*
    - o Interpretation of the laboratory sample analyses results determined the Solonetzic and Luvisolic soil sites are representative of the Joslyn and Dover soil series, respectively (Turchenek and Lindsay, 1982).
    - o Subsoil pH, electrical conductivity (EC) and sodium adsorption ratio (SAR) samples were generally in the expected range for Solonetzic and Luvisolic soils. Soil pH of the Solonetzic site ranged from approximately 7 to 8.5, SAR approximately 4 to 12, and EC 0.5 to 2.5 dS/m. Soil pH of the Luvisolic site ranged from approximately 5 to 8, SAR <2 and EC <1 (except for one inspection point).
- *Comparison of vegetation overstory response on reclaimed saline-sodic overburden to non-mine reference sites (Integral Ecology Group and Gyula Gulyas, 2014)*
    - o Substantial differences in aspen overstory growth response between the Solonetzic and Luvisolic sites were found. The mean site index of the Luvisolic soil site was higher than the general range for d ecosites and more in the range of more-productive e ecosites (Beckingham and Archibald, 1996). The Solonetzic soil site was substantially lower than the general range for d ecosites and even lower than less productive b ecosites.
    - o SBH aspen overstory growth response of 35, 50 and 100 cm capping treatments fell between the two reference sites. Mean site index exceeded the Solonetzic soil site but was lower than the Luvisolic soil site. All capping thicknesses at SBH fell into the range of natural variability of d ecosites in the region (Beckingham and Archibald, 1996).
    - o Includes a comparison of tree height-growth performance (site index) at SBH with the non-mine reference sites that represent low (Solonetzic soil) and expected (Luvisolic soil) growth performance for uplands on fine textured parent geologic material in the area.
- *Comparison of Rooting Distributions for Vegetation Growing on a Reclaimed Saline-Sodic Overburden and Natural Undisturbed Landscapes (Van Rees, 2014)*
    - o Root biomass of the Luvisolic and Solonetzic soil sites were more than double the root biomass of the 15-year-old SBH sites.
    - o Approximately half of the root biomass of the reference sites was found in the forest floor layer. The root biomass within the mineral soil profile of the reference sites was comparable to the root biomass in the SBH capping treatments.
    - o Rooting trends for SBH capping treatments followed a similar pattern as the reference sites; the highest root biomass was at the surface and decreased exponentially with soil depth.
    - o Roots were present in both the Clearwater overburden and in the elevated EC and SAR zones of the Solonetzic soil site.

- *Identification of roots in South Bison Hill Capping Study and selected and natural soils (Karst and Landhäusser, 2014)*
    - o Roots of aspen and spruce trees growing at SBH were detected at similar depths as those growing at the reference sites.
    - o Tree roots were detected in the overburden of the SBH capping treatments for all depths (35, 50 and 100 cm capping thickness).

LESSONS LEARNED

South Bison Hill Soil Capping Research Synthesis

The report synthesis studies showed multiple lines of evidence that a capping thickness of 50 cm has been sufficient to ensure an equivalent land capability for forestry to date, with minimal increases in vegetation growth with capping thicknesses greater than 50 cm.

Soil-water modelling suggests a soil cover of 75 cm is sufficient in providing enough soil-water to vegetation during drought conditions. Soil cover thickness increases above 75 cm will see minimal increases in vegetation growth and allow for more salt ingress via diffusion processes, while reducing the amount of water released by the soil cover for downstream receptors (e.g., wetlands).

Comparison of Overstory Response and Root Dynamics on Reclaimed South Bison Hill and Reference Sites

The supplemental overstory and rooting study found the following:

- Tree growth performance on Clearwater overburden with capping thicknesses ranging from 35 to 100 cm is similar to reference upland forests in the region;
- Rooting patterns and depths of Clearwater overburden reclamation are similar to reference upland soils in the local study area; and
- Tree species planted on reclaimed Clearwater overburden landforms are rooting into the overburden.

LITERATURE CITED

Beckingham, J. and Archibald, J. 1996. Field guide to ecosites of northern Alberta. Special Report 5. Canadian Forest Service, Edmonton, Alberta.

Turchenek, L.W. and Lindsay, J.D. 1982. Soils Inventory of the Alberta Oil Sands Environmental Research Program Program Study Area. Alberta Oil Sands Environmental Research Program (AOSERP). Report 122 and Appendix 9.4. Alberta Environment, Research Management Division.

PRESENTATIONS AND PUBLICATIONS

Baker, T., Iverson, M. Straker, J. and Gulyas, G. 2014. Comparison of vegetation overstory response on reclaimed saline-sodic overburden to non-mine reference sites. Prepared by Integral Ecology Group.

Carey, S.K. 2013. A 10 Year Assessment of Evaporation and Net Ecosystem Exchange from South Bison Hill. McMaster University, School of Geography & Earth Sciences, Canada.

Garrah, K., Gulyas, G., Straker, J. and Thrower, J. 2013. South Bison Hill research synthesis – vegetation overstory response to reclamation cover depth. Prepared by Integral Ecology Group Ltd.

Huang, M., Barbour, L and Carey, S. 2012. Numerical Modelling of the Long-Term Water Dynamics and the Impact of Soil Cover Depth on Transpiration from Reclamation Soil Covers over Shale Overburden. University of Saskatchewan, Department of Civil and Geological Engineering and McMaster University, School of Geography and Earth Sciences.

Karst, J. and Landhäusser, S. 2014. Identification of roots in South Bison Hill Capping Study and selected natural soils. University of Alberta, Edmonton, Alberta.

Klohn Crippen Berger. 2013. Syncrude Canada Ltd. South Bison Hill Research Synthesis – 2012 South Bison Hill Salinity Study. Saskatoon, Saskatchewan.

NorthWind Land Resources Inc. 2013. South Bison Hill 2012 Research Synthesis – Root Sampling and Salinity Sampling Field Programs – Methodology and Results. Edmonton, Alberta.

NorthWind Land Resources Inc. 2014. South Bison Hill Capping Study and Selected Natural Sites – 2013 Root and Soil Sampling Methodology and Results. Edmonton, Alberta.

Syncrude Canada Ltd. 2013. South Bison Hill Soil Capping Research Synthesis – Mildred Lake Mine.

Van Rees, K. 2014. Comparison of Rooting Distributions for Vegetation Growing on a Reclaimed Saline-Sodic Overburden and Natural Undisturbed Landscapes. Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan.

Van Rees, K. 2014. South Bison Hill 2012 Research Synthesis Root Distributions. University of Saskatchewan, Department of Soil Science, Saskatoon, Saskatchewan. Revised January 2013 report.

RESEARCH TEAM AND COLLABORATORS

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Joel Hilderman	Klohn Crippen Berger	Senior Geoenvironmental Engineer		
Dr. Sean Carey	McMaster University	Professor		
Robbie Price	NorthWind Land Resources Inc.	Environmental Scientist		
Dr. Justine Karst	University of Alberta	Assistant Professor		
Dr. Lee Barbour	University of Saskatchewan	Professor and NSERC IRC		
Dr. Ken Van Rees	University of Saskatchewan	Professor		

Evaluating the Success of Fen Creation

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial, Canadian Natural Resources Limited

Status: Year 6 of 6 (one-year extension)

PROJECT SUMMARY

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

Three linked projects have been established with the purpose of answering specific questions associated with the creation of a hydrologically functioning, ecologically successful, carbon sequestering fen wetland and the incorporation of processed tailings materials into the construction.

Broad-scale objectives of the research have been to:

1. Identify strengths and weaknesses in the conceptual fen design;
2. Test the methods of construction including materials, their placement and the sensitivity of design characteristics, through modelling of water and contaminant flows;
3. Develop thresholds and milestones for hydrological, water quality and carbon sequestration rates or thresholds as monitoring tools; and
4. Determine the most suitable vegetation communities and reintroduction methods for fen reconstruction.

Sub-scale objectives have been to:

1. Determine if upland areas facilitate sufficient recharge flow to the fen, and if sodium salts (Na) and naphthenic acids (NAs) leach from tailings and how quickly they flush from the upland tailings aquifer;
2. Determine if transport and attenuation processes in fen peat hold these contaminants below plant toxicity thresholds in the rooting zone;
3. Determine if the fen sequesters carbon (C), and if revegetation strategies for the fen affect C accumulation;
4. Determine if different functional relationships exist for vegetation communities at the upland and fen due to moisture or nutrient conditions;
5. Identify the most successful and appropriate revegetation methods for respective species and how varying hydro-geochemical gradients and propagule inputs affect vegetation survival, composition, photosynthesis and transpiration; and
6. Determine whether microbial communities at the constructed fen reflect those at the reference fen sites, and determine if these communities develop the ability to degrade NAs.

PROGRESS AND ACHIEVEMENTS

Observations for 2017

The project's reference sites are referred to throughout this document and are comprised of a moderate-rich fen 'Poplar', poor fen 'Pauciflora' and a saline-spring 'Saline' fen wetland. Rich and poor denote the dominant vegetation assemblages. The Nikanotee fen is referred to as the constructed fen.

Reference fen hydrology

Poplar Fen receives groundwater discharge from a local flow system generated in adjacent topographic highs.

Contrary to fens with a regional groundwater connection, Poplar Fen does not receive supplemented groundwater discharge during dry periods, as its groundwater supply is recharged by local precipitation and consequently, Poplar Fen's water table flux is very susceptible to trends in rainfall.

Hydraulic connectivity between Poplar Fen and the surrounding landscape (with uplands and their underlying groundwater) is most dynamic during periods of high precipitation and water tables. However, during periods of low water availability, as seen through 2012 to 2017, this connectivity virtually shuts off.

Although fens can recharge uplands and groundwater respectively during these periods, the overall water fluxes become negligible due to low hydraulic conductivity of the lower fen peat substrate, and the weak hydraulic gradients that result. These feedbacks help to conserve sub-surface water in the fen during dry periods, thereby reducing potential drops in the water table and subsequent peat decomposition.

Evaluating carbon accumulation potential of a constructed fen

The growing seasons between 2013 and 2015 show a trend towards higher carbon sequestration in the fen. This is seen in the Gross Ecosystem Productivity (GEP) and Net Ecosystem Productivity (NEP) values. The largest difference in seasonal GEP values occurred between 2013 and 2014, -559 g C m^2 $Year^{-1}$ and -1080 g C m^2 $Year^{-1}$, respectively. Increased GEP in 2014 was a result of being the first full growing season with planted donor vegetation. 2014 through 2017 have experienced relatively stable yearly GEP values of -1080, -1090, -515 and -975 g C m^2 $Year^{-1}$, respectively, with much of the variation being attributed to the duration of seasonal observations (the 2016 study period was shortened considerably due to the Horse River Wildfire at Fort McMurray). Since 2015, seasonal trends in GEP show an increase in GEP in the early growing season, peak GEP values in the middle of the growing season, and reduced values towards the later stages of the growing season. Apparent seasonal trends in GEP show that the vegetation is adapting to the seasonal variations in environmental conditions and that they are wintering well.

From 2013 through 2015, the fen experienced a transition from a carbon source (+ve NEP) of carbon to a sink (-ve NEP), as shown by the observed NEP value, 124, -41 and -229 g C m^2 $Year^{-1}$, respectively. In these early years post construction, the vegetation matured, increasing in coverage and density, which resulted in considerable increases in the carbon uptake of the fen. However, on an annual basis since 2015, NEP values within the fen have stabilized at -229, -192 and -201 g C m^2 $Year^{-1}$, respectively. NEP stability within in the fen is a result of the relatively consistent biomass growth in fen vegetation coverage, achieved in 2015. However, it is important to note that *Typha* dominate the vegetation composition within the fen. Therefore, we are quantifying the partitioning of carbon between the *Typha* and the prescribed planted species. Partitioning the carbon budgets by the vegetation species will show how natural fen species are sequestering carbon in the fen outside of invasive species influence.

Surface and atmospheric controls on water use efficiency (WUE)

Since 2013, the constructed fen has experienced a consistent increase in average annual WUE values. Average (arithmetic) annual WUE values from 2013 through 2017 are 1.40, 2.59, 2.57, 2.97, 3.11 g C kg H_20^{-1} m^{-2} Day^{-1}, respectively. The increase in annual WUE from 2013 through 2017 is a result of the increasing vegetation surface cover and greater density. Increased vegetation cover across the fen impacts WUE by increasing the GEP through biomass accumulation and decreasing evapotranspiration (ET) through the reduction in openly ponded areas as a result of vegetation expanding into them. WUE data from 2016 and 2017 show vegetation coverage across the fen has remained relatively constant (similar to NEP, a result of the rapid growth in previous monitoring years).

Since planting in 2013, the constructed upland has experienced an increase towards higher annual WUE values. From 2013 through 2017 average annual WUE values are 1.25, 1.81, 1.34, 2.08 and 1.84 g C kg H_20^{-1} m^{-2} Day^{-1}. (Note: 2016 values are inflated because the measurements were only recorded during the peak productivity period.) A year-on-year trend towards a higher WUE is reflective of the upland vegetation growth and mirrored by NEP values. This vegetation is growing and transitioning to more mature species, which are more efficient with respect to water usage.

Average ET rates for the fen varied between 2013 and 2017, largely due to differences in the length of the annual observational period. However, data shows a general decreasing trend in average annual ET rates between 2013 to 2017, 2.95, 2.46, 2.72, 3.50 and 2.27 mm Day^{-1}, respectively. Average ET rates for 2016 are abnormally high due to bias introduced by the shortened observational period, which only had observations during the peak growing season. While precipitation inputs varied over the growing seasons, there are no significant correlations between precipitation inputs and ET. Decreasing average annual ET rates are a result of the decreasing coverage of ponded water by the growth of vegetation. As a result of the changing vegetation and observational periods, ET rates within the fen have yet to reach equilibrium.

In summary, as of 2017, the fen seems to have reached equilibrium with respect to carbon accumulation rates. Based on the results, ET and WUE within the fen are still evolving. WUE appears to be stabilising, and continued observations of ET will show how it is evolving. Based on other parameters, ET should begin to stabilise shortly, with future variability being a result of changes in precipitation inputs and energy inputs.

Compared to the fen, the carbon dynamics of the upland have developed at a slower rate due to the slower growth of woody upland species. This development of vegetation follows successional development, and has resulted in the upland trending towards being a carbon 'sink', as shown by average annual GEP (-2.34, -4.09, -2.74, -3.65 and -4.16 g C m^2 Day^{-1}) and NEP (4.46, 2.43, 2.49, 0.87 and 1.12 g C m^2 Day^{-1}) values from 2013 to 2017, respectively. Following the trend in the data, the upland will continue to grow and sequester more carbon until it reaches maturity. As of 2017, the upland has yet to be an annual 'sink' of carbon. However, following the trends shown above, it is reasonable to presume that the upland will be a net 'sink' of carbon in the coming years.

Annual trends in GEP are observed starting in 2017 and indicate that seasonal vegetation growth is occurring, and the vegetation is copying the expected annual cycle (foliation, stable and defoliation). In previous years, annual GEP trends have had a linear shape associated with them, meaning that there were little to no variations in seasonal vegetation growth, which indicates that the vegetation was comprised of primarily early successional species.

Hydraulic lift and evapotranspirative demand in a constructed upland

From 2013 through 2015, there was very little vegetation in the upland, resulting in transpiration rates being equal or close to zero. Therefore, evaporation dominated the ET balance with the majority of ET being derived from surface evaporation that was directly driven from precipitation inputs. Between 2015 and 2017 there was an increasing trend in ET as a result of upland vegetation growth.

Annual precipitation for 2013 to 2017 totalled 256.6, 295.7, 217.6, 120.1 and 198.2 mm, while annual ET values were 211.7, 185.1, 226.7, 145.0 and 205.5 mm, respectively. From 2013-2015 precipitation was greater than ET indicating that energy was the limiting factor driving ET values. However, in 2016 and 2017 ET was greater than precipitation, representing that precipitation was the limiting factor to ET rates and showing that the vegetation is starting to acquire water from groundwater sources.

Microbial degradation of naphthenic acids

Laboratory column tests show that, thus far, oil sands process affected water (OSPW) does not significantly influence either the community microbial potential activity or community catabolic evenness in all three reference sites (poor fen, treed rich fen and saline fen) with contrasting vegetation types and physicochemistry. Exposure to OSPW caused marginally significantly different substrate-induced respiration (SIR) responses across sites and dates for four substrates: D-glucose, arabinose, D-fructose ($F=2.30$, $p=0.037$), and N-acetylglucosamine, but these changes were not significant within a given site and sampling date. These results suggest that attenuation of the OSPW contaminants occurred through sorption on the peat substrate, and that longer incubation periods are required in such incubation tests.

Exposure to OSPW caused an inhibition of methanogenesis shown as a significant decrease in both methane production rate and peak concentration in the treed rich fen and the hyper saline fen. The depression of methanogenic activity at Poplar Fen under OSPW is due to a synthesis of the high salt (Na) concentration of the water, naphthenic acid toxicity, the toxicity of some other contaminant entirely or most likely, and the introduction of an alternative electron acceptor.

In the poor fen (Pauciflora), methanogenesis was slowed but not entirely inhibited. A possibility is that the syntrophs of the poor fen site (which are likely to provide the precursors for hydrogenotrophic methanogenesis, due to site conditions) proved more resilient to the contaminants present in OSPW than the Poplar Fen syntrophic community (which likely provided precursors for acetoclastic [convert acetic acid to methane] methanogenesis for similar reasons).

Identification and comparison of methanogenic and methanotrophic microbes

Incubation experiments characterized methane production potential under an anaerobic (water logged) condition for the same sites. Mean potential methane production rates at the reference sites did not differ between the treed rich (Poplar) fen and the poor (Pauciflora) fen but both were higher than the production rate at the saline-spring fen. In the saline-spring peatland, there is a high level of alternative terminal electron acceptors, notably sulfate, which suppressed methane production through competitive inhibition.

The three reference sites displayed contrasting and distinct microbial assemblages, with the constructed site microbial communities appearing distinct to all three, but more similar to Poplar (the treed rich fen) than Pauciflora (poor fen) or Saline (saline-spring fen).

Methanogenic and methanotrophic organisms have been identified by metagenomics analyses of microbial communities across the three reference sites and in the constructed fen. This supports the idea that methane-related processes are being constrained by the physico-chemical environment or competitive inhibition rather than because key organisms are not present in the constructed site.

Distribution and movement of solutes in and between upland and fen; modeling the transport and fate of Na and naphthenic acids (NAs) in the constructed system

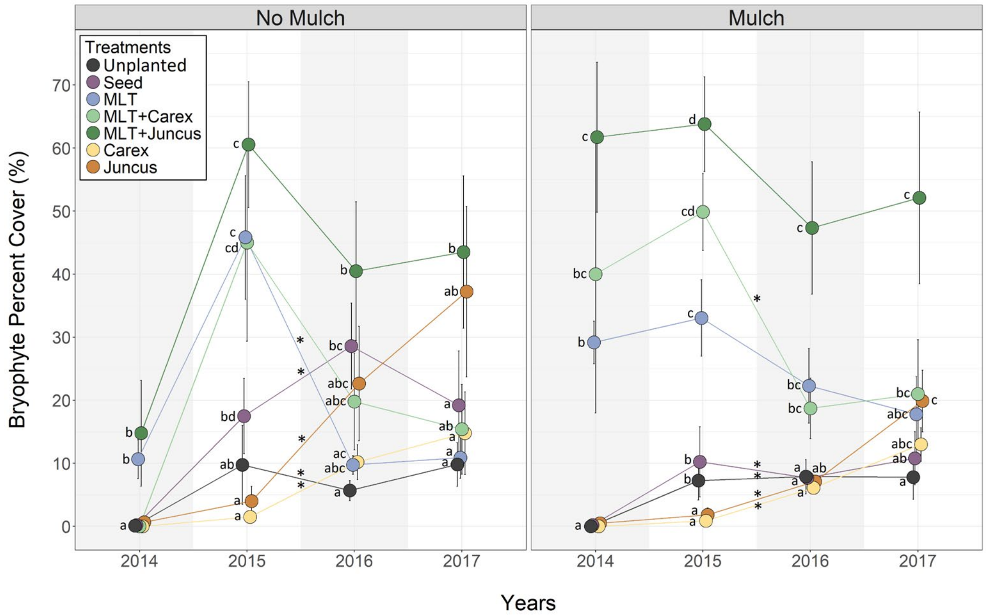
Groundwater recharge to the upland tailings sand aquifer was assessed using a simplified one-dimensional unsaturated flow model HYDRUS-1D. Given the relatively short period of monitoring at the Nikanotee Fen, historical climate data has parameterized the model. Precipitation data from 1944-2003 was used to simulate recharge under stable climatic conditions. Average and standard deviation recharge during the simulation were 61 mm and 44 mm, respectively. These statistical qualities of recharge will be incorporated into a Monte Carlo simulation to assess the long-term hydrologic trajectory of upland recharge to the Nikanotee Fen. This method avoids the wholly unsatisfactory approach of assigning a temporally uniform recharge rate for the long-term simulations, and instead uses the historical climate data to improve the predictive capabilities of the model.

In 2017, investigation of the solute transport properties of the tailings sand focused on determining the longitudinal dispersivity, which quantifies the amount of solute spreading due to pore and field-scale heterogeneities. Given that the dispersivity is a scale-dependent parameter, values are generally obtained from field-scale experiments. A lithium bromide plume was injected and traced within the upland between May and September 2017 to quantify the dispersivity of the tailings sand aquifer. Down-gradient migration of the plume was monitored with a network of observation wells. Plume trajectory evolution and shape was then analyzed using the spatial moments method to direct values for plume mass, velocity, and dispersion. Analysis of the groundwater plume indicates that the average linear groundwater velocity in the vicinity of the test is 0.32 m d^{-1}, considerably faster than expected, and indicating an advective/dispersive dominated system (as opposed to a diffusive dominated system).

Analysis indicates dispersivity of tailings sand (in the direction of groundwater flow) is ~ 0.06 m, which is small compared to other peer-reviewed field-scale tracer tests. Given the artificial deposition and homogenization of the grain sizes in tailings sand (from the extraction process) a low dispersivity was expected. Therefore, solutes transported under the influence of groundwater flow will experience minimal mechanical dispersion, or mixing, due to the fundamental structural nature of the tailings sand incorporated as a construction material.

Bryophyte establishment, control by species

Bryophytes successfully established in all experimental plots, initially from the moss layer transfer (MLT) treatment and then through dispersal and propagation over time (Fig 1). Establishment over the four years was affected by planting treatment in all four years but only mulch cover in 2014. After four years, bryophyte establishment was greatest and did not differ over time in MLT+Juncus plots with or without mulch, averaging 48% cover by 2017 (SE = 8.9%).



Bryophytes initially established in the MLT and MLT+Carex plots but had declined significantly by 2017 to an average of 14% and 19% cover respectively (SE = 3.3 and 5.6, respectively).

In the planting treatments where bryophytes were not introduced, bryophyte establishment did occur through dispersal over time. The largest increase was in the Juncus plots, which averaged 37% cover in unmulched plots by 2017 (SE = 7.3). Bryophyte establishment was also negatively affected by depth to water table, with the lowest percent cover recorded when the depth to water was measured to be within 10 cm of the peat surface.

Vascular plant establishment, above and below ground growth and physiology

Vascular plant establishment varied by planting treatment and year but was unchanged by weeding of *Typha latifolia* or mulch cover. Overall, vascular plant cover increased from 2014 through 2016 and appears to have stabilized between 2016 and 2017.

Declines in vascular cover were recorded in 2016 and 2017 in unplanted and seeded treatment plots, but no significant changes occurred in all other planted treatment plots. In 2017, vascular plant cover was lower in areas with shallower water tables in 2017.

Typha latifolia establishment: In non-weeded treatment plots, unplanted and seeded plots had the greatest relative cover of *T. latifolia*, averaging 17% across all years (Fig 2). However, when seedlings were planted, the average cover declined 5%, which is similar to the weeded plots that average of 2% across all years. This suggests that planting seedlings provides comparable results to hand weeding in limiting *T. latifolia* establishment without the need for a manual annual treatment. *Typha latifolia* cover was positively affected by depth to water table, with the higher percent covers recorded when the depth to water was measured within 20 cm of the soil surface.

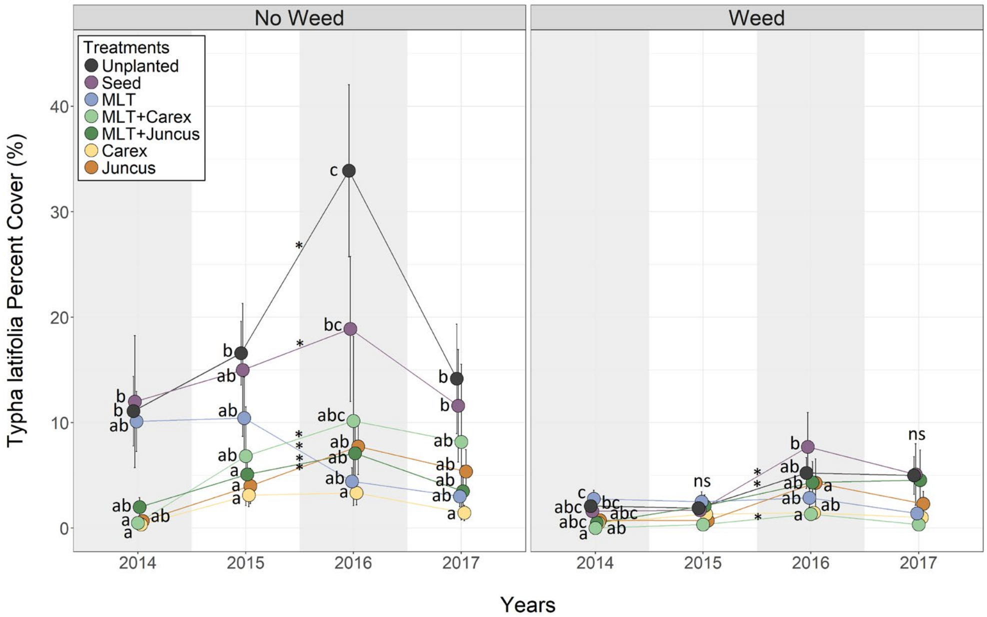


Figure 2. Effects of planting and weeding treatments on the percent cover of *Typha latifolia* from 2014 to 2017. Bars represent mean values with +1 standard error. Means with different letters are significantly different within a year (Tukey-adjusted comparison of least squares means, P < 0.05). Asterisks indicate significant differences over time.

LESSONS LEARNED

- Fen water use efficiency – variability in WUE from this point on will be a result of seasonal variations in meteorological conditions given stabilised WUE values.
- More water than anticipated was provided by incorporating adjacent landscapes into the design, effectively increasing the upland to fen ratio to 9:1; triple the modeled minimum required by the design. However, as vegetation has developed on adjacent reclaimed slopes, and upland, these landforms are increasingly intercepting rainfall and infiltrating surface water. Consequently, the upland/hillslopes hydrological function will progressively favour water storage over conveyance, and groundwater input to the peatland will decrease. Based on the performance of the 2007 and 2011 reclaimed slopes, little to no surface runoff will be directed to the constructed fen system in response to rain events within approximately 5-10 years of placement.
- Materials showed lower hydraulic conductivity than design values, although some materials increased somewhat over time. In the constructed upland, low infiltration and water detention capacity of the LFH-mineral mix was improved by furrowing across the slope and creating recharge basins. This treatment enhanced water recharge into the upland. During the initial years post-construction, upland LFH soils are largely bare of vegetation, hence surface erosion can occur, in turn carrying sediment with invasive seed material to the peat. The use of furrowing should be considered as a coversoil treatment on newly reclaimed upland areas that surround future constructed fen locations. Detaining water is important not only for total recharge but to reduce surface runoff and decrease overland flow that can carry sediment to bare peat surfaces and undermine effective fen design.
- Initial fen wetting was enhanced by snowmelt, due to a thermal sink through frozen placed peat into the underlying underdrain. In the future, wetting-up of constructed peatlands immediately after placement should not be left to chance. Spring runoff should be detained and intentionally recharged to the system.
- A key aspect of the design was to ensure a high-enough water table in the fen to sustain wetland processes. During monitoring, there were some dry seasons, but not persistently so. Nevertheless, during this period the water table in the fen remained relatively high and stable, because of the strong groundwater input from the constructed upland.

- Some natural reference fens (e.g., Poplar Fen) demonstrated large ranges in water table depths. This suggests constructed fens can be designed in the future to rely less on groundwater than the current design, as long as they are kept sufficiently wet in the early stages of plant establishment. Nevertheless, in the reference fens it was found that the susceptibility of fens to drought stress decreased in locations where there is good groundwater connectivity that helped maintain a high water table.
- A sequence of progressively wetter and increasingly stable water table regimes was observed in interconnected reference fens. Thus, constructed systems could be designed to replicate the cascade of wetland-to-wetland flows on the closure landscape at a variety of scales, with smaller basins and ephemeral draws progressively coalescing into larger, wetter systems.
- Irregular boundaries and upland connectivity in reference fens was found to correlate to greater biodiversity. Constructed systems should look to replicate this by incorporating slopes of different configurations, gradients and sizes, and using different material thicknesses to increase the spatial variability in hydrological conditions. Moreover, placement to take advantage of cascading water flows can result in progressively more stable water regimes downslope, thus promoting a different progression and development.

Geochemistry

- In creating a fen peatland, the mineral-rich water sources from groundwater and surface water inflows are the main vector for dissolved solids that arrive at the fen. Construction material analysis found elevated amounts of Na, Mg, Ca and S in peat, but these were strongly tied to the organic structure of the peat, and thus were the least available. These elements were most leachable in sand. Given that sand forms the upland aquifer, a large pool of highly mobile dissolved solids remains, especially sodium (Na). The peat does not possess sufficient capacity to absorb all available cations that will flow into it. They will eventually migrate to the rooting zone and surface of the fen.
- Analysis of the petroleum coke, which forms the underdrain beneath the fen, suggests the risk associated with metals leaching from coke because of the alkaline anoxic conditions present is low. However, since the alkalinity of the tailings sand and coke is low, it is susceptible to changes in pH and over time. Flushing with relatively acidic rainwater and generation of humic acids from upland vegetation will see immobilized metals in the coke, released, should aqueous pH drop significantly.
- Sodium distribution within the upland groundwater reflected the locations of recharge basins, with decreased concentrations originating beneath the basins, the basins acting to enhance flushing of Na from the tailings sand.
- This flushing with relatively fresh water increased Na desorption and dissolution from sands in the vadose zone, thus increased the mass flux of Na to the fen. The direction and patterns of flow and transport were also strongly affected by the petroleum coke underdrain. This directed the dissolved minerals relatively uniformly below the fen, where their rise to the rooting zone was delayed by strong adsorption to the peat. We believe that as long as the increase in Na (and other ions) within the fen occurs relatively gradually, the fen plant community will change through succession towards more salt tolerant vegetation. The fen chemistry (and biogeochemical processes) was strongly affected by high sulfate (SO_4) concentrations. It is believed that these were a result of enhanced mineralization of the donor peat that was drained two years prior to extraction and placement. It is recommended the donor peat be used as soon as possible after drainage.
- Future designs that rely on more parsimonious flows of groundwater can limit solute flows to the fen but prolong the period of transition into a system with a stabilized geochemical regime. However, designs that rely less on groundwater flows will be more susceptible to drought-induced stresses.
- In the reference systems, subtle differences in hydraulic gradients between adjacent systems can have a notable effect on their water quality, and hence, their ecology. Similarly, the complex shapes and forms of natural systems increased the variability of patterns of water quality (hence biodiversity). In the reference fens, even

those with thin peat deposits, there can be an appropriate water table dynamic that ensures vertical flushing of solutes to maintain conditions suitable for sensitive bog and fen plant species. Given the geochemistry of the reference fens, the constructed fen can be categorized as moderately brackish, and is well within the range of salinity found in reference fens. Its salinity was an order of magnitude less than a natural saline fen, but an order of magnitude more than more common rich fens in the area.

Biogeochemistry and greenhouse gas exchanges

- There was net carbon loss from the upland during the study but with a decreasing trajectory (towards net carbon uptake).
- Within the upland, mixing LFH with peat substrates (salvaged from new lease sites), improved the moisture and nutrient conditions that promote seedling survival without additional fertilizer.
- The constructed fen has become a small carbon sink; after 2014 it has sequestered more CO_2 versus the reference fens, although the upland has been a source of carbon to atmosphere. Plant introduction significantly increased net CO_2 uptake, but there was no clear difference between moss layer transfer and planted seedlings.
- Losses of CH_4 in the fen were very low (due to high SO_4 content of the peat); vegetation introduction strategy did not affect CH_4 emission. Dissolved organic carbon (DOC) losses from this system are limited during the summer period, because of the low surface water discharge with no significant difference in DOC concentration or chemistry between vegetation introduction strategies.
- A wide range of carbon fluxes measured at each reference site over time illustrates the importance of longer-term measurements to characterize the biogeochemical function of a peatland. In this study the constructed fen sequesters more CO_2 than the reference sites, and CH_4 and DOC losses were less than in reference fens.
- Following the current trends in the data, the trajectory of the upland looks promising with regards to the vegetation's carbon and water dynamics. Hydrometeorological results show that the upland is starting to show a more stable regime, demonstrated through the development of annual trends and the current trend towards a carbon accumulating system. However, this system is still in its infancy and will require continued monitoring to be able to assess with greater confidence the future success of the upland.

Bryophyte and vascular plant establishment, above and below ground growth and physiology

- The moss layer transfer (MLT) method was effective at establishing peat-forming moss species in the fen. Moss species that are prolific establishers, such as *P. pseudotriquetrum*, colonized all treatment plots after three years, but target peat-forming mosses with high productivity, such as *T. nitens*, did not significantly colonize new areas, and declined over time.
- The use of wood-strand mulch improved *T. nitens* establishment when planted with *J. balticus*, but deterred establishment in areas not planted with moss. Moss survival was lowest when the water table was within 0-5 cm of the soil surface, and was highest under *J. balticus* and when the water table was -10 to -25 cm below the soil surface. Moss establishment was reduced at EC levels ≥ 6000 uS/cm and soil EC was significantly greater in unmulched plots than mulched plots.
- For vascular plants, by 2015 mean above and below-ground biomass production was within the range of reference fens. Introduction of *J. balticus*, a salt tolerant species, was most effective when planted as seedlings at high densities. By 2016, *C. aquatilis* dominated biomass production and was outcompeting and eliminating *J. balticus*. However, planting treatment showed no significant effects on total biomass, relative to the control site. Weed management treatments had no effect on total biomass production. By 2016, vascular species had homogenized across planting treatments, with the dominant species *C. aquatilis* contributing to a decline in

community and planting treatment diversity. *J. balticus* did not spread effectively from MLT, but existed only because its seedlings were planted; it is susceptible to being out-competed by more aggressive *Carex* species and may reduce the resilience of the system to increasing salinity levels.

Below-ground processes and microbial diversity in a constructed fen

- The noted inhibition of methanogenesis in the constructed fen is likely due to an alternative electron acceptor. While a problem in having the constructed fen demonstrate reference fen natural processes, this may resolve itself as the alternative electron acceptor pool is exhausted in the anaerobic portion of the peat deposit. The apparent ability of Sphagnum peat to attenuate this effect, however, may prove to be of considerable use in the creation of these reconstructed fens. If OSPW is present in reconstructed fen sites, the choice of substrate peat used appears to be crucial in determining their initial methane production potential, at least in the short term.

Distribution and movement of solutes in and between upland and fen

- Since industrial processes that produce coarse tailings sand results in a relatively consistent product, it is anticipated that the dispersivity value of 0.06 could be applied to other coarse tailings aquifers and landscapes.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Gingras-Hill, T. 2017. Hydrogeochemical soil dynamics relative to topography for forested land units undergoing reclamation in a post-mined landscape in the Athabasca Oil Sands Region, Alberta. M.Sc. thesis. University of Waterloo, ON.

Journal Publications

Bocking, E., Cooper, D.J., Price, J. 2017. Using tree ring analysis to determine impacts of a road on a boreal peatland. *Forest Ecology and Management*, 404:24-30. DOI: 10.1016/j.foreco.2017.08.007.

Elmes, M.C., Thompson, D.K., Sherwood, J.H., and Price, J.S. 2017. Hydrometeorological conditions preceding wildfire, and the subsequent burning of a fen watershed in Fort McMurray, Alberta, Canada. *Nat. Hazards Earth Syst. Sci. Discuss*., https://doi.org/10.5194/nhess-2017- 312.

Murray, K.M, Borkenhagen, A., Cooper, D.J., & M. Strack. 2017. Growing season carbon gas exchange from peatlands used as a source of vegetation donor material for restoration. *Wetlands Ecology and Management*, 24(4), pp501-515. DOI: 10.1007/s11273-017-9531-5.

Murray, K.R., Barlow, N., Strack, M. 2017. Methane emissions dynamics from a constructed fen and reference sites in the Athabasca Oil Sands Region, Alberta. *Science of the Total Environment*. 583. DOI: 10.1016/j.scitotenv.2017.01.076.

Ketcheson, S.J., Price, J.S., Sutton, O., Sutherland, G., Kessel, E., & Petrone, R.M. 2017. The hydrological functioning of a constructed fen wetland watershed. *Science of the Total Environment*, 603, 593-605.

Scarlett, S.J., Petrone, R.M., Price, J.S. 2017. Controls on plot-scale evapotranspiration from a constructed fen in the Athabasca Oil Sands Region, Alberta. *Ecological Engineering*. 100: 199-210. DOI: 10.1016/j.ecoleng.2016.12.020.

Simhayov, R.B., Price, J.S., Smeaton, C.M., Parsons, C., Rezanezhad, F., Van Cappellen, P. 2017. Solute pools in Nikanotee Fen watershed in the Athabasca oil sands region. *Environmental Pollution*. 225: 150-162. DOI: 10.1016/j.envpol.2017.03.038.

Volik, O., Petrone, R.M., Hall, R.I., Macrae, M.L., Wells, C.M., Elmes, M. Price, J.S. 2017. Long-term precipitation-driven salinity change in a saline, peat-forming wetland in the Athabasca Oil Sands Region, Canada: a diatom-based paleolimnological study. *Journal of Paleolimnology*. 58(4): 553-550. DOI: 10.1007/s10933-017-9989-4.

Volik, O., Petrone, R.M., Wells, C.M., Price, J.S. 2017. Impact of salinity, hydrology and vegetation on long-term carbon accumulation in a saline boreal peatland and its implication for peatland reclamation in the Athabasca Oil Sands Region. *Wetlands*. DOI: 10.1007/s13157-017-0974-5.

Wells, C., Ketcheson, S.J., Price, J.S. 2017. Hydrology of a wetland-dominated headwater basin in the Boreal Plain, Alberta, Canada. *Journal of Hydrology*. 547: 168-183 DOI: 10.1016/j.jhydrol.2017.01.052.

Conference Presentations/Posters

Borkenhagen, A., & D.J. Cooper. 2017. Lessons in Establishing Plant Communities on Constructed Fens for Oil Sands Mine Reclamation. Invited Keynote Speaker at the Native Plant Society of Saskatchewan Conference on Native Plants in a Working Landscape. Saskatoon, Saskatchewan. January 28, 2017. Presentation.

Borkenhagen, A., Cooper, D.J., House, M., & D.H. Vitt. 2017. Lessons in establishing plant communities on constructed fens for oil sands mine reclamation. Oral presentation at Ecological Society of America Annual Meeting, Portland, OR. August 7, 2017. Presentation.

Elmes, M. and Price, J.S. 2017. The Hydrological Response of a Burned Moderate-Rich Fen Watershed in the Athabasca Oil Sands Region, Northern Alberta, Canada, CGU Annual Meeting, University of British Columbia, Vancouver, Canada, May 2017, Poster.

Elmes, M., Thompson, D.K., Sherwood, J.H. Price, J.S. 2017. The Hydrological Conditions Leading to the Burning of a Fen Watershed in Northern Alberta, CGU Annual Meeting, University of British Columbia, Vancouver, Canada, May 2017, Presentation.

Messner, L. 2017. Vascular biomass production on a reclaimed fen. Feb. 22-23, 2017. Front Range Student Ecological Symposium 2017. Colorado State University, Fort Collins CO. Presentation.

Osman, FI; Price, JS, Petrone RP. 2017. Sources of Sulphate in the Nikanotee constructed fen watershed within the Athabasca Oil Sands Region, Alberta, Canada. CGU Eastern Section Student Meeting – Biogeosciences. Feb. 4, 2017, University of Guelph, ON. Poster.

Sutton, O., Price, J. 2017. Simulating the Hydrologic Trajectory of a Constructed Fen Watershed, Athabasca Oil Sands Region, Alberta. Canadian Geophysical Union & Canadian Society of Agricultural and Forest Meteorology conference, May 28 – May 31, 2017, Vancouver, BC. Presentation.

Sutton, O., Price, J. 2017. Numerical modelling of sodium transport and fate at a constructed fen watershed, Athabasca Oil Sands Region, Alberta. Canadian Geophysical Union & Canadian Society of Agricultural and Forest Meteorology conference, May 28 – May 31, 2017, Vancouver, BC. Poster.

Van Beest, C., Nwaishi, F., Petrone, R. 2017. Spatial and temporal changes in nutrient cycling and carbon fluxes of western boreal peatlands impacted by wildfire. World Wetlands Day, University of Waterloo, Feb 2, 2017, Waterloo, ON. Poster.

Van Huizen, B., Petrone, R. 2017. Seasonal Ground Ice characteristics of a Western Boreal Plains Peatland and its potential impacts on early growing season Evapotranspiration rates. Canadian Geophysical Union Student Conference, Feb. 4, 2017. Guelph Ontario. Presentation.

Van Huizen, B., Petrone, R., Price, J.S. 2017. Seasonal Ground Ice characteristics of a Western Boreal Plains Peatland and its potential impacts on early growing season evapotranspiration rates. World Wetlands Day, Feb.2, 2017, Waterloo Ontario. Poster.

Van Huizen, B., Petrone, R., Price, J.S. 2016. Assessing the spatial and temporal trends of seasonal ice in a peatland in the Western Boreal Plains; Methods and Preliminary Results. Canadian Association of Geographers Ontario meeting, Oct.29, Waterloo, ON. Poster.

Volik, O., Petrone, R.M., Wells, C.M., Hall, R.I., Price, J.S. Salinity change in a saline boreal wetland in the Athabasca Oil Sands Region, Canada: a diatom-based paleolimnological study. The Ontario-Quebec Paleolimnology Symposium (PALS), Brock University, St. Catharines, Canada, 2017. Presentation.

Volik, O., Petrone, R.M., Wells, C.M., Price, J. Salinity change and long-term carbon accumulation in a saline boreal fen: implications from paleoecology to wetland reclamation in the Athabasca Oil Sands Region. 2017 CGU Annual Meeting, Vancouver, Canada, 2017. Presentation.

Reports & Other Publications

Industry Technology Transfer Manual - Evaluating the Success of Fen Creation. March 2017. Price, J.[1], Petrone, R.[1], Strack, M.[1] and Cooper D.[2] (Eds: Sherwood, J; Kessel, E; Sutherland, G). [1] Department of Geography and Environmental Management, University of Waterloo, ON, [2] Department of Forest and Rangeland Stewardship, Colorado State University, CO. pp.122

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Sandhill Fen Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

Syncrude Canada Ltd. (SCL) has undertaken over 30 years of research and monitoring to understand and develop best practices for out of pit landforms and structures (i.e., upland landscapes conducive to the development of upland forests) such as overburden disposal areas, tailings dyke beaches, and slopes of tailings storage areas. The closure landscape will also contain in-pit 'soft tailings' landforms. Soft tailings are generally defined as tailings that do not possess sufficient shear strength to support the earth moving equipment utilized for closure and reclamation operations. Soft tailings include unamended fluid fine tailings (FFT), densified FFT, FFT centrifuge cake (FFTC) and composite tailings (CT). CT, a mixture of coarse and fine tailings with gypsum, is one of the tailings treatment technologies first developed and commercialized in the industry.

The objectives of the Sandhill Fen Research Watershed (SFRW) are to:

1. develop technology and practices for reclamation of sand 'soft tailings'; and
2. test the ability to re-establish fen wetlands.

The SFRW is located in the northwest corner of Syncrude's East in Pit (EIP). EIP is a former mine pit, which has been hydraulically filled with CT to a depth of approximately 50 m and a portion of EIP is capped with varying amounts of tailings sand. The design intent of the SFRW was to create a watershed with the necessary initial conditions to support a wetland with the potential to develop into a fen over time. Sandhill Fen was designed, constructed, reclaimed and revegetated as an instrumented watershed between 2008 and 2012, and has been operational since June 2013. SFRW is approximately 55 ha, and includes a nearly 17 ha primary wetland surrounded by an upland area with 7 hummocks, 2 perched fens, and associated infrastructure (roads, research centre, boardwalks). The hummocks were constructed with mechanically placed tailings sand directly on top of the tailings sand cap.

The SFRW program utilizes the Instrumented Watershed Research approach to address these objectives. Watershed Research is a scientific approach that involves intensive monitoring of constructed landforms, which enable the execution of concurrent, integrated, multi-disciplinary research programs. Central to the watershed approach are the determination of:

- water and energy balances (location, quantity, quality and movement of water in a landscape);
- mass balances (including inorganics, organics, ions, nutrients, metals); and
- plant and ecological responses.

The design of the entire watershed and the individual hummocks enable the study of integrated watershed performance and permits discrete comparisons between hummocks. Each of the seven hummocks vary in height, shape and orientation. Five of the seven hummocks were reclaimed with a 'dry' target moisture regime (a/b ecosite), and two of the seven hummocks were reclaimed with a 'moist' target regime (d-ecosite). The 'dry' hummocks were reclaimed with 30 cm of subsoil and 20 cm of upland surface soil salvaged from a d ecosite source location. The 'moist' hummocks were reclaimed with 40 cm of coarse sand and 15 cm of upland surface soil from an a/b ecosite source location. Each hummock has areas with coarse woody debris. The SFRW uplands and hummocks were revegetated with the Standard tree species mix (Table 1).

Table 1: Planting prescriptions for upland areas of Sandhill Fen Research Watershed

Prescription Type (Density)	Tree species
No planting (0 stems/ha)	No trees planted
a/b ecosite (5000 or 10000 stems/ha)	10% Aspen (*Populus tremuloides*) 10% White Spruce (*Picea glauca*) 80% Jackpine (*Pinus banksiana*)
d ecosite (5000 or 10000 stems/ha)	80% Aspen (*Populus tremuloides*) 10% White Spruce (*Picea glauca*) 10% Jackpine (*Pinus banksiana*)
Standard (2000 stems/ha)	20% Aspen (*Populus tremuloides*) 20% White Spruce (*Picea glauca*) 20% Jackpine (*Pinus banksiana*) 20% White birch (*Betula papyrifera*) 20% Black spruce (*Picea mariana*)

Plots of varying tree density and species composition (Table 1) were established on different aspects (north-facing, plateau, south facing) of each hummock. Control plots (no trees planted) were also established.

In the central wetland, a 50 cm clay till layer was placed and overlaid with 50 cm of fresh salvaged peat. A native seed mix (6 dominant and 15 subdominant wetland species) was broadcast to the wetland area in the winter of 2011 and summer of 2012. Twenty-two experimental wetland vegetation plots (9 m x 9 m) were planted with native wetland seedlings in the summer of 2012.

The SFRW is also instrumented with a large number (>175) of piezometers, two eddy-covariance monitoring stations, a weather station, a freshwater pond, a leaky berm, four underdrains and an outlet weir.

To support collaboration and integration among the multi-disciplinary SFRW studies, an online metadata and mapping tool system was developed by the University of Windsor. The tool system allows researchers access to information being collected by others, thereby assisting in collaboration and integrated interpretation.

RESEARCH TEAM AND COLLABORATORS

The SFRW team includes a number of research disciplines for each research study. A list of active research projects, including the primary investigator and their classification within COSIA are provided in the table below (completed studies are captured in previous annual reports). A more detailed description of the individual projects and their results to date can be found in the accompanying project updates in this document.

Project Type	COSIA Project Number	Project Title	Principal Investigator(s)
Single Industry	LJ0204	Water and Carbon Balance in the Constructed Fen	McMaster University and Carleton University Dr. Sean Carey Dr. Elyn Humphreys
Single Industry	LJ0204	Hydrogeologic Investigation of Sandhill Fen and Perched Analogues	University of Alberta Dr. Carl Mendoza Dr. Kevin Devito

Single Industry	LJ0204	Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality	University of Windsor Dr. Jan Ciborowski
Single Industry	LJ0204	Forest Reconstruction on Upland Sites in the Sandhill Fen Watershed	University of Alberta Dr. Carl Mendoza Dr. Kevin Devito

LESSONS LEARNED

See individual SFRW COSIA project updates for more details.

PRESENTATIONS AND PUBLICATIONS

See individual SFRW COSIA project updates for more details.

RESEARCH TEAM AND COLLABORATORS

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

Industry Lead: Carla Wytrykush, Syncrude Canada Ltd.

Sandhill Fen: Water And Carbon Balance Of The Constructed Fen

COSIA Project Number: LJ0204

Research Provider: McMaster University and Carleton University

Industry Champion: Syncrude Canada Ltd.

Status: Year 6 of 6 (one-year extension started in 2016)

PROJECT SUMMARY

One of the primary goals of the Sandhill Fen Research Watershed (SFRW) is to assess the ability to re-establish fen wetlands. As part of a program to measure the water and carbon balance of SFRW, McMaster University and Carleton University researchers have undertaken detailed measurements of ecosystem water and carbon fluxes since 2013. This includes documenting the rate, timing and pathways of water and carbon movement in the SFRW ecosystem while also collecting comprehensive data on water quality and biogeochemical cycling.

The specific research objectives of this program are to:

1. Measure the ecosystem-scale annual water/energy and carbon (C) balance for the reclaimed fen over a 5 year period (2012–2017) based on complete year measurements of all the major inputs and outputs to the system;
2. Establish the intra-fen variability in net ecosystem production (NEP) and methane flux FCH4 to establish which areas of the fen are more productive (successful) than others and link this to the ecosystem-scale flux (2012–2018);
3. Characterize the quantity and quality of dissolved organic carbon (DOC) and particulate organic carbon (POC) released from the Sandhill Fen through surface and subsurface hydrological pathways (2012–2017);
4. Monitor changes in DOC and POC quantity and quality across a range of hydrological conditions (2012–2017);
5. Establish whether the concentrations, fluxes, and quality of DOC and POC are similar to reference wetlands in the local area and other reclaimed fens;
6. Assess mercury output from the fen and compare it to reference fens in the area;
7. Assess soil nutrients using plant root simulator probes and soil chemical analysis to understand the availability and limitations of nutrients for plant growth and assess intra-fen variability in soil quality status; and
8. Use stable isotopes and hydrochemistry to better understand the linkage between runoff flow pathways and sources of water.

PROGRESS AND ACHIEVEMENTS

Excellent progress continues to be made on water and carbon balance of the Sandhill Fen Research Watershed, with continuous year-over-year measurement since 2013. There have been considerable changes in all aspects of the water and water and carbon cycle, reflecting the evolution of the watershed in terms of vegetation and its integration with the surrounding landscape.

Carbon Balance

Objective 1: Measure the ecosystem-scale annual water/energy and carbon (C) balance for the reclaimed fen over a 5 year period (2012–2017) based on complete year measurements of all the major inputs and outputs to the system.

The carbon cycle reflects the evolution of the watershed in terms of vegetation and its integration with the surrounding landscape. The carbon balance was monitored with two eddy covariance stations: one in the upland and one in the lowland. The eddy covariance towers provide 30 minute measurements of surface-atmosphere water, CO_2 and CH_4 (for the lowland) exchange. The lowland tower provides continuous data year-round on AC power and the upland tower operates throughout the growing season. CO_2 and CH_4 data is supplemented from a network of chambers within the Sandhill Fen Watershed. DOC quantity and quality was measured monthly from April through October in a series of near-surface wells and the outlet. Carbon balances indicate that the watershed is moving towards a net carbon sink status, although at this point it is likely carbon neutral. Methane fluxes remain very low, although they are increasing. 2017 was an interesting year as it was wetter than previous, resulting in lower carbon uptake in the lowlands.

Water Balance

Objective 2: Establish the intra-fen variability in net ecosystem production (NEP) and methane flux FCH4 to establish which areas of the fen are more productive (successful) than others and link this to the ecosystem-scale flux (2012–2017).

The water balance was estimated using precipitation (3 sites and snow surveys) and evaporation measurements (using Eddy Covariance) along with monitoring of any inflows and outflows that occur. In addition, water table and surface-groundwater interactions were monitored through a series of near-surface wells within the fen. The continuously operating meterological sites on the Sandhill Fen Watershed were used for supplementary meteorological information. Water balances are continuous from January 2013 and are ongoing. Fluxes of water are largely vertical, with evapotranspiration being the major loss of water from the system balanced by snow and rain inputs. The general precipitation regime has been slightly drier than normal since commissioning and the bulk of the inputs are from rain, often during intense summer storms. The timing of rainfall during the year is considered particularly important. This is seen in 2016-17 where late season rains resulted in very high, water tables in 2017. Evapotranspiration (ET) has been relatively conservative over the years, with some increase seen in the uplands as vegetation develops. Since commissioning, we have not observed the vegetation to become stressed and limit water uptake, as ET has largely been driven by climate and weather conditions.

Salinity and Water Chemistry

Objective 3: Characterize the quantity and quality of dissolved organic carbon (DOC) and particulate organic carbon (POC) released from the Sandhill Fen through surface and subsurface hydrological pathways (2012–2017).

The major ion geochemistry in Sandhill Fen Watershed is changing rapidly and expected to continue to change. Monthly water samples from near-surface wells, open water areas and the inlet/outlet were analyzed for major ions and stable isotopes. One of the most notable changes that is occurring in the watershed is ongoing salinization in certain lowland and transition/margin areas, presumably where tailings water is reporting to the surface.

Six graduate students and one post-doctoral fellow have completed their work at Sandhill, and one student continues to do work there. In addition, there are several undergraduates who have completed theses at the site.

LESSONS LEARNED

Carbon Balance

Vertical CO_2 balances were computed for the fen and terrestrial eddy covariance towers for both the growing season and annual totals for the lowland tower. During summer, the fen is a seasonal carbon sink as production (photosynthesis) is high. The greatest CO_2 uptake appears to be in the fen and each year photosynthetic capacity is increasing. However, in 2017 the uptake in the fen is lower than the upland, largely because of the submerged conditions. It is remarkable to note how quickly carbon is accumulated in the growing season once vegetation establishes, but respiration continues to be an important flux and through 2016, the lowland can only be considered a weak carbon sink.

Methane is not a significant flux at present, although data suggests that it is increasing with time. There is also an association between methane and the presence of aerenchymatous plants that allow the transport of methane to the atmosphere from depth. Ongoing work by Graham Clark will clarify these processes and the biogeochemical and redox controls on methane emissions.

Water Balance

Snow water equivalent is measured continuously at three sites on the fen and is supplemented by snow surveys each spring. There was considerable variability in snow depth in 2013, although for the past four years, snow has been less variable and far below the long-term Ft McMurray average of ~100 mm. It is generally observed that the fen <u>is not</u> a sink for snow compared to other sites at Mildred Lake. A possible strategy for increased percolation could be to design the landscape to create lee slope positions where snow accumulates and flushing is enhanced. In 2018, some intense snow surveys will be conducted to compare how the Sandhill Watershed compares to other watersheds at the Mildred Lake mine.

Rainfall is measured at a number of sites on and adjacent to Sandhill Watershed. Rainfall is not highly variable across the watershed. 2013 and 2016 were relatively wet, although 2016 was not wet during the growing season and received considerable late-season precipitation. 2014 and 2015 were relatively dry when compared with the Fort McMurray climate normal. Much of the precipitation is delivered in large convective events of short duration that can occur at any time throughout the year. It is important to note the very wet fall in 2016 and early season rain in 2017, which resulted in very high water levels, are reported below.

Evapotranspiration was measured using the eddy covariance technique at three sites (3 sites for entire monitoring period, 2 sites in 2017): a tower located in the centre of the wetland area (2013-2017), one to the south of the fen representing the terrestrial surface (2012-2017) and one at the perched fen (2014-2015). Evapotranspiration among the four study years was relatively conservative at the fen (lowlands), and differences among years is largely due to weather and water table position in the lowland. The rate of evaporation during the growing season has not changed considerably, although at upland sites it appears that with time evaporation is increasing (which is expected) as vegetation develops. There is greater ET in 2017 in the uplands than the lowlands. Inter-annual differences are largely due to differences in weather which are driving evaporative demand.

In 2017 there was one major pumping event in July that was estimated to remove 100 mm of water from the watershed lowland area. In 2016, to the best of knowledge, the pumps were not active. As summarized in previous reports, 2013 was problematic in terms of assessing the influence on the water balance, whereas during 2014 and 2015, small controlled pumping events occurred. In 2015, changes in water quality were closely monitored during the pumping.

It is important to note operationally that pumps have a large influence on the fen, both in terms of the inflows and outflows. Furthermore, underdrains are very effective.

Shallow water tables were measured at a large number of sites throughout the fen (reduced somewhat in 2016). There is considerable intra-fen variability in water table dynamics, which appear to influence geochemistry as areas of the watershed become connected and disconnected from each other. The water table is virtually always above the surface, and in the early years the pump had a strong influence on the system. In 2017, the lowland was extraordinarily wet and pumps were turned on in July to remove water. The high water tables are a result of late season rains in 2016 and subsequent early season rains in 2017, highlighting the importance of weather on the system.

As noted last year, the upper fen is disconnected from the lower fen in terms of the water table. Water drains from west to east when the system is wet, but as it dries, the upper portions of the wetland disconnect and water flows from the centre of the wetland towards the outlet, yet also back towards the inlet pond. This suggests that there are areas of hydrological isolation in the upper fen, which will be more susceptible to drying and water level decline. In addition, in 2015 the upper fen did not respond to the pumping test, again suggesting its isolation.

Salinity and Water Chemistry

Over the monitoring period, the fen appears to be increasing in salinity. This increase has also been noted by researchers working on other programs at the Fen. This is particularly evident along the margins of the wetlands and uplands. A general trend of increasing salinity is evident, particularly among the margins where electrical conductivity values were in excess of 4000 μ S/cm^{-1} in 2017. Water in the central part of the fen typically remains below 2000 μ S/cm^{-1}.

From a water chemistry perspective, the increase in solutes is accompanied by a change in the ionic composition. At much of the fen, the increase in salinity is being driven by increased sodium in solution. 2017 water chemistry data analysis is not complete at this time. It is believed that this sodium increase is caused by process water entering the fen from depth and particularly along the base of hummock 7/8/9 where groundwater from East-in Pit is moving north into the Sandhill Watershed. Stable isotopes of water show that hotspots along the southern edge of the lowland have an isoptic composition trending towards OSPW, suggesting mixing of waters at that location.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Submitted for Peer Review or in Final Form:

Clark MG, Humphreys ER, Carey SK. Three years of low methane emissions from a newly constructed wetland in Northern Alberta. To be submitted to Journal of Geophysical Research – Biogeosciences.

Spennato H, Ketcheson SJ, Carey SK, Mendoza C. An assessment of water table dynamics in a constructed fen, Fort McMurray, AB. To be submitted to: Hydorlogical Processes.

Biagi KM, Nicholls, Oswald CJ, Carey SK. Hydrochemical changes following a shift from a managed to a natural hydrologiacal regime in a constructed wetland, Fort McMurray, AB. To be submitted to Science of the Total Environment.

Conference Presentations/Posters

Clark MG, Humphreys ER, Carey SK. Downscaling eddy covariance measurements of energy and carbon dioxide fluxes in a constructed boreal wetland. Presented at CGU Annual General Meeting, May 2017. *Award for Best Student Presentation from the Canadian Society for Agriculture and Forest Meteorology*.

Lukenbach MC, Spencer CS, Mendoza CA, Devito KJ, Landhausser SM, Carey SK. Variability saturated flow between constructed upland hummocks and wetland in a reclaimed watershed following oil sands mining. Presented at CGU Annual General Meeting, May 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: McMaster University

Principal Investigator: Sean Carey

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Sean Carey	McMaster University	Professor		
Elyn Humphreys	Carleton University	Associate Professor		
Michael Treberg	McMaster University	Research Technician		
Gordon Drewitt	McMaster University	Research Technician		
Graham Clark	Carleton University	PhD Student	2014	2018
Kelly Biagi	McMaster University	PhD Student	2016	2019
Chelsea Thorne	McMaster University	MSc Student	2013	2015
Erin Nicholls	McMaster University	MSc Student	2013	2015
Kelly Biagi	McMaster University	MSc Student	2013	2015
Jessica Rastelli	McMaster University	MSc Student	2014	2016
Haley Spennato	McMaster University	MSc Student	2014	2016
Arthur Szybalski	McMaster University	BSc Student	2014	2015
Hannah Ponsonby	McMaster University	BSc Student	2017	2018

Research Collaborators: Carl Mendoza, University of Alberta; Kevin Devito, University of Alberta; Lee Barbour, University of Saskatchewan; Matt Lindsay, University of Saskatchewan; Simon Landhäusser, University of Alberta; O'Kane Consultants

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

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 6 of 7 (two-year extension started in 2017)

PROJECT SUMMARY

Oil sands mining temporarily disturbs lands. Once mining is complete, the process to reclaim lands begins. A priority in the reclamation and certification of disturbed lands is the redevelopment of forested landscapes, including the rapid re-establishment of tree cover. Planting trees remains one of the most effective strategies in rehabilitating boreal forest affected by industrial disturbance to functioning forest ecosystems. The quick development of a continuous tree canopy on a site helps suppress establishment of weedy forb and grass species, which can significantly hinder tree survival and growth. One approach to speed up forest canopy development is to increase the planting density of trees.

The overall goal of this research project is to examine the inter-relationships among tree species and density, understory development and potential water use on different reclamation ecosites on the 7 hummocks found on the Sandhill Fen Research Watershed.

Objective 1: Evaluate tree seedling establishment, early growth and canopy development in response to planting density of jack pine, trembling aspen and white spruce on substrates salvaged from a/b ecosite or d ecosites, guided by questions including:

- What is the impact of soil type (a/b and d ecosites) and microsite parameters (e.g., coarse woody debris [CWD], soil temperature, soil moisture, soil nutrient availability) on the growth of planted seedlings?
- How does individual tree biomass allocation aboveground (stem and leaves) and belowground (fine and coarse roots) differ between tree species, ecosite and stem density treatments?
- What is the initial leaf area development of jack pine and aspen seedlings in relation to other growth parameters (e.g., height and diameter) on reclamation sites?

Objective 2: Investigate understory vegetation development in response to different site conditions and forest floor substrates salvaged from a/b ecosite or d ecosites, based on questions including:

- How do overstory density, CWD, and resource (nutrient and water) availability affect understory vegetation development on the two different ecosites?
- How does the initial seed bank contribute to understory vegetation development in d ecosites and how do different environmental conditions (aspect) affect its expression?
- What is the potential for natural (unassisted) tree regeneration on upland sites and what microsite conditions promote establishment?

Stand level leaf area development and potential water use are key drivers of the water cycle in natural and reclaimed forests. The three major components of water use at the stand level are tree transpiration, understory transpiration and evaporation from the soil. However, very little is known about how these water use components in upland reclamation environments interact and respond to environmental conditions such as soil water potential, tree density or tree species composition.

Objective 3: Gain a better understanding of the water balance in reclamation landscapes by determining how much water (as estimated by leaf area) is potentially used by vegetation (trees and understory) over time, with different planting densities and on soil types that have different abilities to store water, guided by questions including:

- How does planting density affect stand level leaf area development of jack pine and trembling aspen?
- How does planting density affect understory leaf area development on the differing ecosites?
- What is the potential water use of tree seedlings and how does that relate to planting density, species and soil moisture availability?

PROGRESS AND ACHIEVEMENTS

Objective 1: Evaluate tree seedling establishment, early growth and canopy development in response to planting density of jack pine, trembling aspen and white spruce on substrates salvaged from a/b ecosite or d ecosites.

Linear and structural equation models were used to explore relationships between seedling performance and multiple environmental and management parameters as measured in earlier field sampling programs. Key outcomes included:

- Initial seedling survival varied by species and soil type; pine on coarse textures soils experienced 94.5% survival while aspen on fine textured soils experienced 62.5% survival; growth was significantly better on fine texture soils than on coarse textured soils for spruce, pine and aspen;
- Fine textured soils support a higher leaf area than coarse textured soils, resulting in greater water demands and more soil drying through the growing season; fine textured soils were drier than coarse textured soils by the end of the growing season due to vegetation water use;
- Pine height was significantly higher on north as compared to south facing slopes on coarse textured soils;
- Pine seedling height was negatively correlated with soil moisture on coarse soils, possibly due to increased vegetative competition;
- In the first year after planting, seedling performance was best correlated to foliar N levels, likely reflecting stored reserves from the nursery; and
- After the first growing season, seedling performance became increasingly correlated to site conditions; pine appeared to be particularly influenced by available potassium as indicated by foliar P levels, with a lesser but significant correlation to proximity of coarse woody debris.

Objective 2: Investigate understory vegetation development in response to different site conditions and forest floor substrates salvaged from a/b ecosite or d ecosites.

- No work was completed in 2017 for this objective. Papers are planned for 2018 using data previously collected.

Objective 3: Gain a better understanding of the water balance in reclamation landscapes by determining how much water (as estimated by leaf area) is potentially used by vegetation (trees and understory) over time, with different planting densities and on soil types that have different abilities to store water.

- No work was completed in 2017 for this objective. Data from this program was leveraged as a contribution to other Sandhill Fen projects related to site water balance.

LESSONS LEARNED

Objective 1: Evaluate tree seedling establishment, early growth and canopy development in response to planting density of jack pine, trembling aspen and white spruce on substrates salvaged from a/b ecosite or d ecosites.

- Both linear and structural equation models were effective for identifying discrete environmental factors correlated to growth, but the structural equation models provided greater insights into potential interactions between factors and theorized changes in influences over time;
- Seedling performance appeared most influenced by nursery practices and resulting seedling condition at time of planting in the first growing season, with increasing influence of site conditions in subsequent years; and
- Influences of any given environmental factor on seedling growth will vary both spatially and temporally; notable interactions may be common.

Objective 2: Investigate understory vegetation development in response to different site conditions and forest floor substrates salvaged from a/b ecosite or d ecosites.

- No incremental additions were made to lessons learned in 2017.

Objective 3: Gain a better understanding of the water balance in reclamation landscapes by determining how much water (as estimated by leaf area) is potentially used by vegetation (trees and understory) over time, with different planting densities and on soil types that have different abilities to store water.

- No incremental additions were made to lessons learned in 2017

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

B. Pinno, M. Merlin, F. Leishman, R. Errington, and S. Landhäusser. 2017. Upland forest development in a reconstructed watershed after oil sands mining in northern Alberta, Canada, Oral presentation. National Meeting of the American Society of Mining and Reclamation, Morgantown, WV. https://wvmdtaskforce.files.wordpress.com/2017/05/2017-pinno-monday-130.pdf.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ruth Errington	Natural Resources Canada	Peatland Technician		
Alex Goeppel	University of Alberta	M.Sc.	2012	2014
Elizabeth Hoffman	University of Alberta	M.Sc.	2013	2016
Shaun Kulbaba	University of Alberta	M.Sc.	2011	2014
Simon Landhäusser	University of Alberta	Professor		
Frances Leishman	University of Alberta	Research Technician		
Ellen Macdonald	University of Alberta	Professor		
Katherine Melnik	University of Alberta	M.Sc.	2008 (B.Sc.) 2013 (M.Sc.)	2013 (B.Sc.) 2017 (M.Sc.)
Morgane Merlin	University of Alberta	PhD	2015	2020
Brad Pinno	University of Alberta	Assistant Professor		

Sandhill Fen: Hydrogeologic Investigations of Sandhill Fen and Perched Analogues

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 6 of 8 (three-year extension started in 2017)

PROJECT SUMMARY

This program involves integrated hydrologic studies to quantify and generalize landscape and transition zone hydrologic interactions within the Sandhill Fen Research Watershed (SFRW) at a number of scales. The studies 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 Watershed, including Simon Landhäusser's work on vegetation succession and very shallow moisture regimes on hummocks, and Sean Carey's work on atmospheric interactions. Monitoring of the hydrologic behaviour of a perched fen complex at the Utikuma Region Study Area (URSA) is also a component of this program. 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.

This program will address the following objectives:

Objective 1: Test the configuration, height and size of coarse grained hummocks required to maintain wetland and forest ecosystems on reconstructed landscapes

Objective 2: Test soil layering in perched fens and the role of water storage in layers of different types and thicknesses on generating a moisture surplus for wetland and adjacent forestland water demands

Objective 3: Determine the role of ephemeral draws on generating moisture surplus and delivering water to wetland and adjacent forests

Objective 4: Use reference perched fens (burned and unburned) to quantify the hydrological behavior of a perched fen overlying coarse-grained substrates

PROGRESS AND ACHIEVEMENTS

Most activities in the reporting period involved ongoing collection of data, interpretation of past data, new laboratory measurements and integration of field results into conceptual models. Analyses of field data and modelling are ongoing.

LESSONS LEARNED

Objective 1: Test the configuration, height and size of coarse grained hummocks required to maintain wetland and forest ecosystems on reconstructed landscapes & Objective 2: Test soil layering in perched fens and the role of water storage in layers of different types and thicknesses on generating a moisture surplus for wetland and adjacent forestland water demands

Ground water flow is dominantly in the horizontal direction; vertical groundwater gradients are negligible throughout the fen (a change from last years report). Although recharge is occurring, it is occurring very slowly which results in negligible groundwater mounding (<1m) below hummocks. Numerical modelling results indicate that the degree of mounding is largely controlled by vegetation and the reclamation material texture and thickness.

Objective 2: Test soil layering in perched fens and the role of water storage in layers of different types and thicknesses on generating a moisture surplus for wetland and adjacent forestland water demands

Horizontal/lateral flow gradients are present. Electrical conductivity values increase slightly along the flow path and more noticeably with depth. Highest electrical conductivities were observed at the toes of the slopes of the hummocks on the south side of the watershed.

Objective 3: Determine the role of ephemeral draws on generating moisture surplus and delivering water to wetland and adjacent forests

Saturation mapping shows a dynamic near-surface system that was inundated with water in the early months of the field season after spring melt, and appreciable changes in the amount of standing water after a scheduled pumping event (water pumped out of SFRW for 3 days).

Additional learnings include:

- This watershed must have a sill, a maximum level to which the water can rise, if it is to mimic a natural system.
- Groundwater flow to the north is being influenced by the lithology at the edge of the mine (a gravel channel), which is influencing the overall groundwater system.
- The current areal extent of the hummocks is too small to function as a recharge area necessary to sustain the wetland as it becomes more established with vegetation.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Lukenbach, M.C., C.S. Spencer, C.A. Mendoza, K.J. Devito, S.M. Landhäusser and S.K. Carey, 2017. Variably Saturated Flow Between Constructed Upland Hummocks and a Wetland in a Reclaimed Watershed Following Oil Sands Mining. CGU/CSAFM *Joint Annual Scientific Meeting*, Vancouver, May. Canadian Geophysical Union, Abstract B04-09.

Lukenbach, M.C., C.S. Spencer, C.A. Mendoza, K.J. Devito, S.M. Landhäusser and S.K. Carey, 2017. Resolving the need for groundwater recharge versus forest productivity in a reclaimed watershed. *Geological Society of America Abstracts with Programs*, 49(6). Seattle, October. doi: 10.1130/abs/2017AM-306440.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Carl Mendoza

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Carl Mendoza	University of Alberta	Principal Investigator		
Kevin Devito	University of Alberta	Principal Investigator		
Maxwell Lukenbach	University of Alberta	Postdoctoral Fellow		
Mika Little-Devito	University of Alberta	Research Technician		
Pamela Twerdy	University of Alberta	M.Sc.	2016	2018
Jordan Pearson	University of Alberta	Research Assistant		
Hayley Hedstrom	University of Alberta	Research Assistant		
Brittany Onysyk	University of Alberta	Research Assistant		

Research Collaborators: Our hydrogeological work is closely tied to a number research programs including:

Forest reconstruction on upland sites in the Sandhill Fen Watershed
Collaborator: Simon Landhäusser, University of Alberta

Water and Carbon Balance in the Constructed Fen
Collaborator: Sean Carey, McMaster University

Applying natural analogues to constructing and assessing long-term hydrologic response of Oil Sands reclaimed landscapes
Collaborator: Kevin Devito, University of Alberta

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

COSIA Project Number: LJ0204

Research Provider: University of Windsor

Industry Champion: Syncrude Canada Ltd.

Status: Complete and awaiting final report

PROJECT SUMMARY

Invertebrate community composition and production are affected by many factors. Factors affecting the aquatic invertebrate community characteristic of marshes are becoming relatively well understood. However, factors that affect the development and ultimate success of the invertebrates associated with wet meadow, fen and semiterrestrial habitats of peatlands are poorly understood. Invertebrates are an essential feature of the food web, converting plant material and detritus (peat) into biomass that sustains higher trophic levels (amphibians, birds, mammals).

The objective of this project is to assess the early community development of the semi-aquatic and upland invertebrates of Sandhill Fen Research Watershed (SFRW), and its relationship to the plants, water and soil characteristics on which the invertebrates depend on for habitat and food. Specifically this project will;

1. Track development of zoobenthic community composition/early-stage succession on aging plots;
2. Assess invertebrate compositions in a suite of natural fens, variously affected by salinity and/or used as a seed source for populating SFRW; and
3. Recommend invertebrate community benchmarks (variables, units of measurement, values) characteristic of reference fens that can serve as 'measures of reclamation success' for semiaquatic habitats of SFRW and other constructed wetlands based on the synthesis of information from objectives 1 and 2.

PROGRESS AND ACHIEVEMENTS

Objective 1: Track development of zoobenthic community composition/early-stage succession on aging plots.

Processing, identification and enumeration of zoobenthic samples collected over the 3 years of the study was completed in December 2016. All submerged areas of the fen that were sampled supported a diverse insect fauna, typical of local marsh habitats. In particular sprawling dragonflies (Libellulidae), damselflies (Coenagrionidae, Lestidae), diving and water scavenger beetles (Dytiscidae and Hydrophilidae), and minnow mayflies (Baetidae) were common, all occurring in at least 25% of all benthic samples. Midges (Chironomidae) and worms (Oligochaeta) were found in almost all samples. In contrast, other non-insect invertebrates typical of marsh habitats were absent (snails, leeches, amphipods) in 2013. Snails became increasingly frequent in 2014 and 2015, but few amphipods and no leeches were collected. Measurements of water depth, dissolved oxygen concentration, conductivity, and aquatic plant cover were longitudinally consistent and changed minimally over the course of each field season, but mean electrical conductivity increased each year of the study.

There was relatively little change in the overall richness or distribution of aquatic invertebrate taxa over the 3 years of the study. However, cluster analysis revealed changes in the composition of samples among years based upon the relative abundance of taxa. In 2013, one year after SFRW was constructed, two clusters of sites were evident – those dominated by aquatic worms, and those dominated by a variety of mayfly and damselfly taxa. Most samples collected in 2014 exhibited higher relative abundances of *Hydra* (snails, damselflies and nematodes) relative to the samples collected in 2013. However, several 2014 samples (those collected at sites with water conductivity of 2,800 µS/cm or higher) clustered more closely with 2013 samples. These were dominated by salt-tolerant taxa – larvae of midges and biting midges (confirmed by samples collected in 2015).

Objective 2: Assess invertebrate composition in a suite of natural fens, variously affected by salinity and/or used as a seed source for populating SFRW

Multivariate analysis of the plant and semi-terrestrial invertebrate communities of reference fens revealed marked differences in composition, reflecting differences in the dominant vegetation of particular fen types. The biota of SFRW was more diverse than that of any of the reference fens, and included elements of fens of quite different type. This reflects the habitat heterogeneity of SFRW relative to natural fens in the region.

Objective 3: Recommend invertebrate community benchmarks (variables, units of measurement, values) characteristic of reference fens that can serve as 'measures of reclamation success' for semiaquatic habitats of SFRW and other constructed wetlands based on the synthesis of information from objectives 1 and 2.

Multivariate analyses (nonmetric multidimensional scaling and cluster analyses) were used to document similarities and dissimilarities among groups of sites based on plant community composition and subsequently on invertebrate composition. Three distinct groups of sampling sites could be identified based on the dominant vegetation present. *Carex-Typha-Scirpus*-dominated sites occurred in the wettest areas of the fen (which tended to have peat substrate). Drier sites, characteristic of the uplands, were dominated either by a *Fragaria-Rubus* association or by a *Meticago-Sonchus-Hordium* association (with LFH-dominated soil). Each vegetation type tended to support distinctive assemblages of invertebrates. The saturated sites were dominated by planthoppers, thrips, and ladybird beetles. *Metacago-Sonchus-Hordium*-dominated sites had fauna consisting of thrips, spiders, ants and wasps. In contrast, the *Fragaria-Rubus* dominated sites were distinguished primarily by reduced relative abundances of thrips.

LESSONS LEARNED

Objective 1

There is a complex correlation among moisture, soil type, vegetation characteristics and invertebrates suggest that the following relationships presently apply to SFRW:

- The prescription soil type (peat vs. LFH) influences plant community composition, both directly and indirectly through its moisture retention capacity.
- Plant community composition in turn determines the composition of the insect community. In other words, semi-terrestrial invertebrate assemblages of SFRW are directly associated with plant community composition and indirectly regulated by soil type.

Objective 2

Overall, the invertebrate taxa richness of SFRW exceeded that of the reference fens sample. Whereas composition of invertebrate communities differed greatly from one reference fen to another, the composition of SFRW invertebrate samples fell near the centre of the range of variation of reference fens. This reflects the early successional stage of SFRW, which supports a much wider range of microhabitats and vegetation types than any single mature reference fen.

Objective 3

The rapid colonization and apparent success of plants and invertebrates observed in Year 1 of the fen has been sustained in Years 2 and 3, despite evidence of increasing salinity in the groundwater and surface waters of the fen. This may reflect the ionic composition of the water (enriched in calcium leached from the placed peat and clays). Alternatively, local zoobenthos may be more tolerant of elevated electrical conductivity than is commonly thought.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Menard, K. 2017. Community development of terrestrial and semi-terrestrial Invertebrates in a reclaimed wetland along environmental gradients. M.Sc. Thesis, University of Windsor, Windsor, ON.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Windsor

Principal Investigator: Jan Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jan Ciborowski	University of Windsor	Professor, Principal Investigator		
Lee Foote	University of Alberta	Professor		
Marie-Claire Roy	University of Alberta	Research Associate		
Amalia Despenic	University of Windsor	Undergrad Research Associate	2012	2016
Crystal Kelly	University of Windsor	Undergrad Research Associate	2011	2015
Dan Marsden	University of Windsor	Undergrad Research Associate	2010	2014
Hannah Bagnall	University of Windsor	Undergrad Research Associate	2009	2013
Hannah Wiseman	University of Windsor	Research Associate		
Mallory Hazell	University of Alberta	M.Sc./ Research Associate	2013	2017
Kellie Menard	University of Windsor	M.Sc.	2014	2017
Chantal Dings-Avery	University of Windsor	MSc./ Research Associate	2014	2018
Rachel Boutette	University of Windsor	Undergrad Research Associate	2013	2017
Hearthy Mayodo	Keyano College	Undergrad Research Associate	2013	2017

NSERC – Syncrude Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms

COSIA Project Number: LJ0210

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 6 of 6 (one-year extension in 2017)

PROJECT SUMMARY

The overarching goal of this research program was to develop methods of characterizing, monitoring, and simulating water movement through reconstructed oil sands mine landscapes. The development of investigative and interpretative tools is focused on the evolving hydrogeology of two of the largest reclaimed landscapes: overburden shale and tailings sands. Two relatively large (100–1,000 ha) closure landscapes on the Syncrude oil sands mine lease – South West 30 Dump (SWD, overburden shale) and South West Sand Storage (SWSS, tailings sand) – are the primary study sites supplemented by other landforms (e.g., Coke Watershed, Aurora Capping Study, etc.).

The original overall objectives of the study were as follows:

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

PROGRESS AND ACHIEVEMENTS

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

Water Balance Modelling of Reclamation Covers

Water balance models have been calibrated for a series of key reclamation covers at Syncrude's Mildred Lake mine site including: South Bison Hill (SBH), also known as South West 30 Dump, the sand tailings site (Southwest Sand Storage – SWSS), as well as for selected covers at the Coke Watershed on the Mildred Lake settling basin, and the covers at the Aurora Capping Study (ACS).

- The modelling for SBH was undertaken by research scientist, Mingbin Huang, and has been published (Huang et al. 2015). This work is now being extended to include full coupled water and heat dynamics with a particular focus on infiltration into frozen soil. This work is being undertaken in collaboration with Dr. Ireson (University of Saskatchewan). A key finding is that there is a need to optimize cover depths to ensure both adequate water for vegetation, as well as water release for down-stream wetlands. In addition, frozen ground infiltration modelling has shown the critical need to incorporate infiltration into macropores in the simulation of snow melt infiltration.

- The work on SWSS is ongoing and was led by research scientist, Huang. A preliminary numerical model of SWSS has been developed to simulate the impact of historical dump construction on long-term performance including the evaluation of the impact of dump chronology on water and salt release from the sand tailings structure. The work to date shows that it is essential in sand tailings structures to incorporate the temporal evolution of the dump to accurately simulate the long-term release of process water.
- The work on the reclamation covers at the Aurora Capping study has been a focus for Shahabul Alam (Ph.D. candidate) and will be discussed below.

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

- Student James Tipman (M.Sc. candidate), has completed a final thesis draft. The key finding from his study was that with proper equipment selection, optimization of data logging protocols, and proper interpretative methods, it is possible to measure daily soil moisture loading (to at least 3-5 mm/day range) using grouted-in vibrating wire piezometers.
- A comparison of the advantages and limitations of the interpretation protocols commonly used for these applications has been published in a conference paper (Tipman et al. 2017).
- More foundational studies of the mechanisms controlling the pore-pressure response of grouted-in vibrating wire piezometers was undertaken by a second student Charles Dourado (M.Sc. candidate) with a final thesis draft recently completed. This study has developed theoretical and numerical methods of interpreting the response of grouted-in vibrating wire piezometers to surface loading with a view to being able to characterize both the hydraulic and geomechanical properties of aquitards based on these interpretations.

Salt Generation in Reclaimed Shale Overburden

- A reanalysis of the M.Sc. research undertaken by Wall (2005) has been completed by Wilemijin Appels (PDF) and published (Appels et al. 2017).
- This work has quantified the rates of oxidation of the sodic-saline shale overburden at Syncrude's South Bison Hill and highlighted how this ongoing oxidation process can lead to elevated salt loading within the surficial 1-3 m of these deposits over relatively short time periods.
- Samples for trace geochemical and biological testing have been provided to Dr. Matt Lindsay, an Associate Industrial Research Chair with Syncrude.

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils

- Matthew Buchynski (M.Sc.) has completed his characterization of the rates of diffusion/dispersion of the stable isotopes of water in unsaturated sand (Buchynski 2017). The characterization of the transport parameters/processes (diffusion, dispersion) for pulses of isotopically enriched water within tailings sand can be applied to the interpretation of isotope profiles to evaluate rates of net percolation within these deposits.

Spatial and Temporal Variability in Net Percolation into Reclaimed Oil Sands Mine Materials

- Shalabul Alam (Ph.D. candidate), is attempting to quantify 'uncertainty' – both spatial and temporal variability – associated with the calibration of the material properties associated with water balance dynamics at instrumented soil cover sites. His work to date has focused primarily on the covers at the Aurora Capping Study (ACS) but will be extended to include covers at South Bison Hill and SWSS. He has shown that including parameter 'uncertainty' in our calibration of material properties from soil cover monitoring data can be incorporated into the long-term modelling of soil cover performance. In addition, he has shown that in the case of hydraulic conductivity, the spatial variability (material heterogeneity) identified in the model optimization can be correlated to direct field measurements of spatial variability.
- Alam has also completed a study on the impact of future climate change on soil cover performance (Alam et al. 2018, *in submission*). The study focused on the water balance for reclamation covers placed over oil sands mine materials (i.e., for saline-sodic overburden and for sand tailings) in comparison to three natural sites. Local climate change data was developed (i.e., by downscaling) based on two different global climate change models (General Circulation Models [GCMs]) combined with three associated representative concentration pathways (RCPs). Calibrated Soil-Vegetation-Atmosphere-Transfer (SVAT) models for the sites were then used to compare changes in water balance for the five soil profiles, over four, time periods: a 30-year historical (i.e., 1961-1990) climate, and three future (i.e., 2016-2040, 2041-2070 & 2071-2100) time periods.

The work has demonstrated that, although actual evapotranspiration is likely to increase for all of these sites, the most remarkable increase is the percentage increase in net percolation at reclamation cover sites and natural sites, which currently have relatively low rates of net percolation. This increase in net percolation is likely to increase (e.g., double) water yield from these sites, but in many cases it will also increase the rates of solute flushing from the underlying mine overburden discard materials.

Profiling the Stable Isotopes of Water within Sand Tailings • Two field drilling programs were undertaken to measure the stable isotopes of water across a transect (Cell32) at SWSS. During the August 2016 field program, 5 multi-level vapour sampling (9 ports) profiles were installed. Several rounds of field sampling of these ports were completed, but the data has not been fully interpreted.

- The stable isotope of water profiles obtained from soil core sampling clearly shows the depth of infiltration of recent meteoric water and the displacement of process water within the unsaturated sand tailings. However, there were difficulties in undertaking direct field monitoring of the isotope profile using field-based measurement of the vapour phase. The primary difficulty was interference caused by the presence of hydrocarbons in the vapour phase (e.g., methane, hexane). This interference is largely absent in the soil samples/testing since these gases either volatilize or oxidize prior to testing of the samples.

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

- Additional testing of the final probe design for the CPT/TDR instrument was completed in 2017.
- The results of two field trials, conducted by M.Sc. student Spencer Chuhaniuk, have demonstrated that the developed CPT/TDR sensor probe is able to track volumetric water content (and cumulative stored water volume) within the sand tailings at SWSS to depths approaching 10 m.
- Laboratory work was also completed to calibrate the CPT/TDR sensor probe for both sand tailings and fluid fine tailings (FFT). It was found that saturated FFT samples did not provide a sufficient range of water contents

to establish a calibration curve. The laboratory work was also able to define a range of working electrical conductivity values within which the TDR wave forms can be interpreted.

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit

- A current M.Sc. student, Spencer Chad, is collating the stable isotope of water signature of site wide waters at Syncrude's Mildred Lake and Aurora mine sites.
- The goal of this research is to provide industry with an additional tool to monitor tailings pond water balances during mine operations.
- A data set of high frequency water samples has been collected from the mine over the past eight years to establish a catalogue of site wide waters, and to track temporal variations within the recycle water (RCW).
- The primary factors controlling isotopic composition of the RCW are identified as: cooling tower blowdown, open water evaporation, and seasonal cycles of meteoric water input. An isotope mass balance model is being used to characterize the relative impact of these factors on the isotopic composition of the RCW. The work indicates this technique may also be used to track the hydrological evolution of reclaimed tailings landscapes as they evolve from oil sands process-affected water (OSPW) signatures to freshwater chemical compositions.

An Assessment of the Water Balance for Reclamation Soil Covers Placed over Unsaturated Coke and Fluid Fine Tailings

- Matt Armoh (M.Sc. candidate) is undertaking a re-evaluation of the water balance for soil reclamation covers on coke capped FFT. The study site is located on the two prototype covers built in 2005 on hydraulically placed coke at the Mildred Lake Settling Basin. Although these covers were similar in thickness and texture to those used successfully to reclaim overburden, early monitoring data at this site highlighted low volumes of water storage which may have contributed to challenges with tree growth. This study is attempting to quantify the relative impact of preferential flow (macropore flow) and convective air flow (as a result of oxidation of released methane from the FFT) on accelerated drying of the covers.

LESSONS LEARNED

Integrated Modelling of Surface Water and Groundwater Flow and Contaminant Transport within the Southwest Sand Storage facility

Incorporating dump chronology has little effect on the location of the water table and the rates of water flow through the sand tailings dyke since the transients associated with changes in the model geometry and net percolation are relatively small (i.e., < 1 year). However, the degree of flushing of process affected water is strongly related to the evolution of the landform over time. Models which incorporate dump chronology forecast increased flushing of the landform prior to the end of operating conditions.

Calibration and Use of Geological Weighing Lysimeters (GWL) for the Measurement of Hydrologic Fluxes in Mine Closure Landforms

The interpretation of GWLs require that careful processing of the data be undertaken to minimize 'noise' which interferes with the soil moisture loading signal. However, once full interpretation of the GWL data is completed, soil moisture loading in the order of 5 millimeters is well defined by the monitoring data. Improved design and operation of GWLs should enable this threshold to be lowered even further.

Characterization of Aquitard Geomechanical Properties using Pore-pressure Responses to Surface Barometric and Point Loading

Interpretation of the rate of rise and magnitude of the pore-pressure response within the barometric response function (BRF) is interpretable relative to both the compressibility and the hydraulic conductivity of the formation.

Salt Generation in Reclaimed Shale Overburden

Sulphate production rates (e.g., pyrite weathering) and depths estimated from solids chemistry and oxygen diffusion profiles were similar. These rates of sulphate production can be used to bound salt production rates from overburden dumps. A model analysis of oxygen diffusion into the overburden suggests the hydrology of the soil reclamation covers plays a role in the depths and rates of oxidation of the saline-sodic overburden.

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils

Profiles of the stable isotopes of water collected within unsaturated sand tailings can be used to identify depths of flushing of process water by recent meteoric water. New theoretical models of the diffusion/dispersion of stable isotopes of water in unsaturated sand can be incorporated into flow and transport models used to interpret these types of data sets.

Spatial and Temporal Variability in Net Percolation into Reclaimed Oil Sands Mine Materials

Modelling of the water balance for various reclamation covers and natural soil profiles has shown that fine-textured overburden (D3) had the highest actual evapotranspiration (AET) and the lowest net percolation (NP) during the baseline period as well as during future periods, while the reclaimed coarser textured SWSS had a higher AET and lower NP than the coarse-textured natural sites. The two ‘a1’ natural ecosites (SV10 and SV27) had similar AET and NP rates, while the third more productive ‘d2’ natural ecosite (SV60) had AET and NP values more similar to the SWSS site. Overall, the use of future climate projections resulted in increased precipitation, potential evapotranspiration, AET, and NP in the reclamation covers and natural sites throughout the 21st century, regardless of which representative concentration pathway or time period was used.

Inverse modelling of 4 cover treatments over lean oil sand overburden landforms showed that spatial uncertainty in model parameters was greater than temporal uncertainty; however, spatial variability as measured by direct testing (Guelph and Air-K testing) was similar to that obtained through inverse modelling.

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

A robust probe can be fabricated to obtain measurements of stored water volume within deep (> 10m) profiles of sand tailings.

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit

Seasonal cycles in the stable isotopes of water in tailings ponds are similar in pattern to those associated with natural freshwater ponds in the region. Isotopic mass balances can be utilized to identify the relative contribution of evaporation and cooling tower inputs to the recycle water circuit.

LITERATURE CITED

Alam, M. S., Barbour, S.L., Huang, M., Doucette, L. (2017a). "An Evaluation of Parameter Uncertainty in the Calibration of a Soil-Vegetation-Atmosphere-Transfer (SVAT) model for a Reclamation Cover on Lean Oil Sands (LOS)". Hydrogeological, *GeoOttawa* 2017, Oct.1-4 (Cdn Geot. Conf) (Poster 304).

Alam, S., Huang, M., Barbour, S.L. Si, B.C. (2017b). "Characterizing Temporal and Spatial Variability in Soil-Vegetation-Atmosphere-Transfer (SVAT) Modelling of Reclamation Covers in Northern Alberta, Canada", *Computational Modelling of Multi-Uncertainty and Multi-Scale Problems Conference*, https://comus17.com/, Sep.12-14/17, Porto, Portugal, S. Alam presenting (oral).

Alam, M. S., Barbour, S.L., Elshorbagy, A., Huang, M. (2017c). "The Impact of Climate Change on the Performance of Oil Sands Reclamation Covers: A Comparison of Multiple General Circulation Models and Representative Concentration Pathways (RCPs)". Mining Oil & Gas, *GeoOttawa* 2017, Oct.1-4 (Cdn Geot. Conf) (Oral 300).

Alam, M. S., Barbour, S.L., Elshorbagy, A., Huang, M. (2018). "The Impact of Climate Change on the Water Balance of Oil Sands Reclamation Covers and Natural Soil Profiles", *In Submission to: J. of Hydrometeorology*.

Appels, W.M., Wall, S.N., Barbour, S.L., Hendry, M.J., Nichol, C.F., Chowdhury, S.R., (2017). "Pyrite Weathering in Reclaimed Shale Overburden at an Oil Sands Mine near Fort McMurray, Canada", *Mine Water and the Environment*, online May 3, doi:10.1007/s10230-017-0454-4.

Buchynski, Matt, M.Sc. (2017). "Characterizing the Transport of the Stable Isotopes of Water in Unsaturated Soils", (jointly with Jim Hendry), Aug. 12.

Chuhaniuk, S., Barbour, S.L. (2017). "Real Time Monitoring of Volumetric Water Content in Reclaimed Mine Waste Using Cone Penetration – Time Domain Reflectometry", Mining - Reclamation & Covers I, *GeoOttawa* 2017, Oct.1-4 (Cdn Geot. Conf) (Oral 727).

Huang, M., Barbour, S.L., Carey, S. (2015). "The Impact of Reclamation Cover Depth on the Performance of Reclaimed Shale Overburden at an Oil Sands Mine in Northern Alberta, Canada", *Hydrol. Proc.*, doi: 10.1002/hyp.10229, doi: 10.1002/hyp.10229, June 15, 29(12): 2840-2854.

Huang, M., Zettl, J., Madaeni, F., Barbour, S.L., Mendoza, C.Madaeni, F., Barbour, S.L., Mendoza, C. (2017). "The Impact of Spatial and Temporal Evolution of Landform Evolution on Salt Release from an Oil Sands Tailings Dyke", *In preparation for submission*.

Tipman, J., Barbour, S.L., van der Kamp, G. (2017). "An Evaluation of Methods to Remove Barometric Effects from Pore Pressure Data", General Hydrogelogy I, *GeoOttawa* 2017, Oct.1-4 (Cdn Geot. Conf) (Oral 770).

Wall, Susan (2005). "Characterizing the Geochemical Reactions in an Overburden Waste Pile: Syncrude Mine Site, Fort McMurray, Alberta, Canada", *M.Sc. Thesis*, Dept. of Geological Sciences, University of Saskatchewan, January.

PRESENTATIONS AND PUBLICATIONS

The following lists include presentations and publications from the IRC's students and research personnel's research in 2017, as well as 'directly related' research by Dr. Barbour.

Published Theses

Buchynski, Matt, M.Sc. 2017. "Characterizing the Transport of the Stable Isotopes of Water in Unsaturated Soils", (jointly with Jim Hendry), Aug.

Dompierre, Kathryn, PhD. 2016. "Controls on Mass and Thermal Loading to an Oil Sands End Pit Lake from Underlying Fluid Fine Tailings", (jointly with Matt Lindsay), Dec.

Journal Publications

Appels, W.M., Ireson, A., Barbour, S.L. (2017). "Impact of Bimodal Textural Heterogeneity and Connectivity on Flow and Transport through Unsaturated Mine Waste Rock", *Accepted (in press): Advances in Water Resources*, Available online Dec.9, https://doi.org/10.1016/j.advwatres.2017.12.008.

Nagare, R., Park, Y-J, Barbour, L. (2017). "Analytical Approach to Estimate Salt Release from Tailings Sand Hummocks in Oil Sands Mine Closure", *Accepted: Mine Water and the Environment (MWEN)*, Nov. 1, doi: 10.1007/s10230-018-0513-5.

David, K., Timms, W., Barbour, L., Mitra, R. (2017). "Tracking Changes in the Specific Storage of Overburden Rock during *Longwall Coal Mining*", *J. of Hydrology* (published online July 29), October, 553:304-320, doi: 10.1016/j.jhydrol.2017.07.057.

Dompierre, K, Barbour, L, North, RL, Carey, SK, Lindsay, MB. (2017). "Chemical Mass Transport between Fluid Fine Tailings and the Overlying Water Cover of an Oil Sands End Pit Lake", *Water Resources Res.*, June, 53(6): 4725-4740, doi: 10.1002/2016WR020112.

Appels, W.M., Wall, S.N., Barbour, S.L., Hendry, M.J., Nichol, C.F., Chowdhury, S.R., (2017). "Pyrite Weathering in Reclaimed Shale Overburden at an Oil Sands Mine near Fort McMurray, Canada", *Mine Water and the Environment*, online May 3, doi:10.1007/s10230-017-0454-4.

Conference Presentations/Posters

Alam, M. S., Barbour, S.L., Elshorbagy, A., Huang, M. (2017). "The Impact of Climate Change on the Performance of Oil Sands Reclamation Covers: A Comparison of Multiple General Circulation Models and Representative Concentration Pathways (RCPs)". Mining Oil & Gas, *GeoOttawa* 2017 – Oct.1-4 (Cdn Geot. Conf) (Oral 300).

Alam, M. S., Barbour, S.L., Huang, M., Doucette, L. (2017). "An Evaluation of Parameter Uncertainty in the Calibration of a Soil-Vegetation-Atmosphere-Transfer (SVAT) model for a Reclamation Cover on Lean Oil Sands (LOS)". Hydrogeological, *GeoOttawa* 2017– Oct.1-4 (Cdn Geot. Conf) (Poster 304).

Chuhaniuk, S., Barbour, S.L. (2017). "Real Time Monitoring of Volumetric Water Content in Reclaimed Mine Waste Using Cone Penetration – Time Domain Reflectometry", Mining - Reclamation & Covers I, *GeoOttawa* 2017– Oct.1-4 (Cdn Geot. Conf) (Oral 727).

Tipman, J., Barbour, S.L., van der Kamp, G. (2017). "An Evaluation of Methods to Remove Barometric Effects from Pore Pressure Data", General Hydrogelogy I, *GeoOttawa* 2017– Oct.1-4 (Cdn Geot. Conf) (Oral 770).

Demars, S., Ireson, A, Barbour, S.L. (2017). “Importance of Winter Processes on Salt Redistribution in a Reclamation Cover”, Cdn Geophysical Union (*CGU*) Annual Mtg., B04B: Mine Reclamation: Multidisciplinary Studies from Across Mining Sectors, Vancouver, B.C., May29-31 (oral).

Dompierre, K., Barbour, S.L., Zettl, J., (2017). “Characterizing Mass Release from Oil Sands Fluid Fine Tailings with Multiple Tracers”, Cdn Geophysical Union (*CGU*) Annual Mtg., B04 (POSTER): Mine Reclamation: Multidisciplinary Studies from Across Mining Sectors, Vancouver, B.C., May29-31 (Dompierre presenting).

Liu, Q., Rudderham, S.B., Lindsay, M.B.J., Barbour, S.L. (2017). “Influences of Biogeochemical Processes on Mass Transport across the Tailings-Water Interface of an Oil Sands End Pit Lake”, Cdn Geophysical Union (*CGU*) Annual Mtg., B04D: Mine Reclamation: Multidisciplinary Studies from Across Mining Sectors, Vancouver, B.C., May29-31 (Liu presenting).

Zettl, J.D., Barbour, S.L., Lindsay, MBJ, Carey, S.K. (2017). “Base Mine Lake Chemical Mass Balance 2013-2016”, Cdn Geophysical Union (*CGU*) Annual Mtg., B04A: Mine Reclamation: Multidisciplinary Studies from Across Mining Sectors, Vancouver, B.C., May29-31 (Zettl presenting).

Smith, L.A., Barbour, S.L., Hendry, M.J., Elwood, D. (2017). “Profiling the In Situ Compressibility of Cretaceous Shale using Grouted in Piezometers and Laboratory Testing”, In: Ferrari A., Laloui L. (eds) Proceedings: *Advances in Laboratory Testing and Modelling of Soils and Shales (ATMSS) International Workshop*, Jan.18-20, 2017, Villars-sur-Ollon, Switzerland, Springer Series in Geomechanics and Geoengineering. Springer, Cham, DOI: 10.1007/978-3-319-52773-4_34, pp. 296-303 (Oral: Elwood presenting).

Reports & Other Publications

Barbour, S.L., Lindsay, M., Bews B.E., (2017). “Progress Report for: CRDPJ 476388 for Y2 (June1/16-May 1/17) – entitled: ‘Examining controls on mass loading to an oil sands end pit lake for Y2’”, *Prepared for:* Christina Wood (NSERC), May 19, 23pp.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Lee Barbour

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dyan Pratt	University of Saskatchewan	Research Engineer		
Brenda Bews	University of Saskatchewan	Research Engineer		
Julie Zettl	University of Saskatchewan	Research Engineer		
Mingbin Huang	University of Saskatchewan	Research Engineer		
Stephanie Villeneuve	University of Saskatchewan	Research Engineer		
Thomas Baer	University of Saskatchewan	M.Sc.	2012	2014
Mengna Lu	University of Saskatchewan	M.Eng.	2014	2014
Mike Amos	University of Saskatchewan	M.Sc.	2012	2015
Matthew Buchynski	University of Saskatchewan	M.Sc.	2013	2017
James Tipman	University of Saskatchewan	M.Sc.	2013	In Progress
Charles Dourado	University of Saskatchewan	M.Sc.	2015	In Progress

Spencer Chuhaniuk	University of Saskatchewan	M.Sc.	2016	In Progress
Spencer Chad	University of Saskatchewan	M.Sc.	2016	In Progress
Matt Armoh	University of Saskatchewan	M.Sc.	2016	In Progress
Yolanda Tang	University of Saskatchewan	M.Sc.	2016	In Progress
Arash Janfada	University of Saskatchewan	Ph.D.	2012	Withdrew Aug 2014
Fatemeh Madaeni	University of Saskatchewan	Ph.D.	2013	Withdrew Dec 2015
Shahabul Alam	University of Saskatchewan	Ph.D.	2015	In Progress
Saidur Chowdhury	University of Saskatchewan	PDF	2015	2015
Willemijn Appels	University of Saskatchewan	PDF	2015	2015
Laura Smith	University of Saskatchewan	PDF	2016	2017

Research Collaborators:

Integrated Modelling of Surface Water and Groundwater Flow and Contaminant Transport within the Southwest Sand Storage facility (Fatemeh Madaeni)
Collaborator: Dr. Carl Mendoza, University of Alberta

Calibration and Use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms (James Tipman)
Collaborators: Dr. Garth van der Kamp, University of Saskatchewan and Dr. Sean Carey, McMaster University

Characterization of Aquitard Geomechanical Properties using Pore-pressure Responses to Surface Barometric and Point Loading (Charles Dourado)
Collaborator: Dr. Jim Hendry, University of Saskatchewan

Salt Generation in Reclaimed Shale Overburden (Willemijn Appels)
Collaborator: Dr. Jim Hendry, University of Saskatchewan

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils (Matthew Buchynski)
Collaborators: Dr. Jim Hendry, University of Saskatchewan

A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste (Spencer Chuhaniuk)
Collaborator: Dr. Dave Elwood University of Saskatchewan

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit (Spencer Chad)
Collaborators: Dr. Jeffrey McDonnell, University of Saskatchewan and Dr. John Gibson, University of Victoria

Development of a TDR In-Situ Probe & Gas Sampler Compatible w CPTu (Mike Amos)
Collaborator: Dr. Bing Si, University of Saskatchewan

Spatial Variability in Net Percolation on Reclaimed Oil Sands Mine Waste (Shahab Alam)
Collaborator: Dr. Mingbin Huang, University of Saskatchewan, and Northwest A&F University

Water Balance Modelling of Reclamation Covers (Mingbin Huang)
Collaborator: Dr. Andrew Ireson, University of Saskatchewan

Osmotic Behaviour of Shales (Yolanda Tang)
Collaborator: Dr. Dave Elwood, University of Saskatchewan

NSERC – Syncrude Industrial Research Chair in Mine Closure Geochemistry

COSIA Project Number: LJ0292

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

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

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

Objective 1: Define the geochemical characteristics of existing waste deposits.
Objective 2: Identify processes and conditions controlling water quality.
Objective 3: Constrain geochemical implications of potential closure scenarios.
Objective 4: Develop conceptual models of the geochemical evolution of closure landscapes.

These research objectives and associated activities initially focused on tailings centrifuge cake (cake) and fluid petroleum coke (coke) for the following three reasons: (i) information on their geochemical characteristics and evolution were limited; (ii) large volumes of these materials will be stored in the closure landscape; and (iii) results are immediately applicable to ongoing closure planning.

PROGRESS AND ACHIEVEMENTS

Strong progress was made in 2017 towards meeting the proposed research objectives. Specific details of this progress are outlined below.

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

This research objective focused on cake and coke deposits and involved several field-sampling campaigns. Detailed analyses were performed on these samples to determine their geochemical, mineralogical, microbiological, and physical characteristics. Research activities associated with this objective were completed in 2016. However, in 2017 additional research was conducted on coke geochemistry, and manuscript preparation is ongoing.

Activity 1.1 – Characterization of existing centrifuge cake deposits

Centrifuged cake is a thickened tailings material produced by amending fluid fine tailings (FFT) with a coagulant (i.e., gypsum) and flocculent (i.e., polyacrylamide) and then centrifuging. Research activities associated with this objective were completed in April 2016. Preparation of two manuscripts for publication in peer-review journals is ongoing.

Activity 1.2 – Characterization of existing petroleum coke deposits

Petroleum coke is an upgrading by-product, which is produced during thermal cracking of the non-distillable bitumen fraction. Although the initial objectives of this research were achieved in May 2016 (i.e., nickel, vanadium), additional research was initiated in 2017 focused on the molybdenum geochemistry of coke deposits.

This additional research was initiated after elevated dissolved molybdenum concentrations (up to 2 mg L^{-1}) were observed within pore waters of the Coke Beach deposit. Dissolved molybdenum concentrations were found to be highest at elevated electrical conductivities and mildly alkaline pH conditions. There is some evidence that sulfidic conditions, commonly found in fluid fine tailings (FFT), may also promote attenuation of dissolved molybdenum. It was determined that adsorbed molybdenum(VI) complexes at coke particle surfaces are likely the principal source of dissolved molybdenum within these deposits. Although generally a minor phase, the abundance of these molybdenum(VI) complexes generally decreases with depth in the deposits, suggesting that they could form via oxidative weathering of molybdenum(IV)-sulfur phases above the water table.

Two journal articles related to this activity were published in 2017 (Nesbitt et al., 2017; Nesbitt and Lindsay, 2017); one additional manuscript was submitted (Nesbitt et al., In Review) and another, focused on molybdenum, is in preparation.

Objective 2: Identify processes and conditions controlling water quality

This objective includes two principal activities that aim to improve the understanding of relationships between biogeochemical and physical processes influencing water quality in cake and coke deposits. This research is dependent upon the findings of the initial field studies outlined above (*Activity 1.1, Activity 1.2*) and was initiated in December 2016. Research activities associated with Objective 2 are ongoing, with completion anticipated by December 2018.

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

This research activity examines interactions among the chemical, biological, and physical processes that influence the geochemical evolution of cake. Field studies (*Activity 1.1*) demonstrated that evaporation and freeze-thaw cycling are important controls on pore-water chemistry in cake deposits. Consequently, two sets of laboratory research experiments are ongoing: (1) biogeochemical implications of coagulant/flocculent addition during cake production; and (2) freeze-thaw-evaporation induced salt redistribution within cake deposits.

Laboratory batch experiments on coagulant/flocculent addition have demonstrated that gypsum addition has a significant impact on water chemistry in cake deposits. For example, systematic increases in gypsum addition produced corresponding increases in electrical conductivity, sodium concentrations, and sulfate concentrations. Despite the increased sulfate concentrations, hydrogen sulfide production was not linearly proportional to gypsum addition and, therefore, initial sulfate concentration. This finding, based upon longer-term data (i.e., > 6 months) and relevant coagulant additions, differs from what we reported last year for preliminary studies using excessively high gypsum amendment rates. Additionally, detectable methane concentrations were apparent throughout the experiment, but a relationship with gypsum addition was not apparent with these gypsum amendment rates. Final sampling of these experiments (64 weeks) will be conducted in July 2018.

Laboratory column experiments were designed during 2017, which will be set up and initiated in January and February of 2018. Six columns (90 cm long by 35 cm diameter) will be packed with fresh cake and each column will be instrumented with thermocouples (temperature profiles), load cells (column mass), and capacitance probe access tubes (water content) to monitor physical and hydrologic properties over time. Experiments will be conducted over six months in a freezer/cold room where there is the ability to control temperature and relative humidity. These columns will be subjected to three, freeze-thaw-evaporation cycles, and detailed sampling and measurements will be conducted following each cycle. These experiments will conclude in August 2018 and data analysis will continue through December 2018.

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

This activity will further examine metal release from fresh fluid petroleum coke for the purpose of optimizing the use of coke in the closure landforms at closure. A series of laboratory column experiments was initiated, based upon initial research findings (*Activity 1.2*), to examine metal leaching capacity under different water chemistries that coke may encounter in closure landscapes. Specifically, consideration is being given to metal leaching during transport of the following solutions through coke: (1) meteoric water (i.e., precipitation/snow melt); (2) oil sands process-affected water (OSPW); and (3) acid rock drainage. These experiments include one large (70 cm long) column and six small (15 cm long) columns. The three solutions are being passed through the large column in sequence, whereas each solution is individually being passed through two small columns. Investigation of transport characteristics within the large column is being conducted using geophysical methods. The experiments were initiated in July 2017 and both geochemical and geophysical monitoring is ongoing. These experiments are anticipated to be concluded in July 2018, with data analysis continuing through December 2018.

Objective 3: Constrain geochemical implications of potential closure scenarios

Research focused on this objective started in October 2015 and will continue through 2018. This objective involves interdisciplinary field and laboratory studies designed to improve the understanding of the geochemical implications of proposed closure scenarios for water quality. More specifically, this research examines chemical, biological, and physical processes controlling the evolution of water chemistry under different closure scenarios. Consequently, the study of the mechanisms and implications of salt release from tailings (i.e., cake, composite tailings) and subsequent transport through overlying materials (e.g., coke, reclamation soil covers) has been ongoing.

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

This activity initially included a series of lysimeter experiments, but later expanded to integrate field (i.e., Sandhill Fen) and laboratory (i.e., columns) research.

The lysimeter experiments were constructed and instrumented in October 2015 using mine wastes and reclamation cover materials to emulate three potential closure scenarios:

1. peat-mineral mix (0.5 m) overlying coke (1.0 m) overlying cake (1.5 m);
2. coke (1.0 m) overlying cake (2.0 m); and
3. cake (2.0 m) overlying tailings sand (1.0 m).

These three scenarios were replicated under water saturated and unsaturated conditions to mimic in-pit and out-of-pit closure landscapes. During 2017 research activities related to the field lysimeter experiments included: (i) ongoing field measurements using data logger systems (i.e., water content, matric potential, electrical conductivity, temperature);

(ii) solid-phase analysis of core samples collected in October 2016; and (iii) interpretation and modeling of data collected from this experiment. Key findings of this research include:

- upward vertical salt transport initially is advection dominated and proportional to cake dewatering;
- limited sodium attenuation occurs within the coke layer;
- evaporation from the surface can support substantial increases in dissolved salt concentrations; and
- reclamation soil covers suppress evaporation and minimize impacts of evaporation on dissolved salt concentrations.

A complementary laboratory column experiment (1.5 m long, 0.2 m inner diameter) was also initiated to examine the influence of cake dewatering on salt transport into overlying coke layers. This experiment started in September 2016 and concluded in May 2017, with data interpretation and transport modeling continuing through December 2017. The key finding from this research is that relative rates of advective salt transports decline with declining rates of cake dewatering. Although this finding is not overly novel, transport models that accurately describe these processes were developed by the researchers.

Monitoring of the lysimeter experiments will continue over the remaining duration of this IRC term. However, research activities related to the other aspects of this research activity were completed by December 2017. One Master's thesis (Cilia, 2017) based upon this research was also completed in 2017.

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

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

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

This final research activity was initiated in July 2016; however, all research included in Objectives 1–3 will support this final activity. This study will integrate the field measurements, laboratory observations, and modeling by Ph.D., M.Sc., and B.Sc. students into a guidance document that will support ongoing mine closure planning. Lindsay (NSERC IRC) will lead this research activity from 2016 through 2018.

LESSONS LEARNED

Research conducted over the past year has provided valuable insight into: (1) the biogeochemical characteristics of centrifuged fine tailings; (2) metal mobility within coke deposits; (3) salt transport within layered waste systems; and (4) salt transport within reclamation soil covers.

Centrifuge Cake: Gypsum amendment corresponds to increased sodium and sulfate concentrations within cake deposits. Although dissolved hydrogen sulfide concentrations are elevated in cake deposits, there does not appear to be a direct relationship between gypsum amendment (i.e., sulfate addition) and hydrogen sulfide concentrations when using relevant amendment rates.

Fluid Petroleum Coke: Leaching of vanadium, nickel and molybdenum can lead to elevated dissolved concentrations within coke deposits. Although solid-phase molybdenum concentrations are up to two orders of magnitude lower than vanadium, dissolved concentrations are similar within coke deposits. Molybdenum mobility increases under oxic and alkaline conditions but decreases under sulfidic conditions commonly found in FFT deposits. Unlike vanadium and nickel, molybdenum does not appear to be associated with porphyrin complexes, which may explain the enhanced leaching behaviour (manuscript in development).

Layered Waste Materials: Initial dewatering of gypsum-amended cake drives upward advective transport of sodium-rich pore-waters. Advective fluxes decline with time and, eventually, diffusion will become the dominant solute transport process. Coke layers provided limited to no capacity for sodium attenuation (i.e., via ion exchange) during dewatering of underlying cake. Reclamation soil covers supressed evaporation and limited evaporative concentrations of dissolved salts within coke layers. However, salt transport and accumulation within the soil covers was observed when water-saturated conditions extended to the ground surface.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Cilia, C.R.C. (2017). Characterizing the physical and chemical transport of dissolved salts in layered oil sands mine wastes undergoing reclamation. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Canada, 150 pp. https://ecommons.usask.ca/handle/10388/8323.

Journal Publications

Submitted:

Nesbitt, J.A., Swerhone, L.A. & Lindsay, M.B.J. (In Revision). Nickel geochemistry of oil sands fluid petroleum coke deposits, Alberta, Canada. *FACETS*, Manuscript ID: facets-2017-015.R1.

Published:

Nesbitt, J.A. & Lindsay, M.B.J. (2017). Vanadium geochemistry of oil sands fluid petroleum coke. *Environmental Science and Technology*, 51: 3102–3109. DOI: 10.1021/acs.est.6b05682

Nesbitt, J.A., Lindsay, M.B.J. & Chen, N. (2017). Geochemical characteristics of oil sands fluid petroleum coke. *Applied Geochemistry*, 76: 148–158. DOI: 10.1016/j.apgeochem.2016.11.023

Conference Presentations/Posters

Cilia, C.R.C. & Lindsay, M.B.J. (2017). Assessing salt transport within layered oil sands mine wastes: Field and laboratory experiments. Canadian Geophysical Union and Canadian Society for Agricultural and Forest Meteorology Joint Annual Scientific Meeting, May 28–31, Vancouver, Canada. [Poster]

Swerhone, L.A., Nesbitt, J.A., & Lindsay, M.B.J. (2017). Geochemical considerations for including petroleum coke in oil sands mine closure landscapes. Canadian Geophysical Union and Canadian Society for Agricultural and Forest Meteorology Joint Annual Scientific Meeting, May 28–31, Vancouver, Canada. [Poster]

Nesbitt, J.A. & Lindsay, M.B.J. (2017). Geochemical controls on vanadium mobility in oil sands fluid petroleum coke deposits. 2017 Joint Annual Meeting of the Geological Association of Canada and the Mineralogical Association of Canada, May 14–17, Kingston, Canada. [Oral]

Lindsay, M.B.J. (2017). Biogeochemistry of oil sands cake deposits: Considerations for mine closure. Oil Sands Innovation Summit 2017, March 21–22, Calgary, Canada. [Oral]

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Dr. Matthew Lindsay

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Kaitlyn (Scott) Heaton	University of Saskatchewan	M.Sc.	2013	2015
Jake Nesbitt	University of Saskatchewan	M.Sc.	2014	2016
Carlo Cilia	University of Saskatchewan	M.Sc.	2015	2017
Mattea Cowell	University of Saskatchewan	B.Sc.	2015	2016
Colton Vessey	University of Saskatchewan	B.Sc.	2015	2016
Lawrence Swerhone	University of Saskatchewan	M.Sc.	2016	2018
Mattea Cowell	University of Saskatchewan	M.Sc.	2016	2018
Mojtaba Abdolahnezhad	University of Saskatchewan	M.Sc.	2016	2019
Dr. Jared Robertson	University of Saskatchewan	Postdoctoral Fellow	2017	2019
Colton Vessey	University of Saskatchewan	M.Sc.	2017	2019
Drake Meili	University of Saskatchewan	B.Sc.	2018	2018
Dr. Lee Barbour	University of Saskatchewan	Professor and NSERC IRC		
Dr. Joyce McBeth	University of Saskatchewan	Assistant Professor		
Dr. Ning Chen	Canadian Light Source	Staff Scientist		

Coal Watershed Research and Development Program

COSIA Project Number: LJ0160

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

Industry Champion: Teck Resources Limited

Status: Year 6 of 7

PROJECT SUMMARY

In 2011 Teck Resources Limited (Teck) embarked upon an applied research and development (R&D) program focused on managing constituents of interest (CIs) in mining-affected watersheds. The overall objectives of the program are to:

1. 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 Applied R&D program is focused on research and development projects to investigate contaminant sources and advance source control methods, specifically related to mine design and water management strategies to manage CIs. The 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 mining activities, to evaluate their impacts, and to identify feasible methods to limit the production and release of CIs from mine wastes. A separate, but integrated, effort is the active water treatment technology program which is focused on the investigation of active water treatment technologies to remove and reduce CIs present in mine-affected water. The active water treatment research is focused on identification of improvements for active water treatment technologies.

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

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

PROGRESS AND ACHIEVEMENTS

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

- ex-pit waste rock dump design and management;
- water balances to aid water management decisions;
- rock drain design and operation;
- saturated zone design and operation; and
- reclamation and selenium (Se) management.

Substantial time and resources have been invested in sampling and instrumenting research areas to commence data collection in support of these research areas. This program continues to answer research questions and many of the original projects continued through 2017. Additional focal areas were added in subsequent years, including research into nitrate management, and an increased focus on evaluating practical strategies for mine design. In 2017, the focus of the program was on the construction of a full-scale trial facility to evaluate one of the more promising alternatives to active water treatment for the mitigation of selenium and nitrate – saturated rock fills.

Saturated Rock Fills – Full Scale Trial

The results from the field scale trial conducted in 2016 indicated that an over 90% of selenium and nitrate were removed from injected water by the saturated rock fill. Those results, coupled with characterization studies for the same site, were positive indications that saturated rock fills should be a viable technology for mitigation of CIs.

The concept for a full-scale trial is fundamentally similar to that of the field scale trial conducted in 2016. Water is injected into the saturated zone and subsequently extracted, with intermediate wells to monitor changes in water geochemistry as it passes through the saturated fill. However, infrastructure for a full-scale trial is significantly more extensive than for the field scale trial conducted in 2016. This is due to the need for larger volumes of water, and the need for an expanded monitoring well field to cover as many potential travel paths through the rock fill as was practical. As well, for the full scale trial, there will be the potential to release treated water, and this required systems to attenuate risks associated with release of water into the receiving environment.

Design of the pumping systems, injection and extraction systems, monitoring wells and systems, and release systems began in 2016. Construction of the full-scale trial facility started in 2016 and was completed in late 2017. Commissioning of the facility began in January of 2018.

Saturated Rock Fills – Study Design

The proposed use of saturated rock fills as a treatment for mine affected water is predicated, in part, on the assumption that an indigenous community of microorganisms in the waste rock is capable of reducing and removing selenium and nitrate from the aqueous phase. Column studies conducted in 2014 and 2015 and the field-scale trial conducted in 2016 indicated that selenium and nitrate reduction by the microbial communities in the waste rock can result in appreciable removal of these CIs from mine affected water at the laboratory and field scale.

However, to fully evaluate function, risks, and removal capacity at a full scale, a full scale trial was required. The full scale ‘trial’ is a function of the full scale system (the physical infrastructure), the study design for that system (the series of evaluations and experiments), and the operating protocols for the system (operating procedures). While all three of these components are inter-dependent, development of the study design is central to the trial.

The foundation of the study design was the rate of pumping, which needed to be similar to anticipated rates necessary to treat mine-scale volumes of affected water. An additional influence on the study design was the need for system redundancy to address potential issues with biofouling of the injection wells or other mechanical issues. The study design also had to account for a range of risks that had been identified in previous work. Lastly, the study design had to account for results from the laboratory and field scale trials with respect items such as the necessary sampling frequencies or the monitoring well spacing. Once these aspects were considered, or decided upon, the study design was developed to describe the experiments to be conducted, how the infrastructure is to be used, and how treated water is to be managed.

Saturated Rock Fills – Associated Considerations

There were three aspects of the full scale trial that were identified either prior to, or during the construction of, the full scale trial facility that needed to be addressed as part of the facility design and construction and the study design. These are 1) management of biofouling in the injection wells, 2) management of total suspended solids from the source water, and 3) management of treated water as a function of treatment efficacy.

Biofouling in the injections wells is a product of excess biofilm growth near the injection well or within the injection well due to the presence of higher concentrations of nutrients for the microbiological communities. Laboratory tests were developed to investigate dosing strategies that would mitigate the potential for biofilm development and these were incorporated into the facility design and study design.

Management of total suspended solids is necessary as the saturated rock fill performance is predicated on the ability to maintain a minimum hydraulic conductivity through the rock fill. Injection of high levels of suspended solids over extended time frames could potentially compromise the ability of the rock fill to effectively function. Suspended solids management is generally focused on reducing disturbance of sediments in the water source.

Management of treated water stems from identification of partial treatment of mine affected water as one of the risks associated with the use of saturated rock fills. A series of studies were performed to estimate water quality based on input water quality and the performance of rock fills at the laboratory and field scale. Physical systems and facility operation protocols were then designed and/or developed to monitor water quality and direct treated water to one of several destinations. In general, these were either discharge into the environment, storage, or recirculation.

LESSONS LEARNED

As the principal focus of the Applied R&D program in 2017 was on the full scale trial, and specific tasks and components of that effort were geared toward developing the facility and study design, there are no 'results' to report. However, several other studies were initiated or are on-going, the results of which are summarized in the Research and Technology Development Progress Report, which will be available to COSIA April 1, 2018.

PRESENTATIONS AND PUBLICATIONS

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

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

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

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

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

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

Kirk, L., et. al., 2016, *Selenium Biomineralization Applied to Mine Facility Design*, Abstract and Presentation submitted to the Goldschmidt Conference, Yokohama, Japan, June 25-July 1, 2016.

Koepnick, H. et. al., 2016, *Selenium Bioreduction in Mine Waste Rock at Cold Temperatures*, Poster submitted to the Montana Biofilm Meeting, Bozeman, United States, July 15, 2016

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

Mahmood, N., 2016, *Nitrate in Coal Waste Rock Dumps, Elk Valley, British Columbia, Canada*, Thesis submitted to the College of Graduate Studies and Research, University of Saskatchewan, Saskatoon. August 2016.

Mahmood, N., Hendry, J. Barbour, S. L., Klein, R., Kennedy, C., 2016, *Origin and Fate of Nitrate in Coal Waste-Rock Dump in the Elk Valley, British Columbia, Canada*, Abstract and Presentation submitted to the University of Saskatchewan, Graduate Student Conference, Saskatoon, Canada, March 4-6, 2016.

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

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

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

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

Schabert, M., 2016, *The Application of Push-Pull Testing to Define Biogeochemical Controls on Selenium and Nitrate Attenuation in Saturated Coal Waste Rock*, Thesis submitted to the College of Graduate Studies and Research, University of Saskatchewan, Saskatoon, October 2016.

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

Villeneuve, S. A., Barbour, S. L., Hendry, M. J., 2016, *An Evaluation of Net Percolation Through a Waste Rock Dump in the Elk Valley, British Columbia, Canada*, an Abstract submitted to the GeoVancouver Conference, Vancouver, Canada, October 2-5, 2016.

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

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

RESEARCH TEAM AND COLLABORATORS

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jim Hendry	University of Saskatchewan	Principal Investigator		
Lee Barbour	University of Saskatchewan	Principal Investigator		
Brent Peyton	Montana State University	Principal Investigator		
Lisa Kirk	Montana State University, Enviromin	Principal Investigator		
Sean Carey	McMaster University	Principal Investigator		
Shannon Shaw	SRK Consulting	Principal Investigator		
Stephen Day	SRK Consulting	Principal Investigator		
Daryl Hockley	SRK Consulting	Principal Investigator		
Dan Mackie	SRK Consulting	Principal Investigator		
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Applying Natural Analogues to Constructing and Assessing Long-Term Hydrologic Response of Oil Sands Reclaimed Landscapes

COSIA Project Number: LJ0215

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited

Status: Year 3 of 4

PROJECT SUMMARY

The Utikuma Region Study Area (URSA) research sites, in the Boreal Plain (BP) region, have been the focus of ecohydrological and hydrogeological research for over 16 years (e.g., TROLS, HEAD, HEAD2, SFMN projects, etc.) that are informing the Oil Sands industry on the natural functioning of aquatic, peatland and forestland systems with heterogeneity in vegetation and geology representative of the Ft. McMurray region (Devito et al. 2012). 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 (Devito et al. 2016). Knowledge gained from this research will direct future management and catchment design and planning by providing the foundation for the development of resilient catchments and self-sustaining ecosystems in the next generation of reclaimed oil sands environments.

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 (AET) 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 of water 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, soil depth, vegetation (wetland – forestlands, HUs) and geology (equivalent material storage – hydrologic response areas, 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 with the succession (or development) of wetland vs. forestland ecosystems; and
- the role of organic (peat) depth vs. local (soils) and regional geology (HRA-connectivity) on the successional trajectory of natural and constructed wetlands and forestlands. By testing this on natural ecosystems following watershed burning, the controls that maintain ecosystem function in response to disturbance can be determined.

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

The overall objective of the research is to determine the distribution and limits of water use within reconstructed landscapes by examining the hydrological processes controlling the fluxes and stores of water within natural analogue landscapes (Devito et al. 2012). The research examines small-scale ecohydrological interactions (Scope 1), large-scale landscape interactions (Scope 2) and landscape evolution in early succession (burned) and mature (unburned) watersheds in order to develop accurate conceptual models of how water moves through the BP landscape (Scope 3), and determine how this affects the trade-offs between catchment runoff and ecosystem productivity.

Specific objectives to address the hypotheses and questions are addressed in 3 Scopes of research and 9 objectives listed below.

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

Objective 1: ***Peatland substrate and ice layering.*** Determine the role of soil layering and ice formation in peatlands and mineral margin swamps on water storage, evapotranspiration rates and moisture conservation.

Objective 2: ***Peatland vegetation succession and moisture conservation.*** Determine the recovery rate following wildfire and the role of succession on ET and water conservation of wetlands/peatlands.

Objective 3: ***Modelling hydrological trajectories and peatland sustainability.*** Determine the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession to model and assess peatland sustainability.

Objective 4: ***Ephemeral draws.*** Determine the controls on ephemeral draw wetland formation and role in generating moisture surplus and delivering water to downstream wetlands and adjacent forests.

Objective 5: ***Forestland hummocks and landscape water balance.*** Determine the influence of the configuration, height, substrate type and size of forestland hummocks on sheltering and water use in sustaining forest and wetland ecosystems.

Objective 6: ***Wetland-forestland interface (WFI) and riparian areas.*** Determine the role of landform and riparian vegetation and root distribution on the dynamics of water and chemical movement to or from the hummocks and adjacent wetland or aquatic systems.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

Objective 7: ***Influence of HU and HRA landscape distribution on runoff.*** Determine the role of HRA (coarse and fine textured landforms) and HU (wetland and forestland ecosystems) proportion and connectivity on landscape scale AET, storage type and long-term runoff response of BP catchments during different climate cycles?

Objective 8: ***HRA connectivity and temporal and spatial background hydro-chemistry and forest biomass.*** a) Determine how surface and groundwater flow and hydro-chemistry vary across the landscape in response to seasonal and climate forcing and succession (post-wildfire); and b) Determine how forest biomass relates to the spatial weighting and configuration of wetland:forestland interfaces on different HRAs and during early succession (post-wildfire).

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

Objective 9: 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

2017 represented the third year of this four-year COSIA project. All projects listed for the objectives or deliverables have been initiated and results are presented in the outcomes section and scientific publications listed below for 2017.

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

All sites were selected by 2016 and detailed hydro-meteorological, eco-hydrological and hydrogeological instrumentation and investigations continued during 2017 along forestland-riparian-wetland transects to answer questions associated with objectives 1 to 6.

Objective 1: ***Wetland substrate and ice layering.*** This objective focuses on examining the role of soil layering and ice formation in peatlands and mineral margin swamps on water storage, evapotranspiration rates and moisture conservation. Addressing the questions listed below will help assess the relative role and effectiveness of potential capping strategies in providing sufficient water yield in a cost efficient manner. The work to address both research questions (Q1.1 and Q1.2) associated with this objective have been initiated, approximately 80% of the work is completed, with final completion of both questions expected by year 4.

The work to address both research questions (Q1.1 and Q1.2) associated with this objective has been initiated.

> *Q1.1, Can layering soils in peatlands (including hydrophobicity and frost formation) be used to reduce evapotranspiration (ET) to behave as an effective capping material and generate surplus fresh water and surface runoff in various Alberta Oil Sands (AOS) landscapes?*

- S. Dixon (PDF) conducted a 1-dimensional numerical modelling investigation into the effects of layering of peat, sand and clay on near surface water balance and ET. This modelling showed that, provided there is a thin surface layer of peat material, then deeper layers can be comprised of sand without leading to dramatic differences in the ET and near surface water balance (Dixon et al., 2017). This work also showed that increasing total storage (depth of sand and peat) leads to a wetter near surface under periods of drying. However, a depth of 0.5 m represents a threshold beyond which additional storage has little effect on near surface moisture content and associated AET.
- S. Dixon (PDF) has completed a series of modelling investigations looking at the role of seasonal frost layers in altering ET and affecting the water balance in the near surface. Results show that seasonal frost layers can create a barrier to water flow between a deep water table and the evaporating surface, which reduces moisture contents above the frost layer and counteracts water supply as a result of ice melt. This work is currently in review with the journal HESS.

Q1.2, Can mineral soil layers provide moisture conditions ideal for peatland vegetation recovery, and thus reduce the demand for peat in constructing wetlands?

- S. Dixon (PDF) showed using 1-dimensional numerical modelling that a surface layer of sand responds differently with regards to ET and near surface water balance when compared to sand overlain by a thin (<0.05m) layer of peat. The mineral soil was unable to regulate water loss during drier periods compared to the peat leading to greater ET.

Objective 2: ***Peatland vegetation succession and moisture conservation.*** This research examines ecosystem recovery following wildfire and the role of succession on ET and water conservation of wetlands, specifically peatlands. Knowledge from this objective will aid in estimating timelines for ecosystem development and anticipating future water balance of HUs on closure landscapes as constructed ecosystems (wetlands-forestlands) grow and mature with time.

Q2.1, What are the expected recovery rates and succession of wetlands (peatlands) with large-scale wildfire disturbance?

- K. Housman (M.Sc.) identified characteristic vegetation communities based on time since fire for both peatland margins and middles based on data from 26 peatlands. The analysis showed that peatland margin canopy composition consists of mixed coniferous and broadleaf deciduous species, with enhanced litter fall characterizing the dominant early to mid-successional ground layer composition. Both peatland bog middle and margin vegetation communities were found to be dominated by feathermoss growth ~60 years following wildfire, which represents an accelerated trajectory from previous chrono-sequence analyses.

Q2.2, How does water loss via evapotranspiration vary through the range of wetland succession trajectories and changes in peat and mineral soil layer, frost formation, and storage?

- P. Moore (PDF) continues development of the PHI-BETA-THETA combined numerical models that simulate peatland radiation and energy balance components, including soil thermal dynamics. The development of the PHI component and completed integration of soil freeze-thaw into PHI-BETA-THETA model simulations continues. Novel approaches were developed to efficiently simulate the effect of fine volumetric spatial discretization of the tree canopy on the radiation balance. Model validation is ongoing (R. Leonard, PhD), including Monte Carlo assessment of parameter uncertainty for PHI-BETA-THETA simulation. R. Leonard used new technology to measure soil temperatures at unprecedented spatial and temporal resolution to both observe the effect of vegetation canopy layering on soil thermal dynamics (Leonard, 2017) and validate of PHI-BETA-THETA (see above).

Objective 3: ***Modelling hydrological trajectories and peatland sustainability.*** Conceptual and numerical models are being developed to determine, the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession, to model and assess peatland sustainability.

Using a Monte Carlo approach, P. Moore (PDF) ran PHI-ALPHA simulation using 20,000 independent parameter sets. PHI-ALPHA (spatially discretized peatland water balance model) simulations were run to test the effect of peat layering, WFI soil properties, and climate on growing season water table dynamics of small perched peatlands. Peatland and WFI soil properties and spatial configuration were parameterized using 2016 field data from K. Housman (M.Sc), R. Ingram (M.Sc.), and S. Wilkinson (PhD). On-going analysis of PHI-ALPHA model outputs have been continued by S. Wilkinson (PhD).

Objective 4: *Ephemeral draws*. The controls on ephemeral draw wetland formation and their role in generating moisture surplus and delivering water to downstream wetlands and adjacent forests is being examined. Such small forested wetlands occur throughout upland forests (Devito et al., 2012). A better understanding of where and how frequent runoff is generated within forest ecosystem can aid in future design criteria, to better anticipate and utilize, the amount and persistence of water yield from constructed forest in closure landscapes vital for maintaining downstream and adjacent ecosystems.

Q4.1, What is the water balance of an ephemeral draw and how does it change from early succession to mature

- Preliminary analyses by A. Hurley (PhD) has shown that the interaction of hydro-meteorology and ecology controls the functioning of ephemeral draws and their impact on water yield to downstream ecosystems and sources of water to adjacent forests. Spatial and temporal variability of evapotranspiration (major water efflux) was a decisive factor in generating moisture surpluses for sourcing water across the ephemeral draw wetland-upland transect during the 2016 and 2017 growing season.
- During 2017 (and 2016) runoff was limited as water storage during spring melt and fall rains, movement of water from the draw to the adjacent forest, and evapotranspiration (across continuum of vegetation structure) dominated the water balance of the ephemeral draw wetland.

Q4.2, What is the role of substrate layering and ice in generating lateral flow in ephemeral draws?

- A. Hurley (PhD) preliminary data has shown that the dynamics of water export as surface runoff and water yield from ephemeral draws to downstream ecosystems is controlled largely by both short (weather patterns) and long-term (decadal) hydroclimatic variability that interact with geomorphologic characteristics (i.e. sub-surface stratigraphy, landscape position).
- Investigations on the ephemeral draw wetland (A. Hurley, PhD) support earlier work conducted on isolated forested wetland swamps. Subsurface stratigraphy (shallow depth [<30cm] confining layer morphology) and formation of frozen surface soil ice, influence the spatial variation and connectivity of surface saturation and lateral flow as surface runoff in response to precipitation (e.g., timing, intensity, amount). The soil stratigraphy (depth to confining layer) and resulting water table configurations was also important in promoting redistribution of water into surrounding upland forests. Integration of the work by A. Hurley (PhD) with numerical modeling of the role of soil layer and ice by S. Dixon (PDF) will provide a conceptual model of runoff generation from ephemeral draws and more regional forests that can be used in the planning of forests on closure landscapes.

Q4.3, How does ephemeral draw width and geometry control the proportion of flow to adjacent forestlands and downslope peatlands and wetlands?

- Research by A. Hurley (PhD) in 2017 explored growth dynamics of forest trees adjacent to an ephemeral draw. Development of a conceptual understanding and models deciphering the interplay of ephemeral draw geometry and water export, focusing on lateral flow generation as well as forestland water use and growth responses is being undertaken.

Objective 5: *Forestland hummocks and landscape water balance.* The influences of the configuration, height, substrate type and size of forestland hummocks on sheltering and water use in sustaining forest and wetland ecosystems are being examined. This will allow the assessment of, the persistence of hydrologic conditions associated with the type and configuration of hummock construction during closure under future climatic and landuse scenarios.

Q5.1, How does hummock texture, configuration, height and size influence the proportion of vegetation water use vs. recharge?

- K. Hokanson (PhD) is collating historic water level data from across URSA to further develop a conceptual model of hydrologic behavior of hummocks based on differences in texture and shape. Current analysis of field data show that rises in water table elevation occur with variable time-lags from wet periods, which are best defined as multi-year cumulative departures from the long term mean precipitation (P). Further analysis is needed to fully quantify the thresholds and patterns involved, but initially appears that in coarse HRA, the time lag in groundwater (GW) recharge is directly related to the scale of groundwater flow, and in the hummocky moraine HRA it is related to the local storage properties of the hummock.
- Integrating numerical modeling with the above field evidence, M. Lukenbach (PDF) found that hummock recharge was primarily dependent on the interaction between hummock texture, soil layering, water table depth, and vegetation characteristics (e.g., rooting depth and LFH thickness). Two-dimensional simulations of upland hummock vertical cross sections highlighted how variability in root water uptake and water table proximity determined overall hummock recharge function. Recharge is greater in coarse-textured hummocks; however, this recharge function can be diminished if layers of finer-textured soils, organic forest floor, or any substrate more conducive to vegetation growth are present. Decreases in recharge are proportional to the thickness of these layers. In fine-textured hummocks, recharge is much lower and limited to periods when potential root water uptake is low (e.g., during spring snowmelt). Moreover, uptake of water, that is lost to down stream flow, can occur if the water table is shallow and a hummock may act as a sink of water. In fine-textured hummocks, recharge is much lower and limited to periods when potential root water uptake is low (e.g., during spring snowmelt).

Q5.2, How does the geometry and configuration of the hummock and forestland shelter, size and orientation of adjacent peatland influence evapotranspiration losses and peat thermal processes?

- Studies show that peatlands often experience turbulent sheltering from their surrounding upland forests, which results in spatial varying ET rates inside the peatlands, and zones of boundary-layer detachment that suppress ET losses. A. Green (M.Sc.) used the Regional Atmospheric Forest Large Eddy Simulation (RAFLES) model which allows for various wetland and upland forest configurations to be simulated at a high temporal and spatial resolution. Results have shown that wetlands with the same area and shape, but different orientation to the dominant wind direction experience significantly different ET loss and spatial patterns of ET.

Q5.3 How does the initial state and succession after fire influence the proportion of vegetation water use and recharge, and the sheltering role of the hummock on adjacent wetlands?

- Regenerating aspen transpiration varied across a burned hillslope-riparian-peatland transect where the highest rates occurred in forests and decreased in riparian areas and peatlands. Photosynthetically active radiation (PAR) and atmospheric vapour deficit (D) typically play large roles in regulating ET. However, burn severity and differences in topographic gradients prevented significant variability in such controls, and subsequently on transpiration. Further, PAR and D usually limit transpiration only when there is sufficient available moisture, though waterlogged peat in this study further inhibited aspen water release. With the detection of aspen two and three years after fire in the peatland with an abundance of water, reductions in stomatal conductance may have restricted transpiration losses due to oxygen deficiencies in roots. Conversely, in forested areas where soil moisture was below wilting point, regeneration continued suggesting that moisture was sufficient in uplands and that aspen do not require wet soils for regeneration. Isotopic results suggest that this was due to hydraulic redistribution from aspen clones with parent trees originating in uplands. Roots likely extended into peatlands and margins pre-disturbance further explaining clonal distribution at peatland edges, though these areas may be vulnerable to upland transformations through continued drying.

- M. Lukenbach (PDF) used numerical modelling to conduct long-term scenario testing of recharge rates in hummocks relative to vegetation structure and stage. Recharge declines with succession and vegetation growth and is proportional to the leaf area index (LAI) of vegetation present (i.e., higher LAI results in lower recharge). Moreover, the development of an organic forest floor, even if only 0.10 to 0.15 m thick, can substantially reduce recharge compared to the period just after fire when an organic forest floor has often been combusted.

Objective 6: *Wetland-forestland interface (WFI) and riparian areas.* This research attempts to determine the role of landform and riparian vegetation and root distribution on the dynamics of water and chemical movement to or from the hummocks and adjacent wetland or aquatic system. An understanding of the role of interfaces between forestlands and wetlands and the relative gain (runoff generation) or loss (vegetation uptake) of water can be utilized to determine the impact of the spatial orientation and configuration of different HUs on the moisture distribution and water yield of closure landscapes.

Q6.1a, How do HRA and texture control the magnitude and direction of water across the WFI?

- K. Hokanson (PhD) has shown how the scale of flow, surficial geology, and local substrate layer control water table configurations and response to climate. Regionally controlled water tables are less sensitive to short term climate but will be susceptible to long term drying or wetting. Local flow systems (fine-textured landforms) and intermediately positioned coarse-textured landforms are generally sensitive to short term climate changes. Analyses of water table responses to wet and dry climate cycles observed at URSA illustrated the sensitivity of forestland and wetlands to long-term climate change. K. Hokanson (PhD) found that wetting and drying at the hummock scale, and thus the WFI, is out of sync with annual precipitation. Cumulating 2, 3, or 4 years of annual precipitation that departs from the mean (either negative, dry, or positive, wet) was required to account for soil moisture and water levels at WFI. Thus, poor correlation was observed between annual precipitation and water levels in WFI and long-time lags in WFI moisture status and threshold responses in forest productivity or runoff can be expected depending on regional and local scale features. For example, moist soil conditions, in response to the previous year's precipitation, may be optimal for forest productivity (high transpiration) during a year with low annual precipitation.
- At the site scale, R. Ingram (M.Sc.) quantified the upland soil stratigraphy and differences in peatland soil properties using multiple soil cores across the WFI at 26 peatlands. Results show that high density peat at the WFI, which is potentially important for peatland water conservation, is correlated with a higher proportion of deciduous litterfall and woody biomass compared to peatland interiors.
- S. Dixon (PDF) has initiated a numerical modelling study and built two-dimensional model domains of wetland-forest interfaces, with a fixed width for the WFI but with different surficial geology and long-term climate scenarios. The numerical modelling will explore how the degree to which the width of the WFI zone and the water balance and ET is influenced by surficial geology and long term climatic conditions. This study is testing whether the WFI should be considered as a more dynamic feature, reflecting long-term climatic conditions. In integrating with findings from objective 4.1 and 5.3, along with Q6.2 below, this work will help partly determine the differences in trajectory of WFI related to surficial geologies in a changing climate.

Q6.2, How does vegetation (succession, species, roots) modify the interaction?

- Numerical modelling by M. Lukenbach (PDF) indicates that vegetation development and increases in maximum rooting depth that occur at the forest-wetland interface can substantially decrease recharge and, when the water table is shallow, root water uptake occurs at the potential rate (i.e. equal to potential evapotranspiration). Net removal of water by roots can have a large influence on the direction and pattern of groundwater flow across the WFI.

Q6.3, What is the role of hydraulic redistribution into forest hummocks and resource exploitation from peatlands by roots on forestland and riparian productivity and how does this change with succession?

- Based on short-term tree responses to water availability and use (cf. Objective 4), A. Hurley (PhD) has shown that the response dynamics translate to long-term tree growth patterns in ephemeral draw-upland complex, suggesting a local productivity-mediating effect. He established tree ring width records dating back to the early 1900s for two species on ephemeral draw interface and in an adjacent upland forest. Initial analyses hint at differences between – and to some extent within - species in growth dynamics in response to hydroclimatic conditions (i.e. temperature, precipitation and moisture deficit) between locations. Further analyses on delineating the impact of ephemeral draw water export are underway.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

The limits of water use and distribution on constructed oil-sand landscapes are key issues in initial and final closure plan developments. In objective 7 and 8 we begin to quantify the proportion and configuration of wetlands (including ephemeral draws) to forestland required in different HRAs to provide adequate surface water inputs and/or groundwater discharge during the range of climate for larger wetlands or aquatic systems (i.e., end pit lakes) and how this may change with succession of the Athabasca Oil Sands landscape.

Objective 7: ***Influence of HU and HRA landscape distribution on runoff.*** The overall objective of the research is to determine the distribution and limits of water use within reconstructed landscapes by examining the hydrological processes controlling the flux and storage of water at natural analogue landscapes (Devito et al. 2012).

Q7.1, How does the proportion and connectivity of HRA (coarse and fine) and HU (wetland and forestland) influence coarse scale AET, storage type and long-term runoff response of BP catchments during different climate cycles?

- The large-scale runoff analyses showed that annual runoff could vary from 0 to 300 mm/year depending on the physical characteristics and the climate cycle. Annual runoff was poorly correlated with annual precipitation. A threshold relationship was observed between annual runoff and 2-year cumulative moisture deficit (CMD) that reflected temporal and spatial differences in effective storage, antecedent moisture state and hydrologic connectivity among catchments with differing portions of land-cover (e.g., wetland vs. forestland) and glacial-deposit types. During dry states (CMD< -153 mm) and lowest flows, catchment annual flow ranged by over one order of magnitude (0 to 80 mm/year) and increased with percent area of coarse textured deposits. In fine textured catchments, runoff was only observed in catchments with >30% peatland area. During mesic conditions (CMD ~0 mm), runoff remained very low in catchments with large proportions of forests and poorly connected open water depressions associated with fine-textured hummocky moraine glacial landforms. Runoff was positively correlated with percent peatland area, suggesting that peatland networks were the primary source areas of surface water to regional runoff. During the infrequent wet states (CMD > 220 mm), runoff coefficients increased in all catchments indicating that both forests and peatlands contributed to catchment runoff. However, a large influence by the heterogeneity in catchment glacial landforms and soil-vegetation land-covers was observed, with fine-textured hummocky moraines (similar to overburden material storage) moderating peak runoff responses from different catchments with similar precipitation.

Objective 8: ***HRA connectivity and temporal and spatial background hydro-chemistry and forest biomass.*** We continued the long-term monitoring of natural systems at URSA in 2017 to examine how processes in they may vary following large-scale disturbance (i.e., wildfire) and to further interpret long-term water yield from larger catchments in objective 7. This information can be used to set baselines and acceptable ranges in hydrology and chemistry of surface and subsurface waters and biomass responses in developing goals for and to assess short and long-term performance of closure landscapes.

Q8.1, How does surface and groundwater flow and hydro-chemistry vary across the landscape (HU interaction with HRA) in response to seasonal and climate forcing and succession (post-wildfire)?

- While chemical composition (facies) does not delineate finite chemical landscapes within URSA, absolute concentrations or strengths of key indications (calcium, magnesium, electrical conductivity, etc.) did vary between HUs within a HRA, and between HRAs. This analysis by K. Hokanson (PhD) provides a strong basis for the natural geochemical characterization of a Boreal Plain landscape.
- Regression analyses using landscape scale synoptic sampling of the chemistry (dissolved organic carbon [DOC], electrical conductivity [EC], anions and cations) of 34 shallow lakes (SL) was undertaken in 2017 (in addition to previous assessments from 2012 to 2016) by E. Pugh (PhD). The analysis shows that SL hydrochemistry varies across the landscape in response to seasonal and climate forces that drives surface and groundwater flow connectivity. The analyses indicate that in a sub-humid climate, small changes in the water balance can have dramatic downstream effects due to a change in the hydrologic connectivity of the watershed. Hydrologic connectivity of a watershed can therefore determine the hydrochemical variability of shallow lake systems, particularly DOC. Further end member analyses from respective allochthonous DOC sources showed that potential surface and sub-surface connections to shallow lakes varied with the proportion of peatland-forestland interactions within larger glacial deposits (coarse or fine-textured). This indicates that the spatial variability of DOC responses in shallow lakes is broadly controlled by the climate cycles and watershed characteristics required to trigger a response in the DOC characteristics of a shallow lake system.

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

Objective 9: ***Catchment design and application.*** To achieve reclamation goals, Alberta oil sands industries are tasked with using an array of different available materials (coarse to fine-grained process material or overburden of variable geochemical quality) to construct viable, sustainable ecosystems. In this objective we develop and parameterize conceptual models of hierarchical scale and complexity to determine the influence of the configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems on water use and movement. These models will aid in the design and construction of sustainable and resilient closure landscapes that maximize water use.

Initial refinements of existing models and developing alternative conceptual models to understand and predict how water, and thus salts, move through complex landscapes based on findings from Scope 1 and Scope 2 are ongoing.

Q3.0a, Which initial configurations of constructed catchment hummocks, forestland, riparian and wetland/ peatland ecosystems are more sustainable and resilient?

- Numerical and analytical models (M. Lukenbach, PDF) highlight that the ability of hummocks to influence local-scale groundwater flow patterns, and by extension solute discharge, was dependent on hydraulic gradients within larger, intermediate to regional-scale groundwater flow systems. Therefore, regional slopes of reclaimed landforms should be used to guide hummock(s) areal extent and configuration. Then, in areas where nested local groundwater flow systems are desirable (e.g., areas with higher dissolved solutes), high recharge rates should be promoted by prescribing xeric soil reclamation covers on hummocks. Alternatively, where it is not desirable to flush solutes from hummocks, mesic soil reclamation covers can promote forest productivity and limit drainage. Overall, the spatial distribution of hummocks in reconstructed landscapes will influence the quality and quantity of water arriving at down-gradient ecosystems and water bodies.
- Analyzing the interactions of climate change on surface mining and reclamation activities by simulating surface water and groundwater flow (period 2014 – 2080) under four climate scenarios using GSFLOW-PMRS has demonstrated that the annual growing season duration is longer, with an earlier snowmelt in 2080. During the growing season, the daily proportion of connected hydrologic units (DPCUs) remains approximately the same in the future, under the different climate scenarios. DPCUs in forestlands are more stable with a growing-season that is ~15 days longer than in wetlands.

LESSONS LEARNED

Research conducted over the past few years combined with previous NSERC-CRDs (HEAD1 and HEAD2, Devito et al., 2012) has provided valuable insight into how climate cycles of the Boreal Plain influence differences in water storage and release within different material storage areas, and the thresholds for and scale of hydrological connectivity between geologic materials water storage at the reclaimed landscape scale.

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

Can mineral-organic soil layering provide moisture conditions ideal for peatland vegetation recovery, and thus reduce the demand for peat in constructing wetlands? Our independent field and numerical modeling studies indicate that soil layering (coarse or fine textured mineral and organic) may be used as an effective capping material and reduce ET, promote frequent soil saturation and generate surplus fresh water and surface runoff in various Oil Sands landscapes. This has implications for designing localized perched systems on constructed landscapes to potentially generate water with moderate salinity for down- stream systems.

Can the influence of hummock texture, height and size influence the proportion of vegetation water use vs. recharge and the potential water yield for downstream ecosystems on the closure landscapes? Field and numerical modeling results indicate that recharge is much lower and limited to periods when potential root water uptake is low (e.g., during spring snowmelt) on fine-textured hummocks (overburden material dumps). Moreover, uptake of water, that is lost to down stream flow, can occur if the water table is shallow and a hummock may act as a sink of water. Recharge is greater in coarse-textured hummocks. However, this recharge function can be diminished if layers of finer-textured soils, organic forest floor, or any substrate more conducive to vegetation growth are present. Decreases in recharge are proportional to the thickness of these layers. Moreover, uptake of water, that is lost to down stream flow, can occur if the water table is shallow and a hummock may act as a sink of water. This has implications on design of hummock size, and capping prescription and anticipated water use or yield in closure landscapes.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

Integration of the research shed light on the importance of landscape hydrological connections in the ecohydrological functioning of wetland and upland landscape units, making this a critical component of lease-scale reclamation strategies. Some early lessons include addressing the question:

How would the proportion and connectivity of HRA (coarse and fine) and HU (wetland and forestland) influence coarse scale AET, storage type and long-term runoff response of closure landscapes? Learnings from the regional runoff regime have important implications in the design of local and lease scale landscapes to ensure long-term water supply and maintenance of downstream ecosystems (wetlands or EPL's). Persistent recharge and water yield (throughout wet and dry climate cycles) is limited to coarse textured hummocks (i.e., landforms), while recharge and water yield from fine-textured landforms demonstrate threshold behaviour, with very little runoff. Understandings from numerical and analytical models (M. Lukenbach, PDF) highlight that the ability of hummocks to influence local-scale groundwater flow patterns, and by extension solute discharge, was dependent on hydraulic gradients within larger, intermediate to regional-scale groundwater flow systems. Therefore, regional slopes of reclaimed landforms should be used to guide hummock(s) areal extent and configuration. Then, in areas where nested local groundwater flow systems are desirable (e.g., areas with higher dissolved solutes), high recharge rates should be promoted by prescribing xeric soil reclamation covers on hummocks. Alternatively, where it is not desirable to flush solutes from hummocks, mesic soil reclamation covers can promote forest productivity and limit drainage. Overall, the spatial distribution of hummocks, the texture and the capping material in reconstructed landscapes will influence the quality and quantity of water arriving at down-gradient ecosystems and water bodies.

LITERATURE CITED

Devito, K., Mendoza, C., and Qualizza, C. (2012). *Conceptualizing water movement in the Boreal Plains*. *Implications for watershed reconstruction*. Synthesis report prepared for the Canadian Oil Sands Network for Research and Development, Environmental and Reclamation Research Group.

Devito, K.J., Mendoza, C., Petrone, R.M., Kettridge, N. and Waddington, J.M., 2016. Utikuma Region Study Area (URSA)–Part 1: Hydrogeological and ecohydrological studies (HEAD). *The Forestry Chronicle*, 92(1), pp.57-61.

Thompson, C., C.A. Mendoza, K.J. Devito and R.M. Petrone, 2015. Climatic controls on groundwater–surface water interactions within the Boreal Plains of Alberta: Field observations and numerical simulations. *Journal of Hydrology*, 527, pp. 734–746. doi: 10.1016/j.jhydrol.2015.05.027.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Housman, K., 2017. Post-fire chronosequence analysis of peatland bog vegetation communities across hydrogeological settings. M.Sc. Thesis, School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario. 192pp.

Ingram, R., 2017. Peatland carbon accumulation following wildfire on the boreal plains: Implications for peatland reclamation and wildfire management. M.Sc. Thesis, School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario.

James, L., 2017 Formation and maintenance of permanent perched wetlands in the Boreal Plain of Western Canada. M.Sc. Thesis, Biological Sciences, University of Alberta, Edmonton, Alberta. 148pp.

Journal Publications

Depante, M., Petrone, R.M., Devito, K.J., Kettridge, N., Macrae, M., Mendoza, C., Waddington, J.M., In Press. Potential influence of nutrient availability along a hillslope peatland gradient on aspen recovery following fire. Accepted Nov 2017, *Ecohydrology*

Devito, K.J, K.J. Hokanson, P. Moore, N. Kettridge, A. Anderson, L. Chasmer, C. Hopkinson, M.C. Lukenbach, C.A. Mendoza, J. Morissette, D.L. Peters, R. Petrone, U. Silins, B. Smerdon, J.M.Waddington, 2017. Landscape controls on long-term runoff in sub-humid heterogeneous Boreal Plain catchments. *Hydrological Processes*. 31(15)2737-2751, DOI: 10.1002/hyp.11213

Dixon, S.J., Kettridge, N., Moore, P.A., Devito, K.J., Tilak, A.S.;,Petrone, R.M., Mendoza, C.A., Waddington, J.M., 2017. Peat depth as a control on moss water availability under evaporative stress. *Hydrological Processes*, 31(23):4107-4121. 10.1002/hyp.11307.

Kettridge, N., Lukenbach, M.C., Hokanson, K., Hopkinson, C., Devito, K.J., Petrone, R.M., Mendoza, C.A.,Waddington, J.M.. 2017. Low evapotranspiration enhances the resilience of peatland carbon stocks to fire. *Geophysical Research Letters*, 44(18): 9341–9349, DOI: 10.1002/2017GL074186

Leonard, R. M., N. Kettridge , K.J. Devito, R. Petrone, C. Mendoza, M. Waddington, S. Krause, 2018. Disturbance impacts on thermal hotspots and hot moments at the peatland-atmosphere interface. *Geophysical Research Letters*, DOI: 10.1002/2017GL075974

Lukenbach, M.C., K.J. Hokanson, K.J. Devito, N. Kettridge, R.M. Petrone, C.A. Mendoza, G. Granath, J.M. Waddington, 2017. Post-Fire Ecohydrological Conditions at Peatland Margins in Different Hydrogeological Settings of the Boreal Plain. *Journal of Hydrology*, 548, 741-753. http://dx.doi.org/10.1016/j.jhydrol.2017.03.034

Moore, P., M. C. Lukenbach, N. Kettridge, R. M. Petrone, K. J. Devito, J. M. Waddington. In Press. Peatland Water Repellency: Importance of Soil Water Content, Moss Species, and Burn Severity. Accepted 18 Sept 2017, *Journal of Hydrology*, HYDROL25632R1

Thompson C., Mendoza, C.A., Devito, K.J., 2017. Potential Influence of Climate Change on Ecosystems within the Boreal Plains of Alberta. *Hydrological Processes*. 31:2110–2124, DOI: 10.1002/hyp.11183

Conference Presentations/Posters (Bold for Presenting Author)

Chasmer, L., **Flade, L.**, Virk, R. , Montgomery, J.S., Hopkinson, C., Thompson, D.K. , Petrone, R.M. , Devito, K. 2017. Quantifying spatial variability of depth of peat burn in wetlands in relation to antecedent characteristics using field data, multi-temporal and multi-spectral LiDAR. American Geophysical Union Fall Meeting, , December 11 -15, New Orleans, LA. [Oral]

Devito, K.J., Barbour, L. 2017. Applying understandings from natural systems for sustaining hydrologic function of constructed landscapes. Canadian Oils Sands Innovation Alliance (COSIA) Innovation Summit, 21-22 March, Calgary, Alberta. [Oral, Invited]

Devito, K.J., Morissette, J.L., 2017 Generalizing riparian hydrologic function in a heterogeneous landscape, Western Boreal Plain, Alberta, Canada. 11th North American Forest Ecology Workshop (NAFEW), 20-24 June, Edmonton, AB. [Oral, Invited]

Devito, K.J., Hokanson, K.J., Chasmer, L. , Kettridge, N., Lukenbach, M.C., Mendoza, C.A., Moore, P., Peters, D.L., Silins, U., 2017. Threshold responses in runoff from sub-humid heterogeneous low relief regions. Abstract ID# 233963, American Geophysical Union Annual Fall Meeting, 11-15 December, New Orleans, LA, USA. [Poster]

Dixon, S. Kettridge N., Moore P., Devito K.J., Tilak A., Petrone R., Medoza C., Waddington J.M. 2017. Shallow peatland ecohydrology - the control of peat depth on moss productivity. Abstract #EGU2017-8854, European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Dixon, S., Kettridge, N., **Moore, P.**, Devito, K.J., **Tilak, A.**, Petrone, R., Mendoza, C., Waddington, J.M., 2017. Shallow peatland ecohydrology - the control of peat depth on moss productivity, HydroEco, 18th-23rd May, University of Birmingham, Birmingham. [Oral]

Green, A., G. Bohrer, G., Petrone, R.M., 2017. The effects of forest sheltering on peatland evapotranspiration in the Boreal Plains, Alberta, Canada. CGU Annual Meeting, Vancouver, Canada. [Oral]

Hokanson, K.J., Devito, K.J., Mendoza, C.A., 2017. Water Table Configurations in a Sub-humid, Low-relief Region: Interaction of Climate and Geology. Abstract ID#: 23922 American Geophysical Union Annual Fall Meeting, 11-15 December, New Orleans, LA, USA. [Poster]

Hokanson K.J., Devito, K.J., Mendoza, C.A. 2017. Substrate layering and climate control water table configurations in sub-humid Boreal Plain landscapes. Canadian Geophysical Union and Canadian Society of Agriculture and Forest Meteorology Joint Annual Scientific Meeting, May 28-31, Vancouver, Canada. [Oral]

Hurley, A., Kettridge, N., Devito, K., Hokanson, K., Leonard, R., Krause, S., & Waddington, J. M., 2017. Spatio-temporal dynamics of evapotranspiration from forested, ephemeral wetlands and its implication for hydrologic connectivity in the Western Boreal Plain in Alberta, Canada. #EGU2017-13592, European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Hurley, A., Kettridge, N., Devito, K., Hokanson, K., & Krause, S., 2017. A concept of ephemeral wetlands as water-transmitting landscape units in Canada's Western Boreal Plain. Abstract # EGU2017-13113, European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Kettridge, N. (2017) Moss and peat hydraulic properties are optimized to maximise peat water use efficiency, 24th November, University of Leeds, Leeds, UK. [Oral, Invited]

Kettridge, N. (2017) Moss and peat hydraulic properties are optimized to maximise peat water use efficiency, Forests under global change, Annual workshop of the midlands soil discussion group of the British Society of Soil Sciences, 24th May 2017, BIFoR Research Forest Site at Nobury, Staffordshire, UK. [Oral, Invited]

Kompanizare, M., Petrone, R.M., Robinson, D., Rooney, R., 2017, Effect of climate change on hydrological connectivity among landscape units in the Athabasca Oil Sands Region. Canadian Geophysical Union and Canadian Society of Agriculture and Forest Meteorology Joint Annual Scientific Meeting, May 28-31, Vancouver, Canada. [Oral]

Leonard, R. P., Moore, N. Kettridge, S. Krause, K.J. Devito and J. M. Waddington, 2017. Hotsotpots and hot moments; the control of structural heterogeneity on the thermal regime of the peatland soil-atmosphere interface, HydroEco, 18th-23rd May, University of Birmingham, Birmingham. [Oral]

Leonard, R. P., Moore, N. Kettridge, S. Krause, K.J. Devito and J. M. Waddington, 2017. Hotsotpots and hot moments; the control of structural heterogeneity on the thermal regime of the peatland soil-atmosphere interface. Abstract # EGU2017-10927, European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Lukenbach, M.C., Spencer C.S., Mendoza C.A., Devito K.J., Landhausser S.M., Carey, S.K., 2017. Variably Saturated Flow Between Constructed Upland Hummocks and a Wetland in a Reclaimed Watershed Following Oil Sands Mining. Canadian Geophysical Union and Canadian Society of Agriculture and Forest Meteorology Joint Annual Scientific Meeting, May 28-31, Vancouver, Canada. [Oral]

Lukenbach, M.C., C.S. Spencer, C.A. Mendoza, K.J. Devito, S.M. Landhausser, S.K. Carey, 2017. Resolving The Need For Groundwater Recharge Versus Forest Productivity In A Reclaimed Watershed Using Numerical Modelling. Abstract # 306440, Geologic Society of America Annual Meeting, 22-25 October, Seattle, WA, USA. [Oral]

Probert, S., Kettridge, N., Devito, K.J., Hannah, D., Parkin, G., 2017 Hydrological resiliency in the Western Boreal Plains: classification of hydrological responses using wavelet analysis to assess landscape resilience. Abstract #EGU2017-8532, European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Probert, S., Kettridge, N., Devito K.J., Hurley A., 2017. Ecohydrology of the wetland-forestland interface: hydrophobicity in leaf litter and its potential effect on surface evaporation. Abstract #EGU2017-8445. European Geophysical Union General Assembly, 23-28 April, Vienna, Austria. [Poster]

Worrall, F., Morrison, R., Kettridge, N., Page, S., Kaduk, J., Evans, C., Rayment, M., and Cumming, A., 2017. The energy and entropy budgets of UK peatlands – are some peatlands near equilibrium? European Geosciences Union General Assembly, 24th-28nd April, Vienna. [Oral]

Worrall, F., Moody, C., Clay, G., Kettridge, N., and Burt, T., 2017. Thermodynamic constrains on the flux of organic matter through a peatland ecosystem, European Geosciences Union General Assembly, 24th-28ndApril, Vienna. [Oral]

Reports & Other Publications

Devito, K.J., Kettridge, N., Mendoza,C., Petrone, R.M., Waddington, J.M., 2017. Applying natural analogues to constructing and assessing long-term hydrologic response of Oil Sands reclaimed landscapes. Collaborative Research and Development (CRD) Grants 2nd Progress Report - CRDPJ 477235 – 14, 27pp.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Kevin Devito

Name	Institution or Company	Degree or Job Title	Degree Start Date* (Students Only)	Degree Completion Date* (Students Only)
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Rich Petrone	University of Waterloo	Professor		
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Emily Jones	University of Alberta	Technician	2016	2016

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Janina Plach	University of Waterloo	PDF	2013	2015
Simon Dixon	University of Birmingham	PDF	2015	2017
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Rebekah Ingram	McMaster University	M.Sc.	2015	Dec-17
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Research Collaborators: Laura Chasmer, University of Lethbridge; Julienne Morissette, Ducks Unlimited Canada, Boreal Program, Edmonton, Alberta

*Dates shown for B.SC. students, are project start/end dates, not degree start/end dates.

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

COSIA Project Number: LJ0009

Research Provider: Lakehead University

Industry Champion: Canadian Natural Resources Limited

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

Status: Year 6 of 6

PROJECT SUMMARY

The Forest Watershed and Riparian Disturbance Project (FORWARD) is a consortium of university, government, and industry partners with the overarching goal of better understanding how natural and anthropogenic disturbances influence the dynamics of forest watersheds, and in particular those that redound to aquatic impacts. Its primary focus is the development of soil and watershed assessment tools and appropriate bio-indicators to support reclamation efforts within forestry, energy and mining sectors. It provides information critical in shaping evolving regulatory approaches to reclamation and water management and support components of progressive reclamation.

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

Component 1. Watershed load and contaminant fate modelling that integrates the current knowledge base of process-specific studies into a watershed modelling framework. The models developed in this component are intended to support industry and regulators as they manipulate the landscape and design reclamation strategies – for example those found in Detailed Forest Management Plans (DFMPs) and mine closure plans. The models are intended to ensure the desired hydrologic and biogeochemical outcomes so that successful reclamation of watersheds occurs. FORWARD II (2006 – 2011) contributed substantively to these outcomes at the small watershed scale for forestry and FORWARD III expanded this to oil sands sites. FORWARD III further developed modelling of transport and fate in the Athabasca River so that cumulative effects management could be predictive in nature as both industries manage a shared boreal forest resource base.

Component 2. Benchmarks for reclaimed and engineered soils that 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. Improvements in these aspects derived from the oil sands sites were also applied to the knowledge already generated for forestry-impacted sites that were the basis of FORWARD II research.

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

Component 4. Risk of toxicity to bio-indicators from natural and anthropogenic load and impacts of organic and inorganic contaminants associated with oil sands extraction and forestry related activities including pulp mill effluents that characterize acute and chronic toxicity to amphibians, macroinvertebrates and fish.

PROGRESS AND ACHIEVEMENTS

The FORWARD III research program is grounded in hydrologic monitoring and model development with focused studies in microbiology and physical characteristics of soils, vegetation diversity, and toxicological effects of oil sands contaminants to invertebrates, fish and amphibians.

Field programs in all components of the project were complete in 2016 and Component 2 (Soils) and Component 3 (Vegetation) were fully reported in previous year's reports. Three graduate students (Ph.D. Lari, M.Sc. Novak, M.E.S. Templeton) completed their programs in 2017 and the remaining two Ph.D. Candidates (Ph.D. Bendszak, Ph.D. Mitter) are expected to complete in 2018.

Final results from all projects are being compiled in a technology transfer document that will be distributed to our Industry Partners early in 2018.

Component 1: Development of watershed load and contaminant fate models

Additional unmonitored inputs were identified during the hydrological monitoring period (2012-2016) for the reclaimed tailing pond site. The Soil and Water Assessment Tool for the Boreal Forest ($SWAT_{BF}$) model relies on comprehensive measurement of all water inputs to reach Component 1 objectives. To appraise potential contributions of unmonitored sources to water quantity and quality, the FORWARD III Core Monitoring team collaborated with industry partners to collect static water samples (tri-replicates) at two known sources. These samples were analyzed by ALS Environmental Laboratories for phosphorus, colour, alkalinity, conductivity, total nitrogen, nitrate & nitrite, ammonia, silicate, dissolved organic carbon (DOC), cations, chloride/sulfate, suspended solids.

Model development of $SWAT_{BF}$ has progressed in the following two areas:

- Development of procedures and files systems for utilization of the model independent parameter estimation tool (PEST) to conduct parameter sensitivity analysis, and auto calibration for the modified $SWAT_{BF}$ model. Calibration of $SWAT_{BF}$ utilizing PEST has been tested on two FORWARD research watersheds (Willow and Kashka) in the Virginia Hills near Whitecourt that have long term streamflow and climate databases.
- Integration of the forest tree growth model 3-PG with the modified $SWAT_{BF}$ model to improve the representation of forest growth (biomass and leaf area index). Procedures for utilizing PEST for sensitivity analysis and auto calibration of the integrated $SWAT_{BF}$ 3-PG model were also developed. Calibration of $SWAT_{BF}$ 3-PG model utilizing PEST has been tested on one FORWARD research watershed (Kashka) in the Virginia Hills near Whitecourt.
- Documents describing model modifications, PEST procedures for model parameter sensitivity analysis and model calibration, model results and example files are in the final editing stages.

Ongoing research by Toomas Parratt (Ph.D. Candidate), that began in 2014, is investigating the influence of black spruce trees upon canopy snowmelt, ground temperature, winter infiltration and snowpack recharge in black spruce dominated peatlands on the Boreal Plains. The objective of this study is to formulate a snowmelt energy balance representation suitable for the Boreal Plain peatlands, which incorporates the effect of black spruce trees, and to develop a conceptual model for treed wetland snowmelt infiltration that can be incorporated into existing hydrological models such as $SWAT_{BF}$ or other hydrological models to strengthen their subsurface and winter hydrological component. In 2017 Mr. Parratt passed his Ph.D. comprehensive examination and is currently working on utilizing the SHAW soil temperature model in the development and testing of his conceptual model for treed wetland snowmelt infiltration.

Component 4: Risk of toxicity and impacts to bioindicators from anthropogenic load

Data were collected and finalized on two projects: (i) establishing whether or not fish inhabiting the Athabasca oil sands region are locally adapted to bituminous contaminants, and (ii) identifying and characterizing the toxicity of oil sands process-affected water to water fleas (*Daphnia magna*). Similar to work reported in previous years on the freshwater scud, *Hyalella azteca* (Beery et al., 2017), territorial fish (fathead minnows; *Pimephales promelas*) from tributaries on the McMurray Formation showed no evidence of being locally adapted to bituminous contaminants. Fish from tributaries that received natural bitumen seeps showed signs of being equally stressed to those downstream of industrial operations, which was higher than fish from reference habitats. We attribute the lack of local adaptation to gene flow throughout the study area, which limits natural selective processes necessary for local adaptation to occur.

Daphnia magna showed no acute sensitivity to full-strength oil sands process-affected water (OSPW). However, feeding, growth, and reproduction were impaired when diluted to 1% or 10% of full-strength (100%) OSPW. We demonstrated that these effects were likely caused by an OSPW-induced reduction in feeding efficiency. Daphniids in dilute OSPW filled their gastrointestinal tracts with non-nutritious inorganic clay leaving little physical volume for nutritious algae cells. Moreover, the dissolved fraction of OSPW inhibited peristaltic activity in the daphniid gut. Peristalsis in *Daphnia* spp.—unlike in humans—increases the food retention time in the gut, which allows sufficient time for digestive enzymes to breakdown food into absorbable nutrients. Daphniids feeding in OSPW show a reduction in food consumption and a reduction in digestion efficiency, as demonstrated by an increase in the number of intact algal cells that can pass directly through the digestive tract. Effects observed on growth and reproduction were attributed to reduced feeding efficiency in OSPW-exposed organisms.

We also demonstrated that OSPW diluted by 99% (i.e., 1% OSPW) can impair olfaction in rainbow trout. Both the neurophysiological responses and behavioural responses to standard olfactory cues are impaired upon exposure to dilute OSPW. However, we also demonstrated that naive fish can use olfaction to detect OSPW at very dilute concentrations and show a consistent avoidance of areas contaminated by very dilute 0.1% OSPW.

LESSONS LEARNED

Component 1: Development of watershed load and contaminant fate models

The unmonitored water inputs were found to have higher concentrations of dissolved and total nutrients (NO_3^-, NH_4^+, PO_4) compared to natural, disturbed, or reclaimed streams. While these additions could contribute to the nutrient-rich and export conditions found in monitored reclaimed streams during baseflow. Without water flux data for these sources it is difficult to partition the relative contributions to the overall watershed stream chemistry. Future development of watershed load and contaminated fate models will require water flux data in order to evaluate the relative contributions of reclaimed streams to overall watershed stream chemistry.

Component 4: Risk of toxicity and impacts to bioindicators from anthropogenic load

It has now been demonstrated twice, that aquatic animals (freshwater scuds and small-bodied, territorial fish) show no evidence for local population adaptation to bituminous contaminants. Fish inhabiting tributaries that receive bitumen seeps appear to be equally stressed as those downstream from industrial operations. Consequently, native aquatic animals inhabiting water bodies affected by naturally occurring bitumen are not adapted to contaminants typically associated with the region. Toxicological responses from lab-reared model species fairly represent the fish inhabiting the region of interest.

Although full-strength OSPW does not induce acute toxicity in *Daphnia magna*, sublethal effects on growth and reproduction are still possible, even if the OSPW is diluted to 1%. These effects are more related to reductions in feeding efficiency than overt toxicity. If OSPW can be filtered prior to being released, many of the problems affecting feeding efficiency (i.e., gut stuffing and inhibited peristaltic activity) will be significantly reduced. Once feeding efficiency has been recovered, the energy required for growth and reproduction will be available to exposed animals.

Rainbow trout olfaction is impaired by 1% OSPW and higher. Because fish rely on olfaction to find food, avoid predators, and successfully reproduce, this olfactory impairment has serious implications for growth, survival, and reproduction. This is an important, ecologically relevant effect. However, olfactory competent fish can detect OSPW at concentrations as low as 0.1% and avoid it. As long as there is a clean refugium to which olfactory-competent fish can retreat in the event of an OSPW pulse, they can escape risk of olfactory impairment. If not, fish will not be able to use olfaction to find food, avoid predators, or reproduce.

LITERATURE CITED

Beery, S.R., P.T. Gauthier and G. G. Pyle. 2017. Testing local adaptation in five populations of Hyalella Azteca in Northern Alberta's oil sands region. *Archives of Environmental Contamination and Toxicology* 72, no. 2: 189–99. https://doi.org/10.1007/s00244-016-0351-z.

Lari, E., E. Mohaddes and G.G. Pyle. 2017. Effects of oil sands process-affected water on the respiratory and circulatory system of *Daphnia Magna* Straus, 1820. Science of The Total Environment 605–606: 824–29. https://doi.org/10.1016/j.scitotenv.2017.06.207.

Lari, E. and G.G. Pyle. 2017. Rainbow Trout (*Oncorhynchus Mykiss*) detection, avoidance, and chemosensory effects of oil sands process-affected water. *Environmental Pollution* 225: 40–46. https://doi.org/10.1016/j.envpol.2017.03.041.

Lari, E., D. Steinkey, E. Mohaddes and G.G. Pyle. 2017. Investigating the chronic effects of oil sands process-affected water on growth and fitness of *Daphnia Magna* Straus 1820. *Science of The Total Environment* 595: 594–600. https://doi.org/10.1016/j.scitotenv.2017.03.239.

Lari, E., D. Steinkey, G. Morandi, J.B. Rasmussen, J.P. Giesy and G.G. Pyle. 2017. Oil Sands Process-Affected Water Impairs Feeding by *Daphnia Magna*. Chemosphere 175: 465–72. https://doi.org/10.1016/j.chemosphere.2017.02.088.

Lari, E., D. Steinkey and G.G. Pyle. 2017. A Novel apparatus for evaluating contaminant effects on feeding activity and heart Rate in *Daphnia* Spp. *Ecotoxicology and Environmental Safety* 135: 381–86. https://doi.org/10.1016/j.ecoenv.2016.10.018.

Lari, E., S. Wiseman, E. Mohaddes, G. Morandi, H. Alharbi and G.G. Pyle.2016. Determining the effect of oil sands process-affected water on grazing behaviour of *Daphnia Magna*, long-term consequences, and mechanism. *Chemosphere* 146: 362–70. https://doi.org/10.1016/j.chemosphere.2015.12.037.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Lari, E., 2017. Effects of water quality on the toxicity of oil sands process-affected water (OSPW) in two aquatic organisms: implications for release. A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of Biology, University of Lethbridge.

Novak, K., 2017. Comparison of soil-water properties for reclaimed oil sand, fire-disturbed, and undisturbed forested soils in northern Alberta, Canada. A thesis submitted to the School of Graduate Studies and Research in partial fulfillment of the requirements for the Degree of Mater of Science, Department of Soil Science, University of Saskatchewan.

Templeton, B., 2018. Survey of Canadian native plant species for resistance to salt and metal stress. A thesis submitted to the College of Graduate and Research in partial fulfillment of requirements for the degree of Master of Environment and Sustainability in the School of Environment and Sustainability, University of Saskatchewan.

Journal Publications (see also Literature Cited)

Biswas, S.R., R.L. MacDonald and H.Y.H. Chen. 2017. Disturbance increases negative spatial autocorrelation in species diversity. *Landscape Ecology* doi: 10.1007/s10980-107-0488-9.

Blain, N.P., B.L. Helgason and J.J. Germida. 2017. Endophytic root bacteria associated with the natural vegetation growing at the hydrocarbon contaminated Bitumount Provincial Historic Site. *Canadian Journal of Microbiology* 63: 502-515 doi: 10.1139/cjm-2017-0039.

Chen, H.Y.H., S. Biswas, T.M. Sobey, B.W. Brassard and S.F. Bartels. 2017. Reclamation strategies for mined forest soils and overstorey drive understorey vegetation. *Journal of Applied Ecology* 2017;00:1-11 https://doi.org/10.111/1365-2664.13018.

Lari, E., D. Steinkey and G.G. Pyle. 2017. Effects of seasonal changes on the toxic Impacts of oil sands process-affected water on *Daphnia Magna. Archives of Environmental Contamination and Toxicology*, October 20, 2017. https://doi.org/10.1007/s00244-017-0460-3.

Mitter, E.K., J.R. de Freitas and J.J. Germida. 2017. Bacterial root microbiome of plants growing in oil sands reclamation covers. *Frontiers in Microbiology* 8: 849. doi: 10.3389/fmicb.2017.00849.

Conference Presentations/Posters (Presenter bolded)

Parratt, T. Oral. Wintertime infiltration and snowmelt processes of Black Spruce peatlands in the Boreal Plain. National Groundwater Association Summit, Nashville, TN, 4-7 December 2017.

Novak, K. and K.C.J. Van Rees. Oral. Investigation of soil-water relationships for reclaimed, fire-disturbed and undisturbed forested soils in northern Alberta, Canada. 2017 Annual Meeting of the Soil Science Society of America, Tampa, FL, 22-25 October 2017.

Lari, E. D. Steinkey, G. Morandi, J. Ramussen, J. Giesy and G. Pyle. Oral. How oil sand process-affected water affects feeding in Daphnia magna? Canadian Ecotoxicity Workshop, Guelph, ON, 1-4 October 2017.

Mitter, E.K., R. Kataoka, J.R. de Freitas and J.J. Germida. Oral. Endophytic root bacteria improve phytoremediation of petroleum hydrocarbons under growth chamber conditions. 14th International Phytotechnologies Conference, Montreal, QC, 24-29 September 2017.

Templeton, B. and J.J. Germida. Poster. Screening native Canadian plant species for potential to remediate metal and salt impacted soils. 14th International Phytotechnologies Conference, Montreal, QC, 24-29 September 2017.

Bendzsak, M. Oral. Leaf litter decomposition on reclaimed Athabasca oil sands tailings. Canadian Soicety of Soil Science Conference, Peterborough, ON, 10-14 June 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: Lakehead University

Principal Investigator: Dr. Ellie Prepas

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Dr. Greg Pyle	University of Lethbridge	Professor and CAIP Chair		
Dr. Michael Rennie	Lakehead University	Professor and CRC		
Dr. Daniel W. Smith	University of Alberta	Professor Emeritus		
Dr. Ken Van Rees	University of Saskatchewan	Professor and Agro-Food Innovation Chair		
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Dr. Yin Chu	University of Saskatchewan	Research Associate		
Dr. Paul Dinsmore	Lakehead University	Research Associate		
Virginia Antoniak	Lakehead University	Project Administrator		
Sarah Bogart	University of Lethbridge	Laboratory Manager		
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Leigh-ann Lowrie	Lakehead University	Project Coordinator		
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Research Collaborators: Dr. Renato deFreitas, University of Saskatchewan; Dr. John Giesy, University of Saskatchewan; Dr. John Headley, Environment Canada; Dr. Bobbi Helgason, University of Saskatchewan; Dr. Michael Lannoo, Indiania University School of Medicine; Jonathan Russell, R.P.F., Dr. Brett Watson, Saskatchewan Polytechnic/University of Saskatchewan

Wetlands

Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel

COSIA Project Number: LJ0227

Research Provider: Suncor Energy Inc., Hatfield Consultants, Millennium EMS Solutions Ltd. (MEMS)

Industry Champion: Suncor Energy Inc.

Status: Year 3 of Ongoing

PROJECT SUMMARY

In March 2005, Suncor Energy Inc. received approval to construct a tailings storage facility for the Millennium Mine project in the upper portion of the McLean Creek watershed. The construction of the tailings pond required the alteration of 3,870 m^2 of fish habitat in upper McLean Creek and approximately 53,000 m^2 of the McLean Creek wetlands system. As part of the project development, a compensation plan was prepared by Suncor, which included a new diversion channel to maintain flow to lower McLean Creek, and a dispersed-flow wetlands system. The South Tailings Pond (STP) Wetlands Complex was constructed between 2004 and 2006; the development included approximately 66 hectares of semi-permanent wetlands and an additional 82 hectare inundation zone consisting of a series of four cross-dykes, with re-vegetation encouraged through natural colonization. Fisheries and Oceans Canada (DFO) specified that monitoring in the area must take place to compare the development of the constructed wetlands condition/function to natural wetlands over time, to ensure the constructed wetlands conform to regional norms and meet DFO expectations.

A long-term wetland monitoring program for McLean Creek and the STP Wetlands Complex has been implemented since 2006 to track hydrologic conditions, water and sediment quality, and benthic invertebrate and vegetation communities through the ecological progression of the constructed wetlands. The monitoring program was designed to compare any changes in wetland condition/function over time to the natural wetlands in the upper portion of the McLean Creek watershed.

Many wetland monitoring programs in Alberta are effects-based as stipulated in project environmental approval conditions. Effects-based monitoring programs have a primary goal of measuring and quantifying potential (predicted) environmental or biological changes resulting from ongoing projects; however, little guidance exists for monitoring of created wetlands to address or minimize the effects of development. Specifically, no guidelines existed for setting performance standards and success criteria for the STP Wetlands Complex.

The objectives of this study are to:

- Establish performance indicators (i.e., measurable ecological indicators for each monitoring component) and success criteria (e.g., range of conditions from natural wetland systems); and
- Determine the variability in performance indicators over time and how they compare to the criteria in order to judge whether success has been achieved across all conditions (i.e., annual and seasonal variability). The performance indicators and success criteria were developed to evaluate whether the ecological function of the created STP Wetlands Complex is sustainable and consistent with the natural wetland systems in the watershed.

The “Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel” provides an outline of the performance indicators and success criteria to determine when the ecological function of the STP Wetlands Complex conforms to regional norms. The data gathered will help determine the success of these constructed wetlands.

PROGRESS AND ACHIEVEMENTS

Monitoring continued in 2017, the data review and analysis will be included in the 2017 McLean Creek / STP Wetlands Complex annual report (April 30th, 2018). A summary of the 2016 assessment (Hatfield and MEMS, 2017) is provided below:

In 2016, the vegetation communities of the STP Wetlands Complex were comparable to the reference wetland in upper McLean Creek. There were no obvious impacts of the May 2016 Horse River Wildfire on vegetation at any station, although air photos show wildfire impacts to the McLean Creek Watershed. Mean species diversity was similar at stations of the STP Wetlands Complex and reference station MC-9A; however, mean species richness was significantly lower at stations STP-1 and STP-2 compared to the reference wetland in 2016. Vegetation vigour remained ‘good’ to ‘excellent’ indicating that macrophyte vegetation was generally robust, green, and healthy across all stations of the STP Wetlands Complex.

Benthic invertebrate community monitoring in 2016 indicated that the STP Wetlands Complex are mirroring natural conditions observed in the upper portion of the watershed. Benthic invertebrate communities at all stations in the McLean Creek watershed were dominated by chironomids or co-dominated by chironomids and ostracods, which is typical of depositional riverine habitat in the Athabasca oil sands region. In general, benthic invertebrate community indices (i.e., taxa richness, abundance, diversity, and evenness) at lotic stations were within or greater than the range of variability observed at the reference station; however, benthic invertebrate communities at lentic stations were below the reference range for several indices including abundance, oligochaete abundance, ETSD (Ephemeroptera, Trichoptera, Sphaeriidae, and Dragonflies/Damselflies [Odonata]) abundance, and ETSD richness. Several indices were also significantly lower than the reference station in 2016, including abundance at station STP-4, and richness and diversity at station STP-2.

Comparisons of performance indicators of each monitoring component to the reference range of variability (i.e., success criteria) indicated that there are some performance indicators that have not achieved the success criteria, particularly related to sediment quality and benthic invertebrate communities at the constructed wetlands. The results of the vegetation community assessment indicated that station STP-2 did not meet the success criteria; however, there continues to be a progression towards reference conditions at all stations as the constructed wetlands continue to mature.

LESSONS LEARNED

Results of the 2016 monitoring program indicated that since their construction, there has been a positive progression in the development of benthos, vegetation, and plankton communities in the compensation habitat of the STP Wetlands Complex. Despite a few isolated differences, indices of the biological communities were relatively consistent between reference and test stations of the McLean Creek watershed. Overall, the results indicate that hydrologic, chemical, and biological conditions of McLean Creek and the STP Wetlands Complex were representative of a functioning and healthy ecosystem; however, they did not meet all success criteria in 2016 indicating that more time is needed for the constructed wetlands to show similar function to mature (reference) wetland systems. The performance indicators developed in 2013 have now been applied to four years of monitoring data, and will continue to be evaluated in 2017.

PRESENTATIONS AND PUBLICATIONS

Hatfield Consultants and Millennium EMS Solutions Ltd. 2017. Suncor Millennium project 35(2): 2016 monitoring program for the McLean Creek watershed. Prepared on behalf of Suncor Energy Inc. April 2017. North Vancouver, BC.

RESEARCH TEAM AND COLLABORATORS

Institution: Suncor Energy Inc.

Principal Investigator: Sarah Aho, Sr. Hydrologist

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Melissa Langridge	Hatfield Consultants	Project Manager		
Laura Patterson	Millennium EMS Solutions Ltd.	Vegetation Ecologist		

Ecohydrogeologic Investigation of Opportunistic and Constructed Wetlands on Syncrude's Mildred Lake Lease

COSIA Project Number: LJ0275

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 2 of 3 (one year extension in 2017)

PROJECT SUMMARY

This project is assessing small-scale opportunistic wetlands on reclaimed sites. Opportunistic wetlands are the cumulative result of geology/material type, surface and/or groundwater flows, as well as physical features of the landform. These wetlands can occur at a range of scales and may or may not be spatially explicit.

This research considers small-scale opportunistic wetlands that develop on the closure landscape as a result of reclamation activities that are not spatially explicit. Because these wetlands are not spatially explicit, they are difficult to predict or account for during the closure planning process. Wetlands, including these small-scale wetlands play an important role in landscape function (Devito et. al, 2012) and will be critical landscape components for closure success. This work will attempt to understand the conditions under which these small-scale opportunistic wetlands develop and their predictability and performance throughout climate cycles. The results from this research will allow improved prediction of the occurrence and performance of these wetlands, and ultimately provide guidance for enhancing opportunities for the wetlands to develop. This work will also be crucial in more accurately accounting for all wetlands that we expect on the closure landscape

PROGRESS AND ACHIEVEMENTS

During the 2017 field season, transect surveys were continued and completed on the abundance, extent, and location of opportunistic wetlands on reclaimed areas on the Syncrude Mildred Lake lease. These areas were either fine-textured landforms (Overburden dumps: South Bison Hills [SBH], W1 Dump [W1]) or coarse-textured landforms (Out of pit sand storage: Southwest Sands Storage [SWSS]). Wetlands located along transects were categorized using soil, vegetation, and hydrologic parameters. Similar transects were completed at natural sites at the Utikuma Region Study Area (URSA) near Utikuma Lake, Alberta. Transects at URSA were conducted to record wetland parameters in natural systems, and to evaluate what site and local properties influence wetland development or occurrence. Two additional opportunistic wetlands were selected for detailed study at SBH and W1. Further instrumentation was installed at detailed study sites established in 2016 at SBH and W1. Detailed sites were instrumented with wells, piezometers, and soil moisture access tubes, and were measured every two weeks from May to September. Pressure transducers were installed in select wells to measure changes in water levels or depth of water between and within opportunistic wetlands, and are continuously monitored (i.e. every hour). Atmometers, soil temperature sensors, air temperature and relative humidity sensors, and rain gauges were installed at SBH and W1 to monitor differences in evapotranspiration within wetlands and between the wetland and the surrounding forested area. This project started in 2016, and is due for completion Q4 2018.

LESSONS LEARNED

Preliminary results suggest opportunistic wetlands are common in greater frequency than predicted on all reclaimed landforms and are characterized by a near-surface confining layer.

Wetlands appear to form in different locations depending on the landform texture. Wetlands form at the toes of slopes or where groundwater intersects the ground surface on coarse-textured landforms. These wetlands are generally large, elongate in shape, and follow the base of the landform. This indicates that external sources of water (groundwater discharge, upstream runoff) are required for wetland formation.

Wetlands form on the flat top, mid-slope, and base of landforms with fine textured substrates, including areas perched above the groundwater table. These wetlands are variable in size and shape, although most are circular or convoluted. Wetlands on fine-textured landforms appear to form on flat areas or depressions that are protected and have less soil water storage, promoting frequent soil saturation. Some elongated wetlands are also found at the landform base.

This indicates that site characteristics and internal feedbacks influence wetland formation. This has large implications for potential wetland construction on lease sites.

LITERATURE CITED

Devito, K., Mendoza, C., and Qualizza, C. (2012). *Conceptualizing water movement in the Boreal Plains*. *Implications for watershed reconstruction*. Synthesis report prepared for the Canadian Oil Sands Network for Research and Development, Environmental and Reclamation Research Group. 164p.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Little-Devito, M., Chasmer, L., Devito, K.J., Kettridge, N., Lukenbach, M.C., Mendoza, C.A. (2017), Learnings from Opportunistic Wetlands: The Role of Substrate and Landscape Position on Reconstructed Landforms in a Sub-humid Climate. Abstract H14E-07 presented at 2017 Fall Meeting, American Geophysical Union, New Orleans, LA, 11-15 Dec. (abstract available online https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/245043)

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Drs. Kevin Devito and Carl Mendoza

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Kevin Devito	University of Alberta	Principal Investigator		
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Jordan Pearson	University of Alberta	Research Assistant		
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Peatland Reclamation Markers of Success

COSIA Project Number: LJ0273

Research Provider: Southern Illinois University Carbondale

Industry Champion: Syncrude Canada Ltd.

Status: Year 1 of 5

PROJECT SUMMARY

The Sandhill Fen wetland vegetation community has changed considerably in its early development: from having an open unvegetated surface to one richly covered with a variety of plant species. We have developed an understanding of how early development proceeds in Sandhill Fen and how we might use benchmark sites to provide a framework for evaluating the progress and success of the wetland. This program is a set of projects building on our current understanding of the vegetation response in the fen to demonstrate how a suite of specific measurements can be developed into markers of success for oil sands reclamation.

Project 1: Tracking key ecosystem variables. After three years of data collection at Sandhill Fen, we have identified four important variables that are dynamic or unpredictable: 1) water chemistry of the peat profile (top 50 cm), 2) plant community development, 3) source-sink carbon flux for monocultures of planted sedges, and 4) diversity and status of indigenous volunteer plant species in the areas of the fen outside of our plots. Each of these variables plays a key role in the success of the fen, and continued monitoring of these factors will supply valuable information for understanding wetland performance and function.

Project 2: Plant response to sodium concentration. Areas of increased salinity at Sandhill Fen have been identified, and it is important to understand how dominant plant species respond to these high sodium concentrations. A series of new plots that cover a range of sodium concentrations will be identified and monitored for plant health and performance through a variety of eco-physiological measures.

Project 3: Development of peatland markers of success. Fundamental to understanding wetland reclamation performance is the establishment and quantification of markers of success based on comparative benchmark sites. This project endeavours to identify a small number of markers that include parameters that compare structure, function, and species diversity for 10 benchmark peatlands.

PROGRESS AND ACHIEVEMENTS

During the 2017 field season at Sandhill Fen, we continued to 1) sample water to a depth of 50 cm using sipper wells, 2) conducted a vegetation survey and collected sedge and organic soil tissue for sodium analysis from these plots, 3) sampled soil from our research plots, 4) re-installed atmospheric deposition collectors for sulphur and nitrogen compounds, and 5) measured decomposition.

In addition to Sandhill Fen, 10 benchmark peatlands were sampled. From these sites, we collected surface water and volumetric soil cores from the surface to a depth of 10 cm. At the end of the field season, we began analyses in the laboratory.

Key findings are summarized below:

Water chemistry: Sodium concentrations in Sandhill Fen have increased in 2017; areas along the southern part of the fen showed an increase in sodium concentrations throughout the 0-50 cm peat profile. Across the fen, sodium values ranged from 115 mg/L to 1258 mg/L. In the northern portion of the fen, sodium values are less than 200 mg/L. Values over 300 mg/L may negatively affect peatland species.

Monitoring of plant ecophysiology along the sodium gradient at the fen will begin in the summer of 2018.

Diversity and status of Sandhill Fen species: There was a marked decrease in diversity and plant cover for both vascular and bryophyte species. This loss is a result of standing water flooding out bryophyte and forb species that occupy the area under sedges and shrubs. Loss of species affected the part of the watershed that in 2016 had the most fen species. Thus, desirable species richness decreased in 2017. The effect of the flood was not as severe for undesirable species. The combined effect could push the fen toward an unfavourable community. Plant species occurrence data suggests that Sandhill Fen is a hybrid system similar to moderate rich and saline fens.

Benchmarks: Porewater electrical conductivity is high at Sandhill Fen, but falls within the natural ranges of the moderate rich and saline fens. The porewater at Sandhill Fen contains low concentrations of dissolved nutrients, but overall is similar to the reference sites. For base cations, porewater Ca^{2+} and Na^{+} concentrations are higher at Sandhill Fen compared to most of the reference sites, but are within the natural ranges of variation for some moderate rich fens, and below the saline fens. Soil bulk density is higher than reference sites. Soil carbon content was lower than at the reference sites, and much more variable. Continued monitoring will be required to determine the possible impacts this could have on ecosystem development.

LESSONS LEARNED

This program was initiated in 2017, and therefore results are too preliminary to be presented as lessons learned.

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University Carbondale

Principal Investigator: Dale Vitt

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Melissa House	Southern Illinois University	Researcher		
Jeremy Hartsock	Southern Illinois University	Researcher / PhD Student	2015	2019

Reclamation Wetlands Index of Biotic Integrity (IBI)

COSIA Project Number: LJ0297

Research Provider: Canadian Natural Resources Limited

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 3

PROJECT SUMMARY

Although large-scale engineered fens have been constructed and are currently monitored by the oil sands industry, these projects represent only one of many potential wetland types or developmental trajectories that reclamation wetlands may exhibit. Currently, the most common wetland types on reclamation areas are shallow open water wetlands and marshes. However, knowledge gaps exist concerning how these wetlands develop over time.

From 2007-2011, Dr. Suzanne Bayley worked to develop and test an approach to evaluate ecological integrity across a range of constructed, disturbed, and natural shallow open water marshes in the Athabasca Oil Sands Region. Dr. Bayley's work was funded by CEMA (contract 2007-2015). Ecological integrity is analogous to measuring homeostasis as an indicator of health (Costanza et al., 1992) – it focuses on a balance of ecosystem components, and is a particularly useful perspective in understanding how systems return to equilibrium or maintain natural ecological structure in the face of disturbance. Therefore, evaluating the ecological integrity of a system is an important step to determine if it is self-sustaining.

The objectives for this project were: 1) Characterize an environmental stress gradient for shallow open water wetlands and marshes; 2) Select suitable biological metrics; 3) Develop an IBI (Index of Biological Integrity); and 4) Test the IBI on an independent set of wetlands. An IBI is a multi-metric approach that characterizes the range of natural variability of systems and the degraded condition that they exhibit. It then uses a suite of metrics to situate sites of interest along that gradient.

Sixty-three wetlands were tested in total (38 "reference", 12 "oil sands reference" [undisturbed, reference wetlands on oil sands leases], and 13 "oil sands process affected" [wetlands receiving process-affected water]). All wetlands exhibited similar ranges in salinity, surface area, depth, and turbidity. To characterize the stress gradient, fifty-two environmental variables were tested at each wetland site, and through Principle Components Analysis it was found that eight variables were the most influential to wetland stress: water cation concentration; total nitrogen in water; percent water in sediment; max depth of wetland; Secchi disc depth; water amplitude; % oil in sediment, and chlorine (Cl^-) concentration in water (Rooney & Bayley, 2010).

To evaluate the biotic integrity of reclaimed wetlands, a vegetation-based IBI was developed. Vegetation was selected over other biotic elements (i.e., invertebrates, algae, etc.) because it is relatively easy to sample, integrative of temporal and environmental trends, indicative of ecosystem functions, biologically important, and can provide diagnostics based on species (i.e., halophytes, low light tolerators, etc.). From this data, a Submerged Aquatic Vegetation (SAV) metric and a Wet Meadow Vegetation (WMV) metric were developed and tested. The Wetlands IBI consists of a combination of the Stress Gradient metrics (above), the SAV-IBI and the WM-IBI to calculate an overall performance indicator score – the Marsh Condition Index (MCI).

The objective of this project is to implement the developed monitoring procedures on five voluntary shallow open water wetlands on the Horizon lease, located within reclamation areas. Wetlands will be assessed annually in order to understand how they are developing in early seral stages. This study is significant as it will provide a means to understand the developmental trajectory of shallow open water wetlands on reclamation areas.

PROGRESS AND ACHIEVEMENTS

Five wetlands were measured for all metrics (submerged aquatic vegetation, abiotic stress, and wet meadow composition) in the summer of 2016 and were re-measured in 2017. Time constraints limiting some data collection last season were not encountered in 2017, so full datasets were collected for each wetland this year. Additionally, small operational changes were made to the protocols to increase field efficiencies.

Although not part of the Wetland IBI protocol, water was analyzed for ionic composition on a monthly basis for each wetland. This was done to investigate how the ionic composition changes throughout the field season and also to determine the ionic composition that drives electrical conductivity.

An additional development is the deployment of water level dataloggers in each wetland. These dataloggers will eventually replace the need to measure water amplitude by inspecting staff gauges biweekly. However, the efficacy of these dataloggers is still being assessed.

Performance indicators for each wetland showed little change between 2016 and 2017, indicating relatively stable development in these wetlands. The most notable changes appeared to be the terrestrialization of two wetlands on Reclamation Area 1, leading to reduced scores in terms of submerged aquatic vegetation, but increased scores in wet meadow development. In this situation, wetland size impacts the degree of adaptation, with a very large wetland showing minor stress, but a much smaller wetland clearly on a different developmental path. It is likely that this smaller wetland will dry up in the coming years, as wet meadow vegetation colonizes more of its shallow depths. The performance indicators provide an interesting means to assess this process.

LESSONS LEARNED

The Wetland IBI protocols represent a clear, teachable, and relatively easy means to assess certain aspects of marsh wetland performance, however it is not without its faults. The strength of these protocols is that they are rapid and easy to employ, and that results can be tracked and plotted over time to understand how wetlands are responding to abiotic and biotic stress. For example: Nutrient and contamination status of a wetland can easily be monitored and tracked. Therefore, this method may aid in understanding how the ecosystem responds in wetlands that have received oil sands process-affected water (OSPW) or other contaminants.

The program was designed to use vegetation as an integrative measure of both abiotic and biotic stress, for a number of operational reasons. While there is surely benefit to this design decision, vegetation alone cannot describe much of the biological function or community structure data that would paint a more complete picture of wetland health. Additionally, it is unclear what management actions can (or should) be taken in order to rectify stresses flagged using these methods, particularly concerning the appearance of halophyte or alkali tolerant plant species that can severely affect vegetation metric scores. Ultimately, while an IBI approach is one tool that can be used to evaluate the health of an ecosystem, this particular IBI (for shallow open water wetlands and marshes) presents a problem in both applicability and relevance to oil sands leases. Natural reference wetlands and oil sands wetlands have very different characteristics (e.g. morphology, size, parent material, vegetation zone development, age, etc.) that inherently result in reclamation wetlands scoring lower in metrics compared to natural reference wetlands. While the original program developed “pass/fail” criteria as part of the tool’s genesis, the pass/fail criteria are not relevant to reclamation wetlands because they are not directly tied to either certification criteria or provincial wetland policies (the IBI program pre-dating the current Alberta Wetland Policy), but instead represent +/- 1 SD from the mean of the natural reference wetlands. While this threshold is a logical way to understand how a reclaimed wetland's health theoretically compares to those found in wetland areas, the characteristic differences between these two wetland types are too large to ignore, and represent a severe bias in comparison. All in all, this program is effective in empowering operators with tools and knowledge to evaluate certain aspects of their reclamation wetlands, and may well be used, in part, in future monitoring efforts that are designed within a more appropriate regulatory and operational context.

LITERATURE CITED

Costanza, R., Norton, B., Haskell, B. (1992). Ecosystem health: New goals for environmental management. Washington, D.C. Island press.

Rooney, R.C. and Bayley, S.E. (2010). Quantifying a stress gradient: An objective approach to variable selection, standardization and weighting in ecosystem assessment. Ecological Indicators 10(6): 1174-1183.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

All research provided by Canadian Natural Resources Limited, Horizon.

Wetland Inventory of Permanently Reclaimed Sites at Suncor Oil Sands Base Plant

COSIA Project Number: LJ0304

Research Provider: LGL Limited Environmental Research Associates

Industry Champion: Suncor Energy Inc.

Status: Year 2 of 2

PROJECT SUMMARY

To date, Suncor has permanently reclaimed over 2000 ha at Base Plant of which, approximately 48 ha have been classified as wetlands. Examination of aerial photos suggest that several additional wetlands have established in depressions on Suncor's permanently reclaimed sites and are not included in the current reclaimed wetland area inventory. Utilizing remote sensing data, a two-phase project was initiated in 2016 to update Suncor's reclaimed wetland inventory by both reassessing the boundaries of the permanently reclaimed wetlands and by identifying, classifying, and delineating wetlands that have developed opportunistically on permanently reclaimed sites. During Phase 1 of the project, aerial and satellite multi-temporal imagery, as well as a satellite-derived digital terrain model (DTM), were used to identify and delineate potential wetlands. Phase 2 of the program was completed in 2017 and involved field verifications of the wetland delineations and typing in Phase 1.

The goal of this project was to ensure that the total reclaimed area (ha) identified as wetlands on Suncor's permanently reclaimed sites was accurate and up to date. Specifically, the objectives of the program were to:

1. Precisely delineate the edges of permanently reclaimed wetlands;
2. Identify, delineate and classify opportunistic persistent wetlands which have developed on permanently reclaimed sites; and
3. Calculate the total reclaimed wetlands area (ha) on Suncor's permanently reclaimed sites.

PROGRESS AND ACHIEVEMENTS

During Phase 1 of this program, aerial and satellite imagery from 2007 to 2016 was used to delineate and classify areas prone to water accumulation. The outcome of this desktop exercise was delineation of an additional 42 ha of Marsh and Shallow Open Water wetlands on the Suncor Base Lease. A total of 673 wetlands polygons were delineated and assigned into 3 wetland types: *Marsh* (n=90), *Shallow Open Water* (n=300), and *Intermittent Wetland* (n=283). Most of the opportunistic marshes (11 ha) and shallow open water (18 ha) wetlands were classified as semi-permanent (*based on* AESRD 2016). Over 85% of the opportunistic wetlands were classified as persistent, suggesting most are not temporary and likely to continue to exist over time.

In Phase 2, a total of four intentional (permanently reclaimed), and 238 opportunistic, wetlands on the Suncor Base Lease were ground-truthed in 2017. The ground truthing exercise confirmed that Suncor's reclamation areas support an abundance of opportunistic wetland habitat. The total area of land occupied by these wetlands is presently estimated to be approximately 210 ha, or 17% of the areas of interest sampled, representing a five-fold increase over previous estimates.

Most opportunistic wetlands were classified as either seasonal or temporary Marsh. A limited number of sampled wetlands (including all intentional wetlands surveyed) supported enough surface water to be classified as semi-permanent Shallow Open Water wetlands. Most sampled wetlands had a typical structure, consisting of two or more distinct but overlapping wetland zones radiating outward from the centre. Six different wetland zones, succeeding from more wetted to less wetted, were mapped: (i) shallow open water; (ii) emergent; (iii) wet meadow; (iv) shrubby meadow; (v) transitional shrubland; and (vi) marginal. Despite the overall structural similarities between wetlands, species compositions varied significantly from reclamation area to reclamation area. Differences in wetland community development appear to be a function of topography (e.g., elevation and slope) in combination with the particular reclamation substrates (soils) that were placed on to tailings prior to seeding/planting.

The desktop exercise was successful at predicting the existence of wetland conditions on the ground over 96% of the time but was much less successful at predicting the spatial extent of those wetlands. Wetland extents were consistently underestimated by the desktop delineations, due mainly to underestimations in the extent of non-inundated wetland zones (e.g., wet meadow, shrubby meadow, and transitional shrubland). The accuracy of desktop delineations may also have been affected by differences in acquisition dates among the aerial photos, digital elevation model (DEM), and field samples, and by the resolution of the existing DEM. The lack of a suitable available method for calibrating the topographic wetness index was likely also a factor affecting delineation accuracy.

LESSONS LEARNED

The experience of the 2017 field campaign demonstrates that remote imaging can be a highly effective tool for identifying the occurrence of potential wetland conditions, but that additional field assessments are needed to accurately delineate the extent of individual wetland complexes. To reduce discrepancies between the two approaches, future desktop delineations should be performed with high resolution remote sensing images and DTM in conjunction with field surveys conducted in close temporal proximity with remote image capture. The gains from this approach can be used to refine mapping, not just of outer wetland boundaries and extents, but also of interior wetland zones (e.g., wet meadows and riparian shrubland).

LITERATURE CITED

Alberta Environment and Sustainable Resource Development (AESRD). 2016. Guide for Assessing Permanence of Wetland Basins. Land and Forestry Policy Branch, Policy Division. 20 pp.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Limited Environmental Research Associates

Principal Investigator: Virgil Hawkes

Compensation Lakes and Aquatics

Horizon Lake Fisheries Monitoring

COSIA Project Number: LJ0011

Research Provider: Canadian Natural Resources Limited, Hatfield Consultants

Industry Champion: Canadian Natural Resources Limited

Status: Year 10 - Ongoing

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural), is in the process of mining the Horizon Oil Sands lease (Horizon), which required the development of a compensation lake (Wāpan Sākahikan) to permanently offset areas of fish habitat that will be affected by Horizon developments. The primary purpose of the compensation lake development, hereafter referred to as Horizon Lake, is the establishment of habitat that will support self-sustaining resident fish populations. 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 and a maximum depth of approximately 20 m.

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". Canadian Natural designed and began the implementation of a monitoring program in 2008 to track the establishment and development of the lake. Monitoring includes documentation of the existing fish populations, water and sediment quality, plankton and benthic invertebrate communities, and growth of macrophytes and shoreline vegetation.

PROGRESS AND ACHIEVEMENTS

Note: Results of the 2016 monitoring program became available in 2017 after the publication of the COSIA Land EPA Mine Site Reclamation Research Report and are therefore presented in this report.

Fish Populations

A total of 10 species of fish have been documented in Horizon Lake since monitoring was initiated in 2008. They consist of Arctic grayling, brook stickleback, burbot, finescale dace, fathead minnow, lake chub, longnose sucker, slimy sculpin, trout-perch, and white sucker.

There were 2,694 fish caught from the lake during the 2016 fall sampling program, including nine recaptures of fish tagged between 2011 and 2016. An additional 309 passive integrated transponder (PIT) tags were deployed during the 2016 sampling period. The assemblages of fish species caught by the different fishing methods have been relatively consistent from 2012 to 2016, though the relative proportions of each species have varied over time. Similar to 2015, fathead minnow and white sucker were the dominant forage and large-bodied fish species in 2016, respectively. The relative proportion of all species captured in 2016 was within the range of previous observations (2009 to 2015), with the exception of white sucker, which comprised a higher proportion (> 2 times) of the species composition compared to previous years. Slimy sculpin and Arctic grayling captures continued to be low, and no finescale dace or burbot were captured in 2016.

Fish Abundance And Production Estimate

A hydroacoustic survey was conducted in 2016 to measure abundance and production of the four most common species in Horizon Lake (fathead minnow, lake chub, longnose sucker, and white sucker). Total production for these four species was 2,731 kg in 2016, with the two sucker species comprising 93% of the total production biomass. Abundance, biomass, production, and production-to-biomass ratio (P:B) in 2016 were all within the range of estimates from the 2014 and 2015 hydroacoustic surveys.

Water Quality

Seasonal in situ profile data from Horizon Lake reflected the effects of regionally warm temperatures and low precipitation during the spring of 2016.

Continuous water temperature data from the thermistor strings showed a thermocline was established in early May and persisted until late September. Average surface water temperature from July to August was 20°C, which decreased to 14°C in September. Daily average temperatures in the deepest portions of the lake gradually increased from May (4.5°C) through September (10.5°C), until lake turnover occurred.

Vertical profiles of pH showed moderate variability through the water column, with values ranging from 5.6 and 8.5 pH remained within water quality guidelines for the protection of aquatic life from spring to fall, but fell below the guideline at all depths during winter sampling; however, a surface composite sample collected during the winter sampling was within the pH range for the protection of aquatic life.

Dissolved oxygen (DO) profiles identified a decline in profundal DO between July and late-August, with near-bottom DO concentrations decreasing to below 2 mg/L at depth in August; however, there was abundant access to well-oxygenated water in the lake at this time, and fish would be expected to simply avoid the low oxygen areas of the lake until fall turnover.

Seasonal and inter-annual variability in key water quality analytes has been relatively low since monitoring began in 2008. The majority of the variability observed is attributable to regular seasonal events like freshet and lake turnover, although inter-annual variability has also been observed in response to specific climatic events, such as the flood conditions during the spring of 2013 and the very dry period that occurred during the spring of 2015. Unlike previous years, there were no substantial seasonal increases observed in metal concentrations (i.e., mercury and aluminum) in the spring of 2016. Analytes that exceeded water quality guidelines in 2016 included total phenols, dissolved copper, and total iron. Phenol and iron exceedances have been observed in the lake in previous years and have been historically common in the Tar River. Overall, most analytes were within historical ranges in 2016, and within relevant water quality guidelines for the protection of aquatic life.

Historically, the lake has generally been classified as an eutrophic system. In 2016, the lake was oligotrophic in winter, mesotrophic in spring, and returned to a eutrophic status from summer through winter 2017. This was the first time the Trophic State Index values have indicated an oligotrophic state since monitoring began in 2008.

Sediment Quality

All metal concentrations in sediments analyzed in 2016 were below applicable interim sediment quality guidelines (ISQG) and probable effects levels (PEL), with the exception of arsenic, which has exceeded in all previous years, and cadmium, which exceeded at two sites in 2016. Exceedances of the arsenic ISQG have also been observed during pre-disturbance monitoring in the Tar River and Calumet River (www.ramp-alberta.org). Hydrocarbon concentrations were below the ISQG, except for Fraction 3 at one site; however, all Fraction 3 concentrations were within the range of historical observations. Concentrations of all PAHs were below ISQG and PEL guidelines in 2016, and well below the Hazard Index threshold.

Plankton

Phytoplankton abundance and biomass in 2016 were within the range of previous years. Simpson's diversity has been relatively consistent since monitoring commenced in 2008, and suggests a moderately diverse community. After a four-year increasing trend, mean annual phytoplankton richness showed a one-year decrease in 2013 before increasing again in 2014 and 2015. Mean richness in 2016 was at the upper end of the range of historical observations.

Cyanobacteria, chrysophytes, and diatoms have consistently been the most abundant taxonomic groups in Horizon Lake since monitoring began in 2008, with cyanobacteria comprising the majority of plankton biomass in the lake from 2008 to 2013, and diatoms contributing a larger proportion of the biomass from 2014 to 2016. Differences in abundance and biomass dominance are the result of differences in cell sizes (i.e., larger taxa which were present in small numbers did not dominate based on abundance, but dominated based on biomass because of their size). Similar to previous years, seasonal peaks in phytoplankton abundance and biomass occurred in the summer of 2016. The dominant phytoplankton group, by abundance and biomass, varied depending on the sampling event.

Zooplankton total abundance was generally higher in 2016 than previous monitoring years. This was due, in part, to the large number of small-bodied rotifers captured. In 2016, spring and summer zooplankton biomass was higher than fall, while total abundance was highest in spring and decreased in summer and fall. The dominant zooplankton group by abundance was Rotifera and by biomass was Rotifera and Cyclopoida.

Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both seasonally and temporally (Findlay and Kling 2001 and Paterson 2002). This natural variability has been observed in phytoplankton and zooplankton taxonomic richness, biomass, abundance, and community composition in Horizon Lake. Zooplankton graze on phytoplankton; therefore, they respond directly to changes in the phytoplankton community. In turn, they can further influence phytoplankton biomass, abundance, and community composition through top-down control (Carpenter and Kitchell 1984).

Benthic Invertebrates

Similar to previous years, total species abundance and richness at the mid-lake and littoral sites were much lower than the near-shore sites in 2016, which was expected given shallower lake regions generally have greater amounts of oxygen, higher habitat heterogeneity, and greater food resources available. Average species richness in the littoral zone was within the range of previous years, while the mid-lake zone was higher than all previous years, and appears to be increasing over time. In the near-shore zone, abundance was within the range of previous observations in 2016, while species richness appears to be increasing over time. Evenness appears to be decreasing over time at all three depths and percent ETO (Ephemeroptera, Trichoptera, and Odonata) has remained low in all sampling years. Density was also lower than previous years at both mid-lake and littoral zones. Overall, benthic invertebrates appear to be moving towards a more balanced and diversified community with a reduced density.

Diptera (true flies, midges, and mosquitoes) were the most abundant taxa at all sites in 2016, followed by *Oligochaeta* (worms); these have been the two most abundant taxa in the lake since it was commissioned in 2008. The presence and abundance of these species was not unexpected, as they are commonly present in shallow lakes.

LESSONS LEARNED

The monitoring strategy for the compensation lake was to evaluate the establishment of the various ecological attributes within the lake for five years following construction, then transition to a focus on the development of fish production in subsequent monitoring years.

The monitoring program has been conducted since the summer of 2008, and the data collected have determined that the lake provides suitable habitat for all life stages of two sucker and six forage fish species and overall production in the lake has exceeded the minimum compensation target of 2,543 kg/year that is required by the Fisheries and Oceans Canada (DFO) Authorization for the Horizon Project. Arctic grayling, a provincially sensitive species, has been documented using the lake for overwintering.

LITERATURE CITED

Carpenter, S.R., Kitchell, J.F. 1984. Plankton community structure and limnetic primary production. Amer Nat 124:159-172.

Findlay, D. L. and H. J. Kling. 1976. A species list and pictorial reference to the phytoplankton of central and northern Canada. Fisheries and Environment Canada, Fisheries and Marine Service, Manuscript Report No. 1503. 619 pp.

Paterson M. 2002. Ecological Monitoring and Assessment Network (EMAN) Protocols for Measuring Biodiversity: Zooplankton in Fresh Waters. Available at: http://www.ec.gc.ca/Publications/7A547B5A-FBD2-42BC-8C6E-98E826F4C9EE%5C FreshwaterMonitoringProtocolZooplanktonFreshwater.pdf. Accessed: March 2015.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants

Principal Investigator: Dan Moats

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Daniel Moats	Hatfield Consultants	Senior Partner		
Cory Bettles	Hatfield Consultants	Fisheries & Aquatics Manager		
Meghan Isaacs	Hatfield Consultants	Environmental Specialist		
Colin Schwindt	Hatfield Consultants	Environmental Specialist		
Aurora Jansen	Hatfield Consultants	Environmental Specialist		
Seumas McGrath	Hatfield Consultants	Environmental Specialist		
Corey Lavin	Hatfield Consultants	Environmental Technician		
Liz Kjikjerkovska	Hatfield Consultants	Environmental Technician		

Tim Poulton	Hatfield Consultants	Environmental Specialist		
Jocelyn Beniuk	Hatfield Consultants	Environmental Specialist		
James Morgan	Hatfield Consultants	Environmental Specialist		
Brian Moore	BioSonics, Inc.	Senior Hydroacoustic Scientist		

Compensation Lake Studies

COSIA Project Number: LJ0260

Research Provider: Golder Associates

Industry Champion: Imperial

Status: Ongoing (started in 2013)

PROJECT SUMMARY

Construction of the Kearl Oil Sands (KOS) Phase I Compensation Lake (Muskeg Lake) was completed in 2010. Monitoring to evaluate the biological development of the lake commenced when the basin was filled in 2013. Muskeg Lake is connected to Kearl Lake via a connector channel. The purpose of Muskeg Lake is to provide permanent compensation for fish habitat impacted by the KOS project and the overarching objective of the study is to evaluate the effectiveness of the constructed lake to support self-sustaining fish populations.

To understand this early biological development of Muskeg Lake, the following parameters are monitored and evaluated:

- Water and sediment quality
- Fish habitat and population
- Benthic invertebrates in littoral and pelagic habitats
- Aquatic vegetation establishment
- Phytoplankton and zooplankton

PROGRESS AND ACHIEVEMENTS

Water quality

Results show that Muskeg Lake was well oxygenated and slightly alkaline in 2017. Concentrations of total suspended solids (TSS) were below the detection limit, with the exception of the September sample concentration, which was higher than the historical range measured in previous monitoring programs. Major ions were in the range of concentrations measured in previous years with the exception of sulphate, which was lower than in previous years. Concentrations of total and dissolved metals, total alkalinity, TDS and nutrients, were generally within the range of concentrations documented in previous years.

Fish and Fish Habitat

Fish sampling, via minnow trapping and gill netting, was conducted in May (spring) and September (late summer) in 2017. A total of nine fish species were captured in 2017. The total number captured (in spring and summer) and average weight (spring) is summarized below:

- Northern pike (*Esox lucius*): 16 (average weight 1173.0 g)
- Longnose sucker (*Catostomus cacatostomus*): 3 (average weight 361.3 g)
- White sucker (*Catostomus commersonii*): 132 (average weight 603.6 g)
- Brook stickleback (*Culaea inconstans*): 3377 (average weight 1.31 g)

- Fathead minnow (*Pimephales promelas*): 15438 (average weight 2.83 g)
- Finescale dace (*Phoxinus neogaeus*): 11231 (average weight 1.57 g)
- Lake chub (*Couesius plumbeus*): 2 (average weight 1.5 g – note this was a late summer catch)
- Northern redbelly dace (*Chrosomus eos*): 1071 (average weight 1.36 g)
- Pearl dace (*Margariscus margarita*): 988 (average weight 5.41 g)

Littoral and pelagic zone habitat data recorded in 2017 included: continuous water temperature, dissolved oxygen, pH and specific conductivity.

Aquatic vegetation

In 2017 the distribution of the aquatic macrophytes in the near shore portion of the littoral zone were mapped. 61 areas of aquatic macrophytes were identified along the shoreline. The vegetation identified included sedges (*Cyperaceae*), sago pondweed (*Potamogeton pectinatus*), cattails (*Typha*), coon tail (*Ceratophyllum demersum*), northern water milfoil (*Myriophyllum exalbescens*) and floating leaf pondweed (*Pontamogeton natans*).

Benthic invertebrate

Data were collected in fall 2017 but sample analysis was not completed at the time of the COSIA Land EPA 2017 Mine Site Reclamation Research Report, so this summarizes the results of the 2016 sampling. Samples were collected from both deep and shallow (littoral) sampling locations. Mean total density of benthic invertebrates was moderate at the littoral sampling location and low at the deep sampling location. Taxonomic richness was high at the littoral sampling location and low at the deep sampling location. Diversity indices were high at both locations. However, evenness was low indicating that although the communities were diverse the distribution of organisms was uneven among the taxa.

At the littoral sampling location, the benthic invertebrate community was dominated by non-biting midges (*Chironomus sp.*) and a genus of mayfly (*Caenis sp.*). They comprised approximately 71% and 13% of the community, respectively.

At the deep sampling location, the benthic invertebrate community was dominated by non-biting midges (*Chironomus sp.*) and a genus of glassworm midges (*Chaoborus sp.*). They comprised approximately 83% and 13% of the community, respectively.

Plankton

Data were collected in fall 2017 but sample analysis was not completed at the time of the COSIA Land EPA 2017 Mine Site Reclamation Research Report, so this summarizes the results of the 2016 sampling. Mean taxonomic richness of zooplankton was found to be 17.7 +-0.9; while that for phytoplankton was found to be 30.3 +-1.2. Total and percent abundance and biomass as well as dominant taxa by biomass were also determined for both phyto- and zooplankton.

Comparisons of results to date have shown that zooplankton mean abundance and biomass have steadily increased year over year (levels recorded in 2016 were the highest to date). Phytoplankton mean abundance and biomass has varied year over year but has generally been similar to previous years (levels recorded in 2016 were slightly lower compared to 2015).

LESSONS LEARNED

A summary of the current level of development and trends for the biological components of the Muskeg Lake based on the monitoring data for the period 2013 – 2017 is highlighted below:

Aquatic macrophyte planting:

- Success of planted pondweed stands has been low to moderate for shallow plantings and nil for deep plantings.
- Bulrush plantings were completely successful (high survival and moderate to high vigor with evidence of spreading).
- Natural colonization of other aquatic vegetation has been observed in the littoral zone and mapping of aquatic vegetation indicate continuing expansion of aquatic macrophytes in the lake.

Plankton (indicator of lake productivity):

- Zooplankton biomass and taxonomic richness has increased annually in Muskeg Lake.
- Muskeg Lake zooplankton biomass was initially much lower than that of Kearl Lake, but 2016 data is > the minimum level in Kearl Lake for the first time.
- Recent taxonomic richness in Muskeg Lake is within the range recorded for Kearl Lake.
- Phytoplankton biomass and richness developed rapidly (unlike zooplankton). By completion and filling of Muskeg Lake in 2013, phytoplankton biomass and richness had already achieved levels similar to lower ranges of Kearl Lake.

Benthic invertebrate communities (indicator of lake productivity and development of the food base for fish):

- Muskeg Lake is providing a strong food base for fish (colonization and development of the benthic invertebrate community in the littoral zone of Muskeg Lake has been rapid, reaching density and richness levels typical of Kearl Lake in less than 2 years of filling).
- The heterogeneous habitat in Muskeg Lake is likely contributing to observable high density and richness (great habitat diversity).

Fish populations:

- The number of fish species captured in Muskeg Lake has steadily been increasing (all fish species present in Kearl Lake have colonized Muskeg Lake).
- Four out of the six forage fish species were on average heavier in Muskeg Lake than Kearl Lake.
- Muskeg Lake is providing secure overwintering habitat for both Muskeg and Kearl Lake fish populations as well as year-round habitat for forage fish, suckers and sport fish.
- Muskeg Lake is providing suitable habitat for large-bodies fish.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates

Principal Investigator: Golder Associates

Fisheries Sustainable Habitat Committee: Refinement of Fish Habitat Pre-Disturbance Models

COSIA Project Number: LJ0225

Research Provider: Hatfield Consultants, Ecofish Research

Industry Champion: Suncor Energy Inc.

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

Status: Year 5 of 5 (final year with 2-year extension)

PROJECT SUMMARY

Developing the oil sands resource in northeast Alberta often results in both temporary and permanent losses of fish and fish habitat. To properly offset those impacts as required by Fisheries Act Authorizations, it is necessary to understand and quantify the level of disturbance using a scientifically defensible and repeatable measurement of habitat. This same approach can then be used to ensure a commensurate offset. The regional habitat suitability index (HSI) models currently in use for this purpose were developed using a combination of scientific literature and expert judgment and have not been regionally validated.

The primary goal of the Fisheries Sustainable Habitat (FiSH) Committee's Refinement of Fish Habitat Pre-Disturbance Models Program (the Program) is to develop a dataset that will allow scientists to refine the existing HSI models to quantify fish habitat in the Athabasca oil sands region in a reliable and scientifically credible manner. The Program has been implemented in two phases. Phase 1 consisted of creating a database of existing fish and fish habitat data collected in support of individual operator programs. Phase 1 provided a synopsis of the information collected to date, which allowed data gaps to be assessed and also identified compatible data that could be used as direct inputs to the process of refining and validating the HSI models. Phase 1 was completed in 2013, and found that individual operators had obtained substantial data for several fish species, but that the information was not sufficient for a number of key fish species, especially commercial, recreational and Aboriginal fishery species. Historically, the various site-specific studies collected data on a limited set of species because the majority of the study areas were located in the upper portion of tributary watersheds, which predominantly consist of small streams and wetland areas.

Phase 2 of the Program involved the design and implementation of a three-year study focused on collecting data for key riverine species. These species had not been captured in sufficient quantities in past years, to facilitate model validation and refinement. Phase 2 aims to meet the following key objectives:

- Collect fish habitat use observations to address the data gaps identified in Phase 1.
- Develop a methodology to integrate data from previous studies into the Phase 2 analysis.
- Assess sample size requirements for model validation.
- Explore relationships in the data that may lead to new suitability indices.
- Develop regionally specific HSI models that are validated with empirical data.
- Satisfy HSI model validation conditions in a number of operator Fisheries Act Authorizations.

PROGRESS AND ACHIEVEMENTS

Fish habitat modeling was completed in the spring of 2016 with a detailed review ongoing. The final product will provide the necessary evidence to refine the HSI models for 14 fish species from the Athabasca oil sands region. The fish species include the priority fish species noted above, two sucker species (longnose sucker and white sucker) and some small-bodied fish species (brook stickleback, finescale dace, fathead minnow, lake chub, pearl dace, slimy sculpin, and troutperch). The analysis uses a model selection and weight-of-evidence approach to identify habitat variables that limit fish abundance. These variables will then be incorporated into a revised HSI model for each species.

LESSONS LEARNED

Using the methods employed, HSI validation on a watershed scale may be possible but not on a regional scale. Work to confirm this emerging outcome will be the focus of the committee's work in 2018.

PRESENTATIONS AND PUBLICATIONS

Technical Report

Hatfield and Ecofish, 2016. Refinement of Fish Habitat Pre-Disturbance Models: Draft Technical Report – Phase 2. Prepared for: CANADA'S OIL SANDS INNOVATION ALLIANCE (COSIA), FISHERIES SUSTAINABLE HABITAT (FiSH) COMMITTEE. *In review*.*

*The draft final report is complete and has been reviewed. However, further analysis is warranted and will be required before the final report is produced.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants[1], Ecofish Research[2]

Principal Investigators: Daniel Moats[1], Dr. Todd Hatfield[2], Dr. Morgan Hocking[2]

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Daniel Moats	Hatfield Consultants	Project Director		
Dr. Todd Hatfield	Ecofish Research	Scientific Advisor		
Dr. Morgan Hocking	Ecofish Research	Modelling Specialist		

Government Collaborators: Fisheries and Oceans Canada, Alberta Environment and Parks

Assessing the Role of Habitat in Determining Age and Growth Relationships of Fish

COSIA Project Number: LJ0170

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 3 of 5

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of the development of a compensation lake (named Wāpan Sākahikan or alternatively, Horizon Lake), which is designed to permanently compensate for fish habitat loss resulting from the development of the Horizon Oil Sands lease. To assess the role of habitat in determining age and growth relationships in fish populations in compensation lakes, such as Horizon Lake, several different approaches have been undertaken including:

- Food web analysis (age structures, blood, liver and muscle tissues; 2016-present)
- Hydroacoustic monitoring (biomass, vegetation, substrate; 2013-present)
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality; 2008-present)

Collecting data within these programs provides further insight into the role of habitat in determining age and growth relationships in fish populations within the Lower Athabasca region. This will have an impact on future compensation lake developments and subsequent management of ongoing projects such as Horizon Lake.

PROGRESS AND ACHIEVEMENTS

IIn May 2016 the project welcomed two graduate students (Michael Terry, Karling Roberts). This allowed the project to be expanded to include sampling on 8 natural lakes within the lower Athabasca region (Goodwin Lake, Steepbank Lake, Wappau Lake, Kirby Lake, Hay Lake, Unnamed Lake 1, Unnamed Lake 2, Unnamed Lake 3). Moreover, a new PhD student joined the project in 2017 (Sebastian Theis), allowing for further expansion of the scope of the project given the data collected.

The students will assist in determining the natural limit of age and growth in relation to habitat and will relate these findings to the design and management of compensation lakes. All of the work completed in 2016 and 2017 was field based.

To summarize, the following progress and achievements were made during the first two field seasons:

- Hydroacoustic, age and tissue collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected in 8 lakes in the lower Athabasca during 3 seasons (spring, summer/fall, and winter; ongoing).
- Hydroacoustic, age and tissue collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected on Horizon Lake (ongoing).

Stable isotope analysis: Age-structured food web analysis

Estimates of fisheries productivity are associated with high levels of uncertainty (Minns, 2015) and provide little information about the structure and functioning of the ecosystem. Food web structure is considered to be an important factor regulating the sustainability and resilience in ecosystems, including primary production, nutrient cycling, and biomass accumulation (Carpenter et al., 2001). Food webs, which are supported by available habitat, can be modelled accurately using stable isotope analysis (SIA) (Parnell et al., 2010). This project will use SIA to model food webs and investigate how food web structure can influence fisheries productivity and ecosystem function in both compensation and natural lakes in the oil sands region of Alberta. Specifically, this includes: 1) modelling food webs in natural and compensation lakes in order to characterize their food web structure; 2) investigate the differences and similarities between the food webs of compensation lakes and natural lakes; and 3) identify whether food web structure confers different fisheries productivities in the northern Boreal region of Alberta, where habitat amount and configuration differs in lakes. All of this will be completed in an age-structured manner, whereby fish populations will be portioned not only by species, but age (juvenile or adult).

SIA uses ratios of carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) isotopes to deduce the composition of an organism's diet (Fry, 2006). In 2016 and 2017, tissue or whole organism samples were collected from primary producers (including attached algae and phytoplankton), invertebrates (including zooplankton, benthic, and terrestrial invertebrates), lower tropic level fish, and piscivorous fishes present in each of the 8 natural lakes and Horizon Lake. Tissue samples (blood plasma, liver and muscle) are now in the process of being prepared and stable isotope ratios will be measured using a continuous flow mass-spectrometry system (Fry, 2006). Subsequent analysis will be conducted using a Bayesian stable isotope mixing model to construct age-structured food webs for each lake. The results will be used to characterize food web interactions within each lake. This will allow the research team to determine where resources are being acquired for species and whether it differs within species defined age classes. *Post hoc* analyses will be used to compare food web interactions, organisms' trophic levels, and trophic niche ellipses among lakes and to investigate relationships between fisheries productivity estimates, lake trophic structure and habitat differences. This portion of the project is currently ongoing, with the final stage of data collection occurring during winter 2018.

Stable isotope analysis: Energetic bottlenecks

The objective is to determine to what degree seasonal variation in resources limits growth in relation to the age of individuals within a population.

Food webs can be modelled accurately using stable isotope analysis (SIA), which is based on a defined trophic level for each species and age class. While traditionally muscle tissue is used to determine trophic level, as it can provide a long-term diet signal, other tissues, such as liver and blood, can provide insight into short-term diets (Matich et al., 2015). Winter is often thought to be an energetically and physiologically difficult season for fish populations to persist and grow (Shuter et al., 2012). We investigate the age-growth relationship of species and link this with seasonal trophic signatures construct ratios of carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) isotopes. This will allow the team to deduce the temporal variability in the composition of an organism's diet (Fry, 2006).

In 2016 and 2017, we collected samples and whole organisms from 8 natural lakes and Horizon Lake (spring/summer 2016, fall 2016, winter 2016, spring/summer 2017, and fall 2017). Sampling is planned on 3 of those natural lakes and Horizon Lake in February/March 2018.

This project will also use SIA to model variability in resources for fish populations and investigate how this variability influences fisheries productivity and ecosystem function in both compensation and natural lakes in the oil sands region of Alberta. This portion of the project is currently ongoing, with collection of data planned for winter 2018. Subsequent processing of samples for carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) isotopes, and data analysis will occur later in 2018.

Hydroacoustic Monitoring

Hydroacoustic units use a series of acoustic pulses to monitor both the biological and physical characteristics of a waterbody to provide an accurate, low-impact alternative for estimating fish abundance (Simmonds & MacLennan, 2005). Furthermore, hydroacoustic data can help to better define habitat-productivity relationships, a current knowledge gap, by providing valuable information on spatial and temporal distributions of fish within a system (Minns et al., 2011). This project will use a combination of hydroacoustics and traditional sampling methods (gill netting) to better define habitat-productivity relationships and determine how lake characteristics may influence age-structured fisheries productivity in natural and compensation lakes.

In 2016 and 2017 acoustic data was collected on 5 natural lakes and Horizon Lake using a Biosonics DTX unit equipped with a 200 kHz split-beam transducer mounted to a survey vessel during a spring (May/June) and summer/fall (August/September/October). All surveys followed recommended guidelines outlined in the standard operating procedures for fisheries acoustic surveys in the Great Lakes (Parker-Stetter et al., 2009). Hydroacoustic data will be analyzed using Echoview software to determine biomass and abundance of fish species in each lake. These results will be compared to direct sampling (i.e., gill netting) to establish species presence and age-growth relationships for the species in each lake. Additionally, productivity will be approximated for each lake using an average production to biomass ratio. Lastly, data collected from Horizon Lake from 2013-2017 will be processed and analyzed to investigate temporal trends in fisheries biomass and productivity. This portion of the project is currently ongoing, with data processing and analysis occurring during 2018.

LESSONS LEARNED

None available for 2017.

LITERATURE CITED

Carpenter SR, Cole JJ, Hodgson JR, Kitchell JF, Pace ML, Bade D, Cottingham KL, Essington TE, Houser JN, and Schindler DE (2001) Trophic cascades, nutrients, and lake productivity: whole-lake experiments. Ecological Monographs 71:163-186

Fry B. (2006) Stable isotope ecology. Springer: New York.

Matich P, Kiszka JJ, Heithaus MR, Mourier J, and Planes S (2015) Short-term shifts of stable isotope (delta C-13, delta N-15) values in juvenile sharks within nursery areas suggest rapid shifts in energy pathways. Journal of Experimental Marine Biology and Ecology 465:83-91

Minns CK (2015) Canadian Fish Habitat Management: Symptoms and Remedies. Pages 213-248 In: Fisher N, Leblanc P, Rose CA and Sadler B, (eds) Managing the Impacts of Human Activities on Fish Habitat: The Governance, Practices and Science. Amer Fisheries Soc, 5410 Grosvenor Lane, Ste 110, Bethesda, Md 20814-2199 USA

Minns CK, Randall RG, Smokorowski KE, Clarke KD, Velez-Espino A, Gregory RS, Courtenay S, and Leblanc P (2011) Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going? Canadian Journal of Fisheries and Aquatic Sciences 68:2204-2227

Parker-Stetter SL, Rudstam LG, Sullivan PJ, and Warner DM. (2009) Standard operating procedures for fisheries acoustic surveys in the great lakes. Great Lakes Fish. Comm. Spec. Pub. 09-01.

Parnell AC, Inger R, Bearhop S, and Jackson AL (2010) Source Partitioning Using Stable Isotopes: Coping with Too Much Variation. Plos One 5:5

Shuter BJ, Finstad AG, Helland IP, Zweimuller I, and Holker F (2012) The role of winter phenology in shaping the ecology of freshwater fish and their sensitivities to climate change. Aquatic Sciences 74:637-657

Simmonds EJ, and Maclennan DN. (2005) Fisheries acoustics. 2nd ed. Oxford: Blackwell Science.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Poesch, M.S., Christensen-Dalsgaard, K.K., Ruppert, J.L.W., Hasler, C.T., Minns, C.K., Cooke, S.J., Lapointe, N., Browne, D., and Mandrak, N.E. Challenges and trade-offs under *Canada's new Fisheries Act*: Should Canada go back to protecting fish habitat? (*In Prep for FACETS*).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark S. Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	M.Sc.	May 2016	December 2018
Karling Roberts	University of Alberta	PhD	May 2016	September 2020
Sebastian Theis	University of Alberta	PhD	September 2017	December 2022
Jonathan Ruppert	University of Alberta	Post-Doctoral Researcher		

Research Collaborators: Department of Fisheries and Oceans Canada

Assessing the Productive Capacity of Compensation Lakes

COSIA Project Number: LJ0171

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 3 of 5

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of the development of a compensation lake (Wāpan Sākahikan / Horizon Lake), which is designed to permanently compensate for fish habitat loss resulting from the development of the Horizon Oil sands. To assess the productive capacity of fish populations in compensation lakes, such as Horizon Lake, several different approaches have been undertaken including:

- Hydroacoustic monitoring (2013-present)
- Analysis of blood metabolites in fish populations to determine energetic bottlenecks (2016-present)
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) and analysis (2008-present)

Implementation of these approaches will provide further insight into the sustained productive capacity of compensation lakes. This could have an impact on future compensation lake developments and its subsequent management.

PROGRESS AND ACHIEVEMENTS

In May 2016 the project welcomed two graduate students (Michael Terry and Karling Roberts). This allowed the project to be expanded to include sampling to assess the relationship between habitat and age-growth relationships in natural and compensation lakes, on 8 natural lakes within the lower Athabasca region (Goodwin Lake, Steepbank Lake, Wappau Lake, Kirby Lake, Hay Lake, Unnamed lake 1, Unnamed Lake 2, Unnamed Lake 3) Moreover, a new PhD student joined the project in 2017 (Sebastian Theis) allowing further expansion to the scope of the project.

The students will assist in determining the natural limit of productive capacity in lakes for the study region, while relating these findings to the design and management of compensation lakes. All of the work completed in 2016 and 2017 was field based.

Historical data available from Horizon Lake (Wāpan Sākahikan; 2008-2015) has provided an opportunity to understand what processes are contributing to fish population productivity during its initial establishment, which in turn can provide insight into the sustained productive capacity of fisheries in the lake. Moreover, fish community datasets from both broad scale (global) and regional (Alberta) data repositories provide opportunities to investigate the relationship between project compliance and ecosystem function and fish community assembly processes.

To summarize, the following progress and achievements were made during 2017:

- Hydroacoustic, blood collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) was collected on 8 lakes in the lower Athabasca during 3 seasons (spring, summer/fall, and winter; ongoing)
- Hydroacoustic, blood collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) was collected on Horizon Lake (ongoing)

- Analysis of historical fish population and invertebrate data from Horizon Lake is complete
- Collection of global habitat offsetting data is complete and analysis of data is ongoing
- Collection of fish community assembly data sets (ongoing)

Hydroacoustic Monitoring

Metrics of fisheries productivity currently rely on extensive fish sampling. However, new advancements in hydroacoustic technology can reduce the effort required to sample fish communities (Simmonds & MacLennan, 2005). Hydroacoustic units use a series of acoustic pulses to monitor both the biological and physical characteristics of a waterbody to provide an accurate, low-impact alternative for estimating fish abundance. Furthermore, hydroacoustic data can help to better define habitat-productivity relationships, a current knowledge gap, by providing valuable information on spatial and temporal distributions of fish within a system (Minns et al., 2011).

This project will use a combination of hydroacoustics and traditional sampling methods to: 1) establish natural ranges of productivity throughout lakes in the oil sands region and 2) determine how lake characteristics may influence fisheries productivity in natural and compensation lakes.

In 2016 and 2017 acoustic data was collected on 5 natural lakes and Horizon Lake using a Biosonics DTX unit equipped with a 200 kHz split-beam transducer mounted to a survey vessel during a spring (May/June) and summer/fall (August/September/October). All surveys followed recommended guidelines outlined in the standard operating procedures for fisheries acoustic surveys in the Great Lakes (Parker-Stetter et al., 2009). Hydroacoustic data will be analyzed using Echoview software to determine biomass and abundance of fish species in each lake therefore providing baselines of productive capacity of natural and compensation lake ecosystems. While data collection is now complete, processing of data is ongoing and analysis of data will be forthcoming throughout 2018.

Energetic Bottlenecks

Winter kill is a common phenomenon in Alberta lakes and is a good example (at the extreme end) of how productivity can be limited through what is often thought to be an energetically and physiologically difficult season for fish populations to persist and grow (Shuter et al., 2012). To understand how seasonal variation in resources and environmental conditions available to fish populations may impact the productive capacity of compensation and natural lakes within the boreal region of Alberta, in 2016, 2017 and 2018 we are collecting and analyzing blood samples from fish populations in Horizon Lake and 5 natural lakes in the lower Athabasca region. We plan to sample 3 of natural lakes and Horizon Lake in February/March 2018. Doing so can provide levels of metabolites and glucose that are a cue for the amount of stress experienced by fish populations (which can come about when competition is high and resources are scarce) (Cooke et al., 2008).

We used an iSTAT handheld and an over the counter glucose meter to measure the amount of glucose, lactate and partial pressures of oxygen and carbon dioxide within the blood sample. Moreover, plasma samples are currently being processed for metabolites (or electrolytes) using Inductively Coupled Plasma (ICP) mass spectrometry. This data will help to address: (1) if seasonal stress, such as limited resources in winter, may influence the productive capacity of northern boreal lakes and compensation lakes and (2) if specific habitat features (e.g., depth) may impact the degree of stress experienced by fish populations. Understanding the key factors that contribute to limit the productive capacities of lakes within the boreal region will help to develop better compensation lake designs and ultimately confer higher levels of productivity in habitat offsets. This portion of the project is currently ongoing, with collection of data, processing of samples and analysis occurring in 2018.

Historical Analysis

In 2016 we used long-term (2008-2015) data set of fish populations and benthic invertebrates from Canada's first compensation lake in the oil sands region of Northern Alberta, Horizon Lake, to address: (1) how fish community structure changes through time, (2) whether there is a similar assembly between fish and invertebrate communities, and (3) we compare the fish assemblage in Horizon Lake to those found in natural lakes within the lower Athabasca region. These findings were summarized in a manuscript that has been submitted to a peer-review journal but not yet approved for publication (expected 2018).

There are many uncertainties with habitat offsetting, including the relationship between project compliance and ecosystem function alongside the processes that contribute to fish community assembly (Minns, 2015). Both global and regional data sets can provide spatial and temporal variability to explore these relationships and processes, which ultimately influence the overall productive capacity of a habitat offset.

Using these data sets we plan to:

1. Determine if there is any relationship between compliance and function for offsetting projects;
2. Assess whether there are any trends across regions, scale of the project, project targets, type of method used for offsetting and ecosystems types in terms of compliance and function for projects; and
3. Determine if there are any general paradigms regarding the assembly and maintenance of fish communities in the lower Athabasca region.

Addressing these objectives will aid in our ability to achieve sustainable productive capacity management targets for habitat offsets. Data has been collected during 2017 and will continue to be collected throughout 2018. Subsequent processing and analysis is expected during 2018.

LESSONS LEARNED

In 2016 and 2017 we completed historical analysis and developed a manuscript detailing how the fish community is significantly changing through time. We find that there is no significant concordance between fish and benthic invertebrate communities (i.e., they are not changing in the same manner). Additionally, the assemblage and composition of fish species in the compensation lake is unique compared to other surveyed lakes within the lower Athabasca region. Although new lakes are expected to be different from natural lakes, these results suggest that to increase overall productive capacity, introducing large-bodied predators into the lake would help to ensure sustainable productive capacity of commercial, recreational and Aboriginal fisheries. We also highlight the need for better regional data to assess fisheries productive capacities of boreal lakes and the need to establish the role of habitat in determining age-growth relationships to ensure long-term sustained no net loss in fisheries productivity. This manuscript has gone through the revision process and is expected to be published and available in January 2018.

LITERATURE CITED

Cooke SJ, Suski CD, Danylchuk SE, Danylchuk AJ, Donaldson MR, Pullen C, Bulté G, O'toole A, Murchie KJ, Koppelman JB, Shultz AD, Brooks E, and Goldberg TL (2008) Effects of different capture techniques on the physiological condition of bonefish Albula vulpes evaluated using field diagnostic tools. Journal of Fish Biology 73:1351-1375

Minns CK (2015) Canadian Fish Habitat Management: Symptoms and Remedies. Pages 213-248 In: Fisher N, Leblanc P, Rose CA and Sadler B, (eds) Managing the Impacts of Human Activities on Fish Habitat: The Governance, Practices and Science. Amer Fisheries Soc, 5410 Grosvenor Lane, Ste 110, Bethesda, Md 20814-2199 USA

Minns CK, Randall RG, Smokorowski KE, Clarke KD, Velez-Espino A, Gregory RS, Courtenay S, and Leblanc P (2011) Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going? Canadian Journal of Fisheries and Aquatic Sciences 68:2204-2227

Parker-Stetter SL, Rudstam LG, Sullivan PJ, and Warner DM. (2009) Standard operating procedures for fisheries acoustic surveys in the great lakes. Great Lakes Fish. Comm. Spec. Pub. 09-01.

Shuter BJ, Finstad AG, Helland IP, Zweimuller I, and Holker F (2012) The role of winter phenology in shaping the ecology of freshwater fish and their sensitivities to climate change. Aquatic Sciences 74:637-657

Simmonds EJ, and Maclennan DN. (2005) Fisheries acoustics. 2nd ed. Oxford: Blackwell Science.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Terry, M.W., J.L.W. Ruppert, J. Hogg, and M.S. Poesch (2017). Using Hydroacoustics to evaluate fisheries productivity and habitat complexity in northern Alberta lakes. Mobile Hydroacoustics Workshop. June 2017 (Poster Presentation).

Roberts, K., J.L.W. Ruppert, and M.S. Poesch (2017). Choosing an effective reference for the design and evaluation of compensation lakes. Northern Research Day. March 2017 (Oral Presentation).

Roberts, K., J.L.W. Ruppert, and M.S. Poesch (2017). Fish Community Composition in Compensation and Natural Lakes in the Alberta Oil Sands. Forest Industry Lecture Series. March 2017 (Poster presentation).

Terry, M.W., J.L.W. Ruppert, J. Hogg, and M.S. Poesch (2017). Using Hydroacoustics to evaluate fisheries productivity and habitat complexity in northern Alberta lakes. Forest Industry Lecture Series. March 2017 (Poster Presentation).

Terry, M.W., J.L.W. Ruppert, J. Hogg, and M.S. Poesch (2017). Using Hydroacoustics to evaluate fisheries productivity and habitat complexity in northern Alberta lakes. Northern Research Day. March 2017 (Poster Presentation).

Roberts, K., J.L.W. Ruppert, and M.S. Poesch (2017). The fish community of a compensation lake differs from natural lakes in the Alberta oil sands. Agriculture, Life, and Environmental Science Graduate Research Symposium. February 2017 (Oral presentation).

Ruppert, J.L.W. (2017). Habitat offsetting for freshwater fisheries in Canada. University of Alberta, Department of Renewable Resources Seminar. February 2017 (Oral presentation).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	M.Sc.	2016	2018
Karling Roberts	University of Alberta	PhD	2016	2020
Sebastian Theis	University of Alberta	PhD	2017	2022
Jonathan Ruppert	University of Alberta	Post-Doctoral Researcher		

Research Collaborators: Department of Fisheries and Oceans Canada

Soils and Reclamation Materials

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 2 of 6

PROJECT SUMMARY

An important part of mine site reclamation is the salvage and storage of upland surface and subsurface soils. Salvaged soils need to be stockpiled for long periods of time until final placement in the reclaimed landscape occurs and during this storage time biogeochemical transformations can alter physical, chemical and biological properties of the soils relative to the pre-disturbance conditions or undisturbed forest ecosystems.

Current regulations stipulate that a/b surface soil (ABSS) and d/other surface soil (OSS) must be stockpiled separately to preserve soil texture and other soil qualities and to maintain separate and distinct seed banks. Recent research, however, suggests that plant propagules at depth in large stockpiles do not retain their viability in stockpiles. Storing ABSS and OSS separately is also very costly and requires more space than if combined in one stockpile.

The purpose of this research project is to determine whether ABSS and OSS can be co-mixed in the same pile without negatively affecting soil chemical and physical properties, or the potential for establishing and maintaining targeted future vegetation communities. Soil quality parameters as well as vegetation will be monitored for at least 6 years in duplicate mixed and unmixed stockpiles (Stockpile ABSS; Stockpile OSS; Stockpile ABSS + OSS).

PROGRESS AND ACHIEVEMENTS

Soil Monitoring:

Monthly soil monitoring for Year 1 (2017) was conducted May through August for the six stockpiles. Three randomly selected sites from the stockpile plateau areas were selected. Using a Morooka drill, soils were sampled at 0.5 m, 2.0 m, and 4.0 m depths, and were composited by depth to yield one bulk sample per depth, per stockpile. After a preliminary review of results in June 2017, monthly sampling was increased to five sites per pile to reduce variability (July and August sampling). The annual sampling protocol replaced the monthly sampling protocol for the month of September. Samples were analysed for physical and chemical properties, fertility parameters, and available nutrients.

While results from the Year 0 (2016) assessment showed changes in most parameters in the month between September (stockpile construction) and October, there was very little monthly variability in soil quality parameters observed in 2017. The change in 2016 was attributed to admixing of surface soil with upper subsoil during soil salvage and stockpiling.

The following is a summary of the 2017 annual monitoring results:

- pH measured at the Mid (2.0 m) and Low (4.0 m) sampling depths at MIXED stockpiles was significantly lower than at the surface of OSS stockpiles.

- Electric conductivity (EC) varied with soil type with the highest values occurring in the MIXED stockpiles, and both EC and the sodium adsorption ratio (SAR) varied with sampling depth with EC increasing and the SAR decreasing with depth. Average EC values exceeded 2.0 dS/m at the Mid (2.0 m) and Low (4.0 m) sampling depths for MIXED stockpiles, and at the Low (4.0 m) sampling depth for OSS stockpiles; average EC remained at or below 2.0 dS/m at all sampling depths for ABSS stockpiles.
- Significant variation with sampling depth was observed for percent sand, percent clay, soluble Ca, soluble Mg, soluble K, soluble Na, TOC (Total Organic Carbon), available P, available K, and available SO_4-S. Subsequent assessments will provide important insight into whether these trends are important, or if they simply reflect variation in the data.
- TOC was dependent on soil type with the highest values observed in samples collected from the MIXED stockpiles.
- Total Kjeldahl Nitrogen (TKN) and Bulk density was not affected by soil type or sampling depth.

Comparing Year 0 (2016) and Year 1 (2017) annual assessments:

- Average pH values remained unchanged at an average of 5.71.
- Average EC increased (from 0.48 dS/m to 1.47 dS/m) and the SAR decreased slightly (from 0.21 to 0.19).
- Average TOC decreased (decreased from 2.15% to 1.59%) and average TKN increased (increased from 915.72 mg/kg to 1060.19 mg/kg).
- Bulk density did not change.

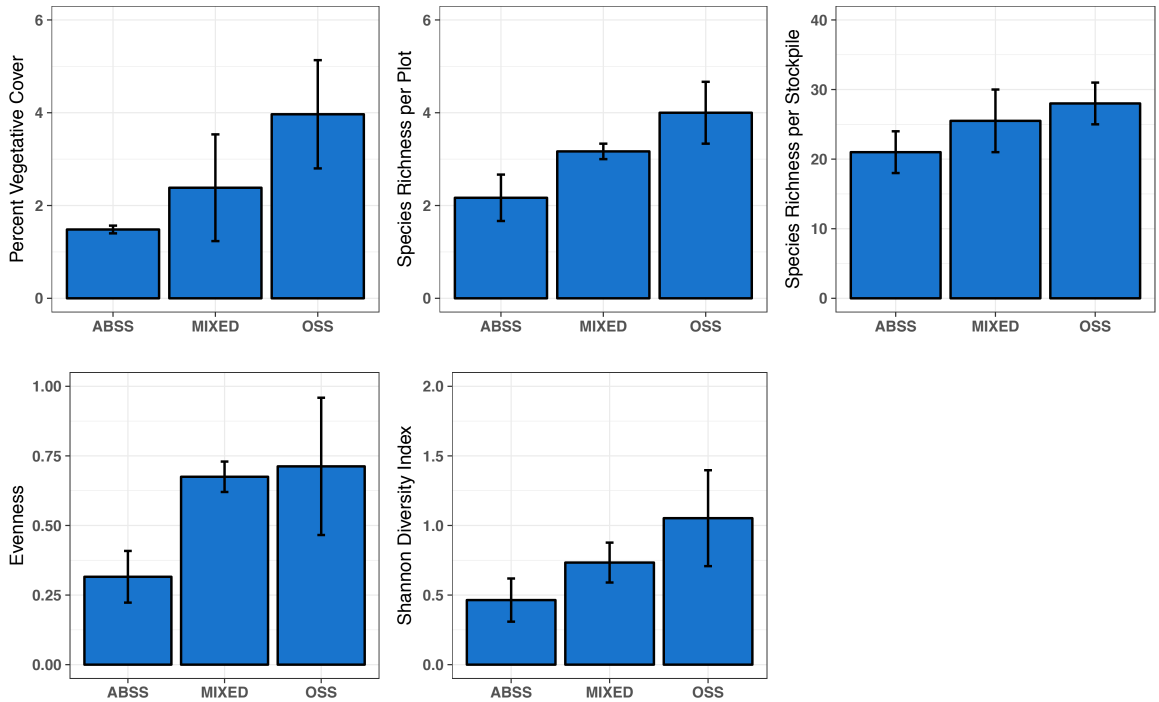
Vegetation Monitoring:

Vegetation monitoring for the Trial was initiated in July 2017 (Year 1). Three 0.5 x 1.0 metre (m) plots were established in diagonal transects along the plateau of each stockpile. Percent cover of vegetation, leaf litter, and bare ground were recorded and used to calculate key vegetation performance parameters. A larger survey of each stockpile was also completed; any species observed on the six stockpiles that were not captured in the vegetation plots were recorded, resulting in a value of true species richness on each stockpile.

None of the performance parameters measured was dependent on soil type in this first year. Vegetation cover estimates were only made on stockpile plateaus. Natural ingress of vegetation on the side slopes of the stockpiles was visibly greater and more diverse than on the plateaus. It should be noted that traffic from the Morooka drill and field crews used for soil sampling was significant over the summer on these plateaus. Average species richness was 3.10 species per plot on stockpile plateaus, and an average 24.83 species when the entire stockpile was assessed. In 2018, only annual sampling (Sept) will be conducted so it is possible that with reduced traffic, vegetation cover will spread on the stockpile plateaus.

Diversity (SDI < 1.5) and evenness (< 0.5) are considered low in the vegetation assessment plots in Year 1 (2017).

Vegetation Performance Parameters for ABSS, OSS, and MIXED Soil Types is shown below.



LESSONS LEARNED

Since this project is in early stages there are currently no lessons learned.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and & Environmental Consulting Inc.

Principal Investigator: Brittany Flemming

Nutrient Biogeochemistry 2: Tracking Nutrient Fluxes Through Reconstructed Soils

COSIA Project Number: LJ0120

Research Provider: University of Alberta, University of British Columbia

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 7 of 8 (contract was amended in 2017)

PROJECT SUMMARY

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

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

- **Objective 1.** How does the addition of fresh litter and forest floor materials interact with peat or peat-mineral mix coversoil, and does this result in a cumulative or a synergistic effect?
- **Objective 2.** How does forest floor development in reclaimed soils compare to naturally disturbed (fire) soils, and how does this influence nutrient availability?
- **Objective 3.** Does litter decompose via the same pathways in reconstructed soils as it does in natural soils, and are the carbon (C) and nitrogen (N) fluxes from the litter to the soil organic pools comparable?
- **Objective 4.** Does forest floor development and soil organic matter accumulation at the reclaimed sites occur faster under planted aspen than under spruce, and is it related to populations and activities of soil fauna?
- **Objective 5.** How does the spatial variability in aboveground vegetation and forest floor, as well as below ground nutrient availability, microbial ecology and enzyme activities, 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 studies of the first six objectives are combined and further analyzed so that a mechanistic model of C and N fluxes in reclaimed soils can be developed.

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements from the work conducted under Objectives 3 and 4. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for other objectives.

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

M.Sc. student (Cassandra McKenzie) characterized microbial communities at a range of natural aspen and spruce sites and a chronosequence of reclaimed sites (8–31 years). Phospholipid fatty acid (PLFA) and multiple substrate induced respiration (MSIR) analyses were used to characterize total microbial biomass, and the structure and function of forest floor microbial communities under trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) dominated stands that were growing on reconstructed soils following surface mining.

The first objective of Cassandra's study was to assess the importance of time-since-reclamation on microbial recovery by comparing forest floor microbial communities in reclaimed stands to their mature undisturbed counterparts. Microbial biomass (total PLFAs nmol g^{-1}) did not show any clear relationship with time-since-reclamation. There was however, an increase in total respiration (µg CO_2-C g^{-1} hr^{-1}) from young to old reclaimed sites where levels became comparable to natural forest floors. These results indicate that while the size of the microbial communities did not follow any clear pattern, the activity of the microbial community reached levels comparable to natural forest floors 30 years following reclamation.

The second objective of Cassandra's study was to assess the effect of different soil materials on microbial biomass, and community structure and function. The forest floor materials, regardless of whether they were sampled from the reclaimed sites or the natural forests exhibited a greater microbial biomass and higher respiration response to substrate addition than the peat-based materials.

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

Brittany McAdams (M.Sc. student) characterized soil mite communities at a chronosequence of 20 reclaimed and natural sites (same sites as the ones that Cassandra McKenzie conducted her M.Sc. study for Objective 3 above). Specifically, Brittany quantified richness, abundance, and diversity of the mite communities.

The best predictor of oribatid mite richness, and a better predictor than time-since-reclamation, was the thickness of the forest floor accumulating on top of the peat coversoil at the reclaimed sites. A forest floor with a thickness ≥ 2 cm significantly increased oribatid mite abundance to levels slightly higher than those found in forest floors of natural, undisturbed stands. Species richness in the (≥ 2-cm thick) forest floor within reclaimed stands was slightly less than within natural stands but was notably higher than in the peat-based reclamation materials. Assemblage diversity followed the same trend as species richness where a forest floor with a thickness ≥ 2 cm was the most similar to natural stands.

While abundance, richness, and diversity of mite communities are recovering in forest floors developing at the reclaimed sites, the mite species present were different from those found in mature natural forest floors. Hence, continued monitoring is important to see whether species composition becomes more similar to natural forest floors as the reclaimed forested stands continue to develop.

LESSONS LEARNED

Below are some key outcomes derived from the work conducted under Objectives 3 and 4. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for outcomes under other objectives.

- Microbial biomass and activity (respiration) within the forest floor developing at the reclaimed sites recovered to levels comparable to natural stands within 30 years of reclamation.
- The most influential factor to oribatid mite recovery at the reclaimed sites was the development of a forest floor on top of the peat or peat-mineral mix coversoil.
- Reclaimed stands planted to high densities of aspen were more successful in forming a forest floor than white spruce, which may result in faster recovery for soil microbial and faunal communities.

PRESENTATIONS AND PUBLICATIONS

Published Theses:

Brittany McAdams. 2017. Oribatid mite communities after ecosystem disturbance in Alberta. Edmonton, AB. 156 pages.

Cassandra McKenzie. 2017. Soil microbial communities in northern Alberta's boreal forest floors following resource extraction. M.Sc. Thesis. Department of Renewable Resources, University of Alberta. Edmonton, AB. 156 pages.

RESEARCH TEAM AND COLLABORATORS

Institutions: University of Alberta and University of British Columbia

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

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Preston Sorenson	University of Alberta	M.Sc.	2008	2011
Tyrel Hemsley	University of Alberta	M.Sc.	2009	2012
Aria Hahn	University of Alberta	M.Sc.	2009	2012
Mark Beasse	University of Alberta	M.Sc.	2009	2012
Charlotte Norris	University of Alberta	PhD	2009	2013
Jill Martin	University of Alberta	M.Sc.	2010	2015
Emily Lloret	University of Alberta	PDF	2011	2013
Sanatan Das Gupta	University of Alberta	PhD	2011	2015
Jeff Anderson	University of British Columbia	M.Sc.	2011	2014
Meghan Laidlaw	University of British Columbia	M.Sc.	2012	2015
Mathew Swallow	University of Alberta	PDF	2012	2014
Jacynthe Masse	University of British Columbia	PhD	2011	2016
Nilusha Welegedara	University of Alberta	PhD	2013	2018
Brittany McAdams	University of Alberta	M.Sc.	2015	2017
Cassandra McKenzie	University of Alberta	M.Sc.	2015	2017

Potential Limitations of Stockpiled Soils – A Case Study

COSIA Project Number: LJ0300

Research Provider: Canadian Forest Service, University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 3

PROJECT SUMMARY

It is a widely held belief within the Oil Sands Industry, that Upland Surface Soil (i.e., topsoil) is the preferential coversoil to be salvaged and used in reclamation activities. However, most of the data that supports this assumption is derived from directly placed topsoil material. The effect that stockpiling has on the quality of topsoil has not been extensively researched and is not well understood. The limited research that has been conducted indicates that soil quality in the stockpile degrades over time.

The goal of this study is to gather data from a reclaimed area that has been reconstructed using stockpiled upland surface soil and peat. The data will be gathered over the first few years of development. Field studies will be used to determine the operational potential of stockpiled coversoils in comparison to direct placed soils on the plant community. In addition, a greenhouse level study will be used to compare the potential of stockpiled versus direct placed soil to regenerate the seed/propagule bank.

Some of the specific questions to be answered with this project include:

1. What is the plant community potential of stockpiled coversoils in relation to direct placed soils?
2. Does initial soil compaction limit plant community establishment and are the de-compaction treatments successful?
3. Is soil from within the stockpile (i.e. greater than 10 or 30 cm from the outer surface of the stockpile) viable for plant regeneration both as a propagule source and as a plant growth medium?

The outcomes from this study are expected to lead to a better understanding of the impacts of using stockpiled soils for reclamation and help in the development of operational reclamation practices that can be implemented to reduce these potential impacts.

PROGRESS AND ACHIEVEMENTS

Seedbank

Greenhouse germination studies were conducted on field-collected soils. These stockpiled soils contained forest floor mineral mix soil. It was found that there is significantly greater species richness and plant abundance in the seedbank at the surface (<10 cm) compared to deeper (>30 cm) soil.

The seedbank of the directly placed soil, in the final reclamation site, is not significantly different from the deep stockpile soil, used in the greenhouse study, in terms of species richness and plant abundance.

Stockpiled vs directly placed reclamation soil

White spruce trees, which had been planted among other species (black spruce, jack pine), were studied in areas reclaimed in 2016. Areas featuring directly placed soil were composed of either upland forest floor soil mineral mix soil, or peat-mineral mix, or a combination of both. The reclamation areas constructed of stockpiled soils contained forest floor mineral mix soil. Soil had been stockpiled for four years prior to its use in 2016. Data on soil physical (bulk density, soil strength, and volumetric water content), chemical (nutrient supply rates, pH, EC) properties and site vegetation is currently being analyzed.

LESSONS LEARNED

Initial findings after the first year of study include:

- Surprisingly, white spruce survival was similar across all treatments; i.e. early post-planting tree survival did not differ between stockpiled and directly placed soil. This is notable since it had appeared that stockpiled soil resulted in very high mortality (~40%). It appears that many trees that were assumed to have been declining or died had recovered after the first year.
- Natural establishment of trembling aspen and other deciduous trees was significantly greater on directly placed soil, in particular peat-mineral mix. In fact, there were no naturally established trees in any of the stockpiled soil plots. These findings on directly placed reclamation areas corroborate previous research at Horizon reclamation areas. However, the complete lack of tree establishment on stockpiled soils is notable and will require future management.
- Forest floor-mineral mix soil had the greatest cover of native forbs, followed by the stockpiled soils and then peat-mineral mix. These findings also corroborate previous plant community research at Horizon.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications to report for 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service, University of Alberta

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Brad Pinno	University of Alberta	Assistant Professor		
Edith Li	Canadian Forest Service	Research Technician		
Sophia Yang	Canadian Forest Services/ University of British Columbia	Student Intern (BSc)	Jan 1, 2017	2020
Chris Wohl	Canadian Forest Services/ University of British Columbia	Student Intern (BSc)	Jan 1, 2017	2018

* Dates shown are project start dates for the students, not degree start dates.

The GERI (Genomics Enhanced Reclamation Index) Stockpile Project: Creating Ecologically Viable Soil Stockpiles for Future Reclamation

COSIA Project Number: LJ0299

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 3

PROJECT SUMMARY

Although direct placement of salvaged soil on a reclamation site is the preferred mechanism for land reclamation, in some cases this approach is not possible. On these occasions, soil must be stockpiled, in some cases for years or even decades prior to placement for reclamation. It is unclear what impact soil stockpiling has on soil health and utility as a future reclamation substrate, although anecdotal evidence indicates that the health of stockpiled soil declines over time, including impacts on physical, chemical, and biological parameters. This uncertainty could lead to increased costs for reclamation.

This project seeks to answer two main research questions:

1. Does stockpiled soil contribute to healthy, functioning ecosystems over time? Will these stored soils require enhancement prior to placement for reclamation? If so, what enhancements will be required?
2. In reclaimed ecosystems, can below ground ecosystem parameters be linked to above-ground ecosystem parameters for a more complete indication of ecosystem health? Importantly, will it be possible to develop this information into a more rapid assessment of ecosystem health (and reclamation trajectory) than is currently used?

To address these questions, this project will assess soil physical, chemical, and biological parameters as well as above ground plant parameters, in operational stockpiles. Cutting edge genomic tools will be used to link above ground and below-ground parameters to obtain a better assessment of soil health.

This project represents the first phase of a larger study investigating soil stockpile health. This phase seeks to understand the ecosystem dynamics present within and between stockpiles. A second, future phase of the project would investigate approaches to maximize soil stockpile viability for reclamation, based on findings in this first phase.

The primary value of this work is the confidence that it could give operators in understanding how to approach their stockpiled assets in the future, and the development of tools for assessing soil health that are more directly relevant to reclamation practices than current methods.

PROGRESS AND ACHIEVEMENTS

In August 2017, stockpiles were surveyed at the Canadian Natural Horizon lease to understand how to approach a sampling scheme for the forthcoming primary field sampling (summer 2018). To optimize sample design, sampling protocols, and lab-based methodology for stockpiles, one stockpile was sampled and an overall scheme for stockpile sampling was developed. Specifically, three blocks selected based on vegetation cover type were sampled. On this stockpile, three main vegetation cover types were identified: wheatgrass (dominated by the slender wheatgrass [*Agropyron trachycaulum*]); clover (dominated by the sweet clover [*Melilotus sp.*] and alsike clover [*Trifolium hybridum*]); and sowthistle (dominated by the sow thistle [*Sonchus arvensis*], along with fireweed [*Chamerion angustifolium*]). This stockpile had not been seeded with a grass seed mixture. For each block, three sites were sampled along a near linear profile, approximately 10 m apart. Soils were collected from several depths for detailed analysis (see Table for details).

In 2018, approximately six stockpiles will be sampled, with at least 3 sites per vegetation block on each stockpile. This project began in 2017 and will be completed by the end of 2019 (see Table).

Table 1 – Timeline and Sampling Strategy

	2017	2018	2019
Main goal	Protocol development, site identification	Primary sampling; above-ground and below-ground analyses	Complete analyses; follow up sampling; model development
Sampling depths	0-10cm; 10-30cm; 30-100 cm	0-10cm; 10-30cm; 1 m; 3 m	N/A
Sites	1	6	0
Samples per site	9	Unknown (3 per vegetation block)	0
Soil parameters	• Microbial community analyses (functional diversity, community richness, community evenness, community composition) • General soil parameters (pH, EC, total C, total N, nutrients, CEC, texture) • Organic matter quality • Bulk density • Field capacity	• Microbial community analyses • General soil parameters • Organic matter quality • Residual organic matter stability • Release of bioavailable nutrients • Bulk density • Field capacity • In situ soil temperature profiles • Pore size distribution	• Complete analysis on 2018 samples • Biodiversity intactness modelling
Plant parameters	• Species abundance • Community richness • Community evenness • Coverage	• Species abundance • Community richness • Community evenness • Coverage • Seed bank quality and quantity • Above-ground, litterfall, and root biomass	• Complete analysis on 2018 samples • Biodiversity intactness modelling

Samples taken in 2017 are currently being analyzed. This initial analysis is expected to be completed prior to the 2018 field season.

LESSONS LEARNED

This project is in its initial stages and thus there are no emerging outcomes or lessons learned for 2017.

PRESENTATIONS AND PUBLICATIONS

There were no publications or presentations in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Brian Lanoil

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Sylvie Quideau	University of Alberta	Professor		
Brad Pinno	University of Alberta	Assistant Professor		
Miles Dyck	University of Alberta	Professor		
M. Derek MacKenzie	University of Alberta	Associate Professor		
Helena Magaldi Ribiero	University of Alberta	M.Sc.	2017	2018

Reclamation Soils Index of Biological Integrity (IBI)

COSIA Project Number: LJ0296

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 3

PROJECT SUMMARY

Microorganisms and soil arthropod communities play important roles in soil nutrient and carbon cycling and underlie most soil biogeochemical and soil health processes. They are also highly responsive to changes in the soil environment, adjusting types and levels of activity as well as community composition/biodiversity. As such, they may be optimal markers for soil function in disturbed ecosystems, such as those found in oil sands mines. Our research question for this project is: Can soil arthropod and microbial biodiversity be used to assess soil function in reclamation areas?

The objective of this study is:

1) To examine the biological implications of soil chemistry in the upland subsoil-surface soil column across a range of sites (both disturbed [reclaimed and clearcut], and undisturbed) on the Horizon lease. The objective will be achieved by:

- Testing upland subsoil for chemical suitability parameters (pH, EC, SAR), while simultaneously examining soil nutrients from the upland surface soil in the soil column.
- Examining the community structure of soil microorganisms and arthropods in the upland surface soil of the soil column.
- Using these data to develop a Soils Index of Biological Integrity (if possible) that may be used to further understand how soil health can be measured and understood in the context of reclamation. The Soils IBI will be further refined and tested with data as new reclamation comes online, and will be used as a tool to monitor reclamation progress and success.

PROGRESS AND ACHIEVEMENTS

Fifty sites were sampled across Canadian Natural's Horizon lease in the summer of 2017. These sample locations consisted of natural undisturbed sites and represented natural, reference d-ecosites according to the Environmental Impact Assessment that was conducted on Canadian Natural's lease (Beckingham, Archibald, & Northern Forestry Centre, 1996).

Upland surface soils were analyzed for nutrient and chemical composition along with microbial and arthropod communities. The subsoil material were also sampled to a depth of 50 cm and analyzed for salinity parameters. Chemical analyses of all samples have been completed, along with the arthropod analyses. The microbial analyses will not be complete until 2018.

LESSONS LEARNED

Soil chemistry, arthropod, and microbial community data will be analyzed together once the microbial analyses are complete. There are no lessons learned from the data thus far.

LITERATURE CITED

Beckingham, J. D., Archibald, J. H., & Northern Forestry Centre (Canada). (1996). *Field guide to ecosites of northern Alberta*. Edmonton: Northern Forestry Centre.

PRESENTATIONS AND PUBLICATIONS

No presentations of publications for public release in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Brian Lanoil

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Brian Lanoil	University of Alberta	Associate Professor		
Dr. Jeff Batigelli	University of Alberta	Researcher		
Dr. Derek MacKenzie	University of Alberta	Assistant Professor		

Lean Oil Sand Soil Capping Synthesis and Risk Assessment

COSIA Project Number: LJ0305

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial

Status: Year 1 of 2

PROJECT SUMMARY

Some geologic formations in the oil sands mine region contain an appreciable amount of naturally-occurring petroleum hydrocarbons (NPHCs). Mine overburden material containing these petroleum hydrocarbons is sometimes referred to as lean oil sands (LOS).

Although the petroleum hydrocarbons in LOS are naturally occurring, uncertainty exists regarding their risk to the environment when they are disturbed and relocated to new positions in closure landscapes. Prior to mining, geologic formations containing NPHCs are in a relatively stable state in the environment and in most cases several meters below the soil solum or rooting zone. However, in the process of salvage and transport the formation is removed and transported to another location in mine site where an overburden landform is constructed and reclaimed. This results in NHPCs directly below the soil reclamation profile with the potential to come in contact with potential receptors such as vegetation roots, groundwater and surface water. The potential environmental risks to these receptors in the closure reclaimed landscape are unknown and may pose a risk to achieving certification of overburden landforms.

Reclamation capping thickness is considered to be a key mitigation measure available for oil sand mine operators to alleviate the environmental risk(s) of materials placed within a constructed landform. To a lesser degree the reclamation material type and configuration may also be employed as a mitigation measure.

Reclamation of overburden landforms containing NPHCs and research studies related to NPHCs are currently underway by COSIA Land Members. The objectives of this project are to compile current reclamation learnings and research findings and conduct a risk assessment on NPHCs with this information. This includes conducting a field study of LOS overburden reclamation with mature forest stands to assess the impact that PHCs in LOS have had on tree growth.

The product of this work can be used as the basis to support an appropriate soil cover design (capping thickness) for future overburden reclamation that contains NPHCs.

PROGRESS AND ACHIEVEMENTS

In 2017 Paragon completed a field study of mature forest stands (approximately 20-40 years of age) growing on reclaimed lands constructed on overburden materials containing NPHCs. Soil information and samples were collected at 20 sites with capping thicknesses ranging from approximately 20 to 50 cm to evaluate the effect of PHC concentration on tree growth. Tree site index measurements were also collected at each site. Soil reclamation placement depth and PHC concentrations will be assessed with tree site index data to evaluate the impact of NHPCs on tree growth performance. Data analysis and interpretation is currently underway. This work will be added to the compilation of available information for the synthesis and risk assessment that will be completed in 2018.

LESSONS LEARNED

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

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in this reporting period.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil & Environmental Consulting Inc.

Principal Investigator: Vivienne Wilson

Revegetation

NSERC Industrial Research Chair in Forest Land Reclamation

COSIA Project Number: LE0012

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Transalta Corporation, Canadian Natural Resources Limited, Imperial, Suncor Energy Inc., Teck Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Nexen Energy ULC

Status: Year 4 of 5

PROJECT SUMMARY

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

The Chair is addressing three general topic areas and associated research questions:

Accelerating Forest Establishment

- How does the application of organic amendments (e.g., salvaged peat or forest floor material) influence tree and vegetation establishment on undeveloped subsoil mineral surface substrates?
- Can a fast-growing herbaceous cover crop be used as a deep soil amendment to improve growing conditions on nutrient poor sites?
- What is the impact of specific fertilization prescriptions on newly planted trees across different capping materials and what is its effect on understory vegetation and competition?
- What is the impact of increased surface roughness on environmental gradients and microsite variability? How do these gradients affect the establishment of tree and understory species and community development in reclamation sites?

Influencing Forest Stand Trajectories

- Can aspen stem density and performance be increased in older reclamation sites by cutting to promote vegetative reproduction (suckering), coupled with reducing competition?
- Can tall aspen stock with high root-to-shoot ratios be developed? How feasible is it to use tall aspen seedling stock on high competition sites?
- Is infill planting of seedlings on low density forest reclamation sites a viable option for forest canopy development and competition control?

Assessing Trajectories of Forest Reclamation

- What role does rooting space play in root water uptake, leaf area, and stand productivity for aspen, jack pine and white spruce in reclaimed oilsands sites?
- What role does soil water redistribution play in aspen roots along drought gradients?
- How do confining soil layers (chemical or physical) affect root growth behavior and rooting space?
- How does the relationship between leaf area/LAI and water use/availability vary on reclaimed sites as a result of stand composition, canopy development, and age and what is its impact on productivity?

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

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

PROGRESS AND ACHIEVEMENTS

Accelerating forest establishment:

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

To explore the use of tall aspen stocktypes for planting on competitive grassy sites Kyle Le (M.Sc.) summarized and analyzed his data and defended successfully his research thesis in 2017. A publication is currently being prepared.

A study that tests the arrangement and usage of municipal compost as an organic amendment for successful tree establishment on nutrient limited sites was in its second growing season. The study is located on Transalta's Highvale mine site. Seedlings planted in 2016 were re-measured in 2017. Erika Valek (M.Sc. candidate) is leading this experiment. This is an ongoing study with no results available at this time. We expect that the research will be summarized and analyzed in 2018.

To study questions related to the feasibility of enhancing micro- and meso-topography for natural establishment of vegetation and trees we monitored early vegetation establishment and tree performance on an operational scale study site on the Canadian Natural Albian Sands lease. Kate Melnik (M.Sc.) studied the early vegetation establishment and has completed her M.Sc. project successfully, defending her work in 2017. In addition, Kate has also successfully published a manuscript in the journal, Restoration Ecology. On the same site, Trevor de Zeeuw (M.Sc. candidate) has been monitoring seedling growth and root system development. This is an ongoing study with no results available at this time. We expect that his research will be summarized and analyzed in 2018. We are currently recruiting another M.Sc. student to take the final tree and vegetation measurements on this site which will be completed at the end of the research program.

Shauna Stack (M.Sc. candidate) established a new study in 2016 to explore nutrient limitations (in particular phosphorous and potassium) as a driver of reduced growth on peat dominated cover soils. In 2016, she applied different fertilizer regimes to plots planted with different tree species and has been monitoring their growth and nutrient uptake.

Influencing forest stand trajectories:

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

In a controlled study, we explored the feasibility of cutting juvenile (8-12 years) aspen of seedling origin to increase stem density through root suckering. This study was led by Carolyn King (M.Sc.) who finished her projects and successfully defended her thesis in 2017. Carolyn also successfully published her work in New Forests in 2017. To explore this topic further, Caren Jones (Research Technician) selected operational reclamation sites in the SAGD and mining region in 2017 to link seedling origin aspen on reclamation sites with their suckering potential. Additionally, Caren successfully published two manuscripts in 2017, which reported on her research on vegetation colonization on reclaimed sites.

Assessing trajectories of forest reclamation:

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

Morgane Merlin (PhD candidate) is in the process of analyzing a complex data set that explores how leaf area, rooting depth, and climatic and edaphic variables can be linked to water-use, and how those linkages change with different species. No firm results are yet available. In the same context, Morgane and Ashley Hart (M.Sc. candidate) executed a controlled greenhouse study that explored the ability of lateral water movement (hydraulic redistribution) in soils through aspen root systems. In a split-root system experiment, physiological and morphological measures were taken to assess hydraulic redistribution in aspen. At this time, no definite results are available, but we expect those to be available in early 2018.

To explore in more depth the accuracy of sap flow measurements to estimate tree water-use, we executed a study in an attempt to validate the Heat Ratio Method for Sap Flow estimation using the cut tree method (whole tree lysimeter). We cut the stem of a mature aspen (21 m tall) under water, maintained it in an upright position using a support tower, and measured and compared in-situ actual water-uptake with sapflow measurements taken at various locations along the stem of the tree. This study was led by Morgane and Kevin Solarik (PDF) and we are in the process of summarizing the measurements taken in 2017.

LESSONS LEARNED

A summary of key findings emerging from this program and its predecessor in 2017 include:

1. seedling origin aspen is capable of reproducing itself after disturbance; the overall abundance of suckers and sprouts is affected by root system size and stored reserves of non-structural carbohydrates and nitrogen;
2. a high root:shoot ratio for aspen seedling contributes to improved seedling growth after outplanting; benefits appear to decline (i) with increasing levels of competition from previously established vegetation communities (and particularly in grass communities where all planted aspen performed poorly) and (ii) on the extremes of resource availability (very good and very poor sites); and

3. the creation of microtopography on the scale of small hills (1.5 m high and 3.5 to 5.5 m wide) can have substantial impacts on the diversity of microsite growing environments, with positive impacts on expression of the emerging vegetation originating from the soil propagule bank; plant abundance and species richness more than doubled in comparison to smoothly graded and slightly ridged sites, with a substantial portion of the increase coming from species preferring moister soil conditions.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Carolyn King. 2017. Regeneration dynamics of seedling-origin aspen: implications for forest reclamation. M.Sc. thesis, 87 pages.

Katherine Melnik. 2017 The role of microtopography in the expression of soil propagule banks on reclamation sites. M.Sc. thesis, 117 pages.

Kyle Le. 2017. Evaluating trembling aspen seedling stock characteristics in response to outplanting and competition. M.Sc. thesis, 95 pages.

Completed theses supported by the chair position, with research funding from other sources

Simon Bockstette. 2017. Roots in reconstructed soils – how land reclamation practices affect the development of tree root systems. Ph.D. thesis, 128 pages.

Sheryl Ramnarine. 2017. Disturbance effects of oil sands exploration practices on coarse-textured soils and *Populus tremuloides* Michx. regeneration. M.Sc. thesis, 146 pages.

Natalie Scott. 2017. Role of host identity, stand composition, soil type and disturbance severity in structuring ectomycorrhizal communities in the boreal forest. M.Sc. thesis, 132 pages.

Journal Publications

Jones, C.E., Bachmann, S., Lieffers, V.J., and S.M. Landhäusser. 2017. Rapid understory plant recovery following forest floor protection on temporary drilling pads [online]. Restoration Ecology. doi: 10.1111/rec.12546.

Jones, C.E. and S.M. Landhäusser. 2017. Plant recolonization of reclamation areas from patches of salvaged forest floor material [online]. Applied Vegetation Science. doi: 10.1111/avsc.12350.

King, C.E and S.M. Landhäusser. 2017. Regeneration dynamics of planted seedling-origin aspen (*Populus tremuloides* Michx.) [online]. New Forests. doi: 10.1007/s11056-017-9614-4.

Melnik, K., Landhäusser, S.M., and K. Devito. 2017. Role of microtopography in the expression of soil propagule banks on reclamation sites [online]. Restoration Ecology. doi: 10.1111/rec.12587.

Refereed publications supported by the chair position, with research funding from other sources

Bockstette, S.W., Pinno, B.D., Dyck, M.F., and S.M. Landhäusser. 2017. Root competition, not soil compaction, restricts access to soil resources for aspen on a reclaimed mine soil. Botany 95: 685-695.

Hupperts, S.F., Karst, J., Pritsch, K., and S.M. Landhäusser. 2017. Host phenology and potential saprotophism of ectomycorrhizal fungi in the boreal forest. Functional Ecology 31: 116-126.

Adam, H.D., Zeppel, M.J.B., Anderegg, W.R.L., Hartmann, H., Landhäusser, S.M., Tissue, D.T., Huxman, T.E., Hudson, P.J., Franz, T.E., Allen, C.D., Anderegg, L.D.L., Barron-Gafford, G.A., Beerling, D.J., Breshears, D.D., Brodribb, T.J., Bugmann, H., Cobb, .R.C., Collins, A.D., Dickman, L.T., Duan, H., Ewers, B.E., Galiano, L., Galvez, D.A, Garcia-Forner, N., Gaylord, M.L., Germino, M.J., Gessler, A., Hacke, U.G., Hakamada, R., Hector, A., Jenkins, M.W., Kane, J.M., Kolb, T.E., Law, D.J., Lewis, J.D., Limousin, J, Love, D.M., Macalady, A.K., Martínez-Vilalta, J., Mencuccini, M., Mitchell, P.J., Muss, J.D., O'Brien, M.J., O'Grady, A.P., Pangle, R.E., Pinkard, E.A., Piper, F.I., Plaut, J.A., Pockman, W.T., Quirk, J., Reinhardt, K., Ripullone, F., Ryan, M.G., Sala, A., Sevanto, S., Sperry, J.S., Vargas, R., Vennetier, M., Way, D.A., Xu, C., Yepez, EA., and N.G. McDowell. 2017. A multi-species synthesis of physiological mechanisms in drought-induced tree mortality. Nature Ecology & Evolution 1: 1285-1291.

Karst, J., Gaster, J., Wiley, E., and S.M. Landhäusser. 2017. Stress differentially causes roots of tree seedlings to exude carbon. Tree Physiology 37: 154-164.

O'Brien, M.J., Engelbrecht, B.M.J., Joswig, J., Pereyra, G., Schuldt, B., Jansen, S., Kattge, J., Landhäusser, S.M., Levick, S.R., Preisler, Y., Väänänen, P., and C. Macinnis-Ng. 2017. A synthesis of tree functional traits related to drought-induced mortality in forests across climatic zones. Journal of Applied Ecology 54: 1669-1686.

Sorenson, P.T., MacKenzie, M.D., Quideau, S.A., and S.M. Landhäusser. 2017. Can spatial patterns be used to investigate aboveground-belowground links in reclaimed forests? Ecological Engineering 104: 57-66.

Wiley, E., Hoch, G., and S.M. Landhäusser. 2017. Dying piece by piece: carbohydrate dynamics in aspen (*Populus tremuloides*) seedlings under severe carbon stress. Journal of Experimental Botany 68: 5221-5232.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jana Bockstette	University of Alberta	M.Sc.	2013	2018
Caren Jones	University of Alberta	M.Sc.	2013	2016
Kyle Le	University of Alberta	M.Sc.	2014	2017
Katherine Melnik	University of Alberta	M.Sc.	2014	2017
Simon Bockstette	University of Alberta	PhD	2011	2017
Morgane Merlin	University of Alberta	PhD	2015	2020
Carolyn King	University of Alberta	M.Sc.	2015	2017
Erika Valek	University of Alberta	M.Sc.	2015	2018
Shauna Stack	University of Alberta	M.Sc.	2016	2018
Trevor de Zeeuw	University of Alberta	M.Sc.	2016	2018
Ashley Hart	University of Alberta	M.Sc.	2016	2018
Kevin Solarik	University of Alberta	PDF	2017	2019
Nichole Moen	University of Alberta	Research Assistant		
Jasmin Danzberger	TU Munich, Germany	Research Assistant		

Andi Fitzsimmons	University of Alberta	Research Assistant		
Caren Jones	University of Alberta	Technician		
Fran Leishman	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

Research Collaborators: Kevin Devito, University of Alberta; Brad Pinno, University of Alberta; Miles Dyck, University of Alberta

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

COSIA Project Number: LJ0127

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

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Suncor Energy Inc.

Status: Year 5 of 6 (one year extension started in 2018)

PROJECT SUMMARY

This project seeks to develop an alternate approach to the assessment of equivalent capability and reclamation performance directly based on, and linked to, ecosystem function, by leveraging long-term eco-hydrological research that measures growing-season water and carbon balances across a range of 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 ecosystem function may be discovered. This will allow more relevant and realistic evaluation of equivalent capability, as well as defining time frames for this evaluation.

This project is divided into three work packages: WP1, WP2 and WP3. WP1 is focused on measurement and interpretation of ecosystem fluxes using the eddy-covariance technique, and is being undertaken by McMaster and Waterloo universities. WP2 is focused on biometric covariates to ecosystem fluxes, and is being completed by Integral Ecology Group. WP3 is a knowledge synthesis that draws together elements of the first two package along with other sources of relevant information. WP3 is a cooperative effort between all three organizations.

PROGRESS AND ACHIEVEMENTS

WP1: Work Package 1 continues to collect data using the eddy covariance technique, and to quantify linkages between hydroclimatic (water table, soil moisture and tension, evapotranspiration) properties, soil physical properties and carbon exchange (net ecosystem exchange) at the ecosystem scale. Existing installations cover a range of canopy conditions and successional stages. Work on WP1 has been underway since 2013, with the potential for continued monitoring beyond the current project's expiry in spring 2018. There are several students and post-doctoral fellows engaged in this project.

There are now sixty site-years of total growing-season water and carbon flux data from upland reclamation and regenerating sites, along with associated hydrologic, climatic and biometric data. This data record is unparalleled in studies of both the Alberta boreal forest and reclamation sites worldwide.

Key findings from research to date include:

1. Evapotranspiration (ET) quickly becomes the dominant pathway for water removal from reclaimed ecosystems, and is closely correlated to increases in leaf area. Leaf Area Index (LAI) is useful as a first order estimator of ecosystem water use in the absence of direct measures.
2. ET is variable between monitoring sites and years, with variation being largely explainable by annual climate and vegetation age/type. There is little difference in ET among reclaimed, regenerating and natural systems having similar stand properties. Sites of differing growth potential follow similar patterns of change in both stand properties and ET, but at differing rates.
3. Water in reclaimed soils is sufficient to support upland vegetation establishment. Total soil water storage influences ecosystem characteristics and stand type, yet there is no evidence of severe water deficits, even in dry years of record. While development rates may be slower on sites with lower soil moisture storage, water availability is not precluding forest establishment.
4. Forests regenerating after harvest, recover water use efficiency (WUE) faster than forests on reclaimed sites, particularly in clonal aspen stands. Maximum water use in reclaimed sites appears to be achieved approximately 10 years after stand establishment, which is shorter than previously believed. Pending manuscripts will address:
   (i) the degree to which expectations from functional assessment of natural analogues can be applied to reclaimed systems;
   (ii) performance envelopes for this functional assessment of reclaimed ecosystems; and
   (iii) methods to distinguish between delayed functional recovery and unacceptable performance.

   To date, there is no evidence in flux and hydrological data that suggests a significant performance deterioration will take place over time on reclaimed sites.

5. Carbon (C) fluxes (particularly gross ecosystem photosynthesis) at reclamation sites are similar to those reported for regenerating and mature natural sites in published literature. However, following disturbance, natural systems typically lose more C due to the presence of labile material at the ground surface. By contrast, carbon (primarily peat) in reclamation soils typically decomposes more slowly, allowing these systems to achieve a positive carbon balance more quickly than naturally disturbed analogues. However, this is a measure of "net" C exchange, and does not mean that these reclaimed systems are more productive than their natural counterparts.

One paper published this year (Strilesky et al. 2017) used 12 years of data to conclude that Syncrude's South Bison Hills study site is developing, from a functional perspective, similar to boreal forests disturbed by fire or logging.

WP2: Work Package 2 has been tasked with characterizing vegetation and soil conditions on the instrumented study sites, and trends in those measures over time, in order to explore correlations of those measures with eddy covariance measures of reclamation development and success.

Field work in 2017 included measurements on 99 permanent sample plots (76 reclamation, 23 reference) co-located on 8 eddy covariance tower sites. Initial site characterizations were completed on two new reclaimed sites, including sampling of soil, forest-stand and vegetation-community attributes. LAI data collected in 2017 appears to confirm and strengthen observed development trends from previous years, which fit within expected patterns for the boreal region.

WP3: This work package consists of synthetic interpretations of data collected in WP1 and WP2, and previous related work. It is scheduled to be completed in Q2 2018.

A research meeting held in October 2017 was an important milestone for setting objectives for WP3 reporting. Aside from summarizing multi-year correlations between trends for ecosystem flux and biometric parameters, the WP3 report will examine the applicability of these trends in supporting extensive use of biometric measures as a surrogate for functional measures of reclamation success. Reporting emphasis will be on potential industry applications of project findings, including reclamation monitoring, water and carbon balance modelling, discussion of equivalent land capability, and possible uses in support of reclamation certification.

LESSONS LEARNED

The knowledge-synthesis portion of this project is still in its early stages, so lessons learned are preliminary.

Flux data from 2017 has not yet been finalized so there are no emergent outcomes to report from the most recent field season. However, several findings discussed below have continued to take shape during this year's data analysis and discussion and they will be addressed in the final report.

The outcomes of this project have important implications in several areas of interest for industry. Flux data allow an understanding of ecosystem function at both a site and landscape level, particularly in relation to water storage and use, and they also allow an evaluation of biometric parameters currently or potentially useful to test ecosystem function.

At the site level, fluxes are an integrative indicator of ecosystem health and performance. The use of both reclaimed and reference sites in this project can inform assessment of equivalent capability. Data from this study shows that reclaimed upland forests are functionally similar to their un-mined counterparts. The results of this project have provided further evidence for the functional competency of reclaimed uplands. There is no evidence in our flux, hydrologic, and biometric data to suggest that reclaimed sites will experience a significant deterioration of ecosystem function over time. This project's work to link simple biometric measures to measured fluxes allows study findings to be extrapolated to the non-instrumented landscape.

At the landscape level, flux results may also prove useful for modelling water-use patterns on the reclaimed landscape, particularly for understanding linkages between upland and wetland hydrology. Data from a reclamation monitoring program that includes flux-related indicators will improve modelling of landscape-level water and carbon balances, as compared to using non-site-specific modelling assumptions.

LITERATURE CITED

Strilesky, S.L., E.R. Humphries, S.K. Carey, 2017. Forest water use in the initial stages of reclamation in the Athabasca Oil Sands Region. *Hydrological Processes* 31:2781-2792.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Gingras-Hill, T., 2017. Hydrogeochemical soil dynamics relative to topography for forested land units undergoing reclamation in a post-mined landscape in the Athabasca Oil Sands Region, Alberta. M.Sc. Thesis, University of Saskatchewan, January 2017. University of Waterloo. [Funded 20% by this Project]

Journal Publications

Gingras-Hill, T., F. Nwaishi, M.L. Macrae, J.S. Price, R.M. Petrone. 2017. Ecohydrological functioning of a forested upland undergoing reclamation on a post-mining landscape of the Athabasca Oil Sands Region, Canada. (Accepted, *Ecohydrology*, 11/17) [Funded 20% by this Project]

Strilesky, S.L., E.R. Humphries, S.K. Carey. 2017. Forest water use in the initial stages of reclamation in the Athabasca Oil Sands Region. *Hydrological Processes* 31:2781-2792.

Sutherland, G., L.E. Chasmer, N. Kljun, K.J. Devito, R.M. Petrone. 2017. Using high resolution LiDAR data and a flux footprint parameterization to scale evapotranspiration estimates to lower pixel resolutions. *Canadian Journal of Remote Sensing* 43(2): 215-229. [Funded 20% by this Project]

RESEARCH TEAM AND COLLABORATORS

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

Principal Investigators: Sean Carey / Richard Petrone / Justin Straker

Name	Institution	Degree	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Stacey Strilesky	McMaster / Carleton	PhD	2014	2018
Gordon Drewitt	McMaster University	Research Associate	2015	2017
Erin Nicholls	McMaster University	MSc	2013	2015
Chelsea Thorne	McMaster University	MSc	2013	2015
Felix Nwaishi	University of Waterloo	Partial Post-Doctoral Fellow	2015	2018
George Sutherland	University of Waterloo	Research Associate	2015	2018
Elise Gabrielli	University of Waterloo	MSc	2013	2016
Tristan Gingras-Hill	University of Waterloo	MSc	2014	2016
Midori Depante	University of Waterloo	MSc	2013	2016
Laura Chasmer	University of Waterloo	Research Associate	2016	2018
Jeff Anderson	Integral Ecology	Consultant		
Trevor Baker	Integral Ecology	Consultant		
Meghan Laidlaw	Integral Ecology	Consultant		

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

COSIA Project Number: LJ0202

Research Provider: Alberta-Pacific Forest Industries Inc.

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 6

PROJECT SUMMARY

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

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

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

Three discrete trials were established in the fall of 2014: trial one was established on the shore of an end pit lake have a water cap consisting of mixed OSPW and fresh water (Base Mine Lake); trial two was established on near-saturated soils having high EC values within an in-pit reclaimed wetland on sand-capped soft tails (Sandhill Fen); and trial three was established on a sand island within the same wetland. The latter two sites are expected to experience a mixture of CT consolidation pore water and fresh water. All three trials were laid out as a randomized block design with single tree plots. Trials one and two were established with four ramets of each of 35 Al-Pac clones and 60 Syncrude control trees planted in three blocks (for a total of 200 trees in each block). Trial three consists of one tree of each of the 35 Al-Pac clones and 25 Syncrude control trees planted in each of six blocks. Each block had a total of 60 trees (10 trees x 6 trees) with three blocks planted on each of the two sand islands (180 trees per island).

PROGRESS AND ACHIEVEMENTS

Work completed on the project in 2017 consisted of measurement of the trials at the end of the growing season. The trials in Sandhill Fen showed very little growth in height or caliper, once again this year. The average increment in height and basal diameter for the Sandhill Fen trees since they were planted (three years of growth) for Treatments 1, 2 and 3 are 9.7, 10.6 and 9.7 cm for height and 1.5, 1.4 and 1.2 mm for caliper, respectively. The average height and basal diameter increment for Sand Island 'A' trees since they were planted (three years of growth) for

Treatments 1, 2 and 3 are 22.5, 16.5 and 10.2 cm for height and 4.2, 4 and 3.6 mm for caliper, respectively. These trees are obviously struggling in these environments as, on average, they have not even doubled their initial height for any of the treatments on either site since they were planted.

It was also observed that there was localized mortality in some of the lower areas on both sites indicating there may have been some flooding, or at minimum, increased soil water levels earlier in the 2017 season.

The trial at Base Mine Lake had much larger growth increments compared to the other trials. The average height and diameter at breast height (DBH) for Base Mine Lake trees (three years of growth) for Treatments 1, 2 and 3 are 233.5, 224.7 and 227.6 cm for height and 13.5, 12.7 and 13 mm for DBH, respectively. Overall survival remains high across all three treatments at 88%, which is unchanged from last year.

The trials were installed in October of 2014 and the project is expected to be completed in the fall of 2019.

LESSONS LEARNED

To date, growth variations between the trial sites are overwhelming much smaller variations between individual clones and the Stream 1 source of cuttings. The Base Mine Lake site benefits from a moist rich growing environment believed to have few growth limitations other than climate, and only very limited influence from lake water. Trial 2 in Sandhill Fen is influenced by cold, wet growing conditions, where a consistently high water table is suspected to result in a severely restricted rooting zone, and cold temperatures to be a severe limitation on physiological activity. The sand island site (Trial 3) should provide better rooting conditions that Trial 2, but may be limited by nutrition. Other data sources from the Sandhill Fen instrumented watershed project will be used to corroborate these observations.

Clonal trends for salt tolerance have not yet been fully evaluated.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta-Pacific Forest Industries Inc.

Principal Investigator: Dr. Barb Thomas

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
David Kamelchuk	Little Creek Agroforestry Inc.	Consultant		
Sebastien Dietrich	Alberta-Pacific Forest Industries Inc.	Contractor		

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

COSIA Project Number: LJ0203

Research Provider: Natural Resources Canada, Canadian Forest Service

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 4

PROJECT SUMMARY

In Alberta oil sands reclamation, the presence of oil sands process-affected water (OSPW) might become problematic if elevated levels of dissolved salts reach concentrations that adversely affect plant growth. Potentially impacted ecosystems include water bodies and their shorelines, peatlands, lowland forests and seepage sites.

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

A greenhouse study conducted by Natural Resources Canada (NRCan) identified numerous willow clones of various native willow species that appear to have particularly high tolerance to OSPW. The current study is a field test of 15 native willow clones from the greenhouse study.

The objectives of the study are to:

1. Determine if willow clones, previously identified in greenhouse studies as tolerant to OSPW, are also tolerant to in-situ conditions when planted along the shoreline of an end-pit lake containing OSPW by monitoring:
    a. survival
    b. growth rate; and
    c. foliar chemistry
2. Monitor the soil moisture and soil chemistry in the rooting zone of the willows.

Approximately 1000 willow container seedlings (6 native species with a variable number of genotypes per species) were grown from cuttings during the summer of 2013, hardened off and cold stored for planting in spring of 2014. The trial site is on the south shore of Base Mine Lake, an end pit lake partially filled with soft tails and capped with a mixture of OSPW and fresh water. Seedlings were planted at the water's edge (0 position), and 30, 60, 120 and 240 centimeters up the slope, with 4 replicates for most clones. Seedling survival was assessed one week after planting and annually thereafter (spring). Seedling stem length and stem diameter were assessed at the end of the 2014, 2015 and 2016 growing seasons. Biomass production was assessed in the spring of 2017. Monitoring of growth was accompanied by environmental assessments including soil pore water chemistry, soil texture, bulk density, soil water content, photosynthetically active radiation, temperature and foliar chemistry.

PROGRESS AND ACHIEVEMENTS

Research activities in the final year of this study focused on the assessment of stem wood biomass and evaluation of cumulative results over the life of the project. A manuscript for journal publication is being prepared for Q1 2018.

LESSONS LEARNED

Early results suggest that differences in soil chemistry are measurable within the 2.4 m distance from the lake shore to the most distant position, that survival rates for seedlings are relatively high and unaffected by position, and that growth rates have been affected by position. Factors other than soil chemistry may also be influencing growth and will be explored in the planned journal article.

LITERATURE CITED

Munns R. and M. Tester, 2008. Mechanisms of Salinity Tolerance. Annual Review of Plant Biology Vol. 59:651-681.

PRESENTATIONS AND PUBLICATIONS

There were no public presentations or publications in 2017. A manuscript for journal publication is being prepared.

RESEARCH TEAM AND COLLABORATORS

Institution: Natural Resources Canada, Canadian Forest Service, Canadian Wood Fibre Centre, Edmonton, AB

Principal Investigator: Richard Krygier

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Martin Blank	Natural Resources Canada-Canadian Forest Service	Land Reclamation Technician		
Natalia Startsev	Natural Resources Canada-Canadian Forest Service	Research Assistant		

A Forest Fertilization Trial in a Mildred Lake Jack Pine Stand

COSIA Project Number: LJ0209

Research Provider: University of British Columbia

Industry Champion: Syncrude Canada Ltd.

Status: Year 7 of 7

PROJECT SUMMARY

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 lift salvage of peat-mineral mix consisting of fen/bog peat and the underlying fine textured mineral material, placed in a single lift 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 nitrogen (N), phosphorus (P), sulfur (S), potassium (K), and the micronutrients copper (Cu) and magnesium (Mg) formulated as NPS and NPKS + Cu and Mg. An original option to also thin the stand as part of the suite of treatments is not being pursued.

The trial is set up as a randomized block design, with block by initial mean tree height. Twenty plots were established with four replicates of five treatments: control, NPS fertilizer, NPKS + micronutrient fertilizer, thinning, and thinning + NPS fertilizer. Given that the tree thinning treatment was never applied, 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 2015, the plots have been measured four 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 soil organic matter and its closely associated soil properties with tree growth (Farnden et al. 2013) has been produced.

PROGRESS AND ACHIEVEMENTS

In the current reporting period, a final project report has been completed, and a journal manuscript is in preparation.

LESSONS LEARNED

This trial has found no significant growth response to a one dose fertilizer application (N, P, K, S and micronutrients) in a 21-year old closed canopy jack pine stand growing on 50 cm of single lift peat-mineral mix over tailings sand. Results of this study suggest that nutrition on this site is not a limiting factor for tree growth.

LITERATURE CITED

Farnden, C., R.J. Vassov, M. Yarmuch and B.C. Larson. 2013. Soil reclamation amendments affect long term growth of jack pine following oil sands mining. New Forests 33:799-810. https://doi.org/10.1007/s11056-013-9375-7

Newton PF, Amponsah IG (2006) Systematic review of short-term growth responses of semi-mature black spruce and jack pine stands to nitrogen-based fertilization treatments. For Ecol Manag 237:1–14. doi: 10.1016/j.foreco.2006.10.009

PRESENTATIONS AND PUBLICATIONS

There were no publications or presentations in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of British Columbia

Principal Investigator: Dr. Bruce Larson

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Adam Polinko	University of British Columbia	Ph.D. Candidate	2014	2018

Plant Community Succession of Oil Sands Reclamation

COSIA Project Number: LJ0129

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

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc.

Status: Year 2 of 2

PROJECT SUMMARY

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

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

Deliverables:

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

PROGRESS AND ACHIEVEMENTS

A literature review relating to plant community assembly and succession on upland oil sands reclamation sites has been prepared and submitted to the science journal Environmental Review for publication consideration. This report provides a synthesis of information relating to the current understanding of successional processes and plant community assembly and identifies knowledge gaps. In addition, three sets of data analysis from the CEMA long-term plot network (LTPN) and Canadian Natural Albian Sands reclamation sites were analyzed, two manuscripts have been prepared for publication and a third is in preparation.

A questionnaire based online survey was conducted to collect expert (e.g., academics, reclamation scientists, soil scientists, forest ecologists, reclamation consultants and practitioners) opinion regarding effects of reclamation practices on vegetation development.

A one-day workshop was conducted on April 05, 2017, to review and discuss ideas related to; the application of plant community assembly theory and succession in oil sands reclamation; to identify key questions and knowledge gaps facing reclamation practitioners in relation to applying ideas about succession and assembly theory; and, to discuss approaches for filling data gaps.

The project is in its final stage. We are working on the development of a strategy and framework to guide future plant establishment, research and monitoring projects, to gain a better understanding of vegetation prescriptions. This report will be prepared in close collaboration with members of the research team and will be based on the literature review, results from data analysis and consultation with a broad range of experts. It will present key research and information needs and will outline a strategy and an initial framework for a research program focused on supporting cost-efficient and effective strategies for restoring forest ecosystems based on successional processes.

LESSONS LEARNED

Online survey questionnaire and workshop:

We invited several academics, reclamation scientists, soil scientists, forest ecologists, reclamation consultants, and practitioners to participate in an online survey designed to determine expert opinion regarding the effects of reclamation treatments on vegetation development. The online survey included 19 questions. In addition, two breakout sessions were held at the workshop on April 5th and a structured questionnaire was administered.

The consolidated opinions of the experts surveyed are as follows:

- Forest floor soil is better than peat mineral soil for reclamation of upland sites with direct placement preferred over stockpiling.
- Using coarse woody debris (CWD) improves vegetation establishment and accelerates development of natural plant communities.
- Growing desirable native species on stockpiles can reduce non-native plant establishment and increase more desirable propagules in the soil.
- Regulatory approval conditions may not adequately address the impact of climate change in the management of reclamation materials.

The following major knowledge gaps were identified:

- There is a lack of knowledge about community assembly and succession to define early thresholds for success.
- Effects of coversoil stockpiling and the influences on vegetation development are not well understood.
- Better definitions of what constitutes reclamation success from a plant community perspective are needed. This includes the identification of appropriate reference conditions and determination of how close we need to be to the reference conditions to declare success.
- The risks of not achieving certification thresholds, given a particular set of starting conditions, need to be defined.
- A better understanding of the mechanisms, including soil-plant relationships that influence the establishment and succession of plant communities following reclamation is needed.
- A better understanding of the succession trajectories is needed to better inform decisions regarding development of reclamation sites towards having similar structure and function to what was historically present.

Literature review and data analysis:

Key findings from the literature review and data analysis conducted were:

- Use of salvaged surface soil and forest floor material enhances plant species cover, richness and diversity relative to use of various other cover soil materials.
- Storage or stockpiling of salvaged surface soils reduces the abundance of native plant propagules and early vegetation community development.
- The direct placement of coversoil supports more rapid succession (from ruderal and annual communities to perennial communities).
- Two decades after reclamation, plant community composition on reclaimed sites differs substantially from the natural forest. Moreover, the plant community assembly process is unstructured or random and does not appear to have reached a stable plant community.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Dhar A., Comeau P. G., Karst J., Pinno B., Chang S., Naeth A. M., Vassov R., Bampfylde C. Plant community development following reclamation of oil sands mine sites in the boreal forest: a review (Submitted to Environmental Review)

Dhar A., Comeau P. G, Vassov R. Effects of cover soil stockpiling on plant community development following reclamation of oil-sands sites in Alberta (Ready to Submit in Restoration Ecology)

Dhar A., Comeau P. G, et al. Effects of reclamation practices on plant community development after oil sands mining in boreal forest (Internal Review)

Dhar A., Comeau P. G, et al. Early plant community succession dynamics on different cover soil types in oil sands reclamation sites (in preparation)

Conference Presentations/Posters

Dhar A., Comeau, P., Vassov, R., 2017. Ecosystem assembly ideas and their application in oil sands reclamation. 11th North American Forest Ecology Workshop (NAFEW) Edmonton, Alberta, Canada, June 19 – 22, 2017. [Presentation]

Paper accepted for presentation in conference

Dhar A., Comeau P., Vassov R. 2018. Effects of reclamation practices on plant community development after oil sands mining in boreal forest. Conference on Ecological Restoration (Western Canada), February 13 – 17, 2018, Simon Fraser University, Burnaby, BC, Canada.

Dhar A., Comeau P., Vassov R. 2018. Effects of cover soil stockpile on plant community development in reclaimed boreal forest. Conference on Ecological Restoration (Western Canada) February 13 – 17, 2018, Simon Fraser University, Burnaby, BC, Canada.

Technical Session in Conference

Dhar A., Comeau P., Vassov R. 2017. Vegetation response in reclaimed boreal forests after oil-sands mining" at the 11th North American Forest Ecology Workshop (NAFEW) Edmonton, Alberta, Canada, June 19 – 22, 2017. http://nafew.org/wp-content/uploads/2012/02/NAFEW-Program-Book-FINAL-VERSION.pdf.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Phil Comeau, Ph.D., Professor

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Justine Karst	University of Alberta	Assistant Professor		
Scott Chang	University of Alberta	Professor		
M. Anne Naeth	University of Alberta	Professor		
Rob Vassov	CNRL Horizon Oil Sands	Reclamation and Research Coordinator		
Amalesh Dhar	University of Alberta	Research Associate		

Research Collaborators: Leylani Wells, Suncor Energy Inc.; Craig Farnden, Syncrude Canada Ltd.; Caroline Bampfylde, Alberta Environment and Parks; Brian Brassard, Alberta Environment and Parks; Brad Pinno, University of Alberta

Oil Sands Vegetative Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting Inc.

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Nexen Energy ULC, Suncor Energy Inc., Syncrude Canada Ltd., Teck Resources Limited

Status: Ongoing

PROJECT SUMMARY

The Oil Sands Vegetation Cooperative (OSVC) was established in 2009 to enable collaborative harvesting and banking of native boreal forest seed for use in revegetation and research. In 2014, COSIA initiated a Land EPA project that provides administrative and technical support for OSVC initiatives including seed collection in the northern Athabasca Oil Sands (NAOS), Southern Athabasca Oil Sands (SAOS) and Cold Lake (COLK) regions, and the identification and development of research projects relevant to revegetation of reclaimed lands.

The scope of work for this project includes collation of seed collection needs, coordination of the annual seed collection program, management of records for OSVC inventories in the Provincial seed bank, provision of technical expertise on the collection, storage and deployment of native seed, technical guidance to the OSVC on research needs, coordination and record keeping for ongoing discussions related to research project development, the preparation of support documents such as literature reviews and data summaries, and the preparation of a bi-annual newsletter.

As in 2016, the bi-annual newsletter was published, and the cross-company record keeping system was updated. Wild Rose Consulting also coordinated the harvest of seeds for the cooperative seed bank and a comprehensive harvest site audit was undertaken.

PROGRESS AND ACHIEVEMENTS

Ongoing activities in 2017 included maintenance of a cross-company record keeping system, coordination of the collection, extraction and Provincial registration of 1435.65 litres of seed from 4 seed zones, administration of the cooperative bank and production of the bi-annual newsletter. Additional activities supporting OSVC initiatives included:

1. Annual reporting on OSVC seed collection activities;
2. An investigation of options for stooling bed and seed orchard establishment, with an initial focus on beaked hazelnut (*Corylus cornuta*);
3. An update to the 2015 Knowledge Gap Analysis;
4. A comprehensive audit of harvest sites;
5. A literature review of vegetative reproduction strategies for priority shrubs; and
6. A draft research plan for a shrub out-planting trial.

In 2017, Oil Sands Companies harvested 1435.65 litres (L) of seed from 4 seed zones in northeastern Alberta. The following were extracted and registered with assistance by the OSVC:

COLK – targeting a single species, which was not productive in 2017, resulted in no harvest for COLK.
SAOS – 919 L of seed from 5 seed lots representing 2 species from seed zones CM 3.1 and LBH 1.5.
NAOS – 516.65 L of seed from 40 seed lots representing 19 species from seed zones CM 2.1 and CM 2.2.

Table 1. Species harvested

SAOS	NAOS
Alnus viridis (green alder)	*Alnus incana* (river alder)
Picea mariana (black spruce)	*Alnus viridis* (green alder)
	Amelanchier alnifolia (Saskatoon)
	Arctostaphylos uva-ursi (bearberry)
	Betula neoalaskana (Alaska paper birch)
	Cornus sericea (redosier dogwood)
	Corylus cornuta (beaked hazelnut)
	Dasiphora fruticosa (shrubby cinquefoil)
	Prunus virginiana (chokecherry)
	Rhododendron groenlandicum (Labrador tea)
	Ribes glandulosum (skunk currant)
	Ribes triste (wild red currant)
	Rosa acicularis (prickly rose)
	Rubus pubescens (dewberry)
	Shepherdia canadensis (buffaloberry)
	Symphoricarpos albus (snowberry)
	Vaccinium myrtilloides (blueberry)
	Vaccinium vitis-idaea (bog cranberry)
	Viburnum edule (lowbush cranberry)

LESSONS LEARNED

With support from this project, the OSVC is continuing development of research opportunities identified in the earlier knowledge gap analysis, with a specific focus on shrub mortality, vegetative propagation of shrubs, seed handling practices, and the establishment of seed orchards and stooling beds for specific species. Support from this project has also been critical in discussions with Provincial seed experts in identifying potential causes for, and solutions to, poor sustainability of aspen seed viability in long term storage.

PRESENTATIONS AND PUBLICATIONS

None available for 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting Inc.

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ann Smreciu	Wild Rose Consulting, Inc.	Principal / Ecologist		
Kimberly Gould	Wild Rose Consulting, Inc.	Field Ecologist		

Research Collaborators: Alberta Tree Improvement and Seed Centre (Government of Alberta)

NSERC Industrial Research Chair in Terrestrial Restoration Ecology

COSIA Project Number: LE0034

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial, Suncor Energy Inc., Teck Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Nexen Energy ULC

Status: Year 2 of 6

PROJECT SUMMARY

After mining, some landforms are reconstructed with lean oil sands (LOS), defined as bitumous ore deposits that contain insufficient hydrocarbons to meet either minimum regulatory or corporate thresholds for processing. As a result, this material is placed in overburden dumps and forms all or considerable portions of some reconstructed landforms. As such, this LOS material can be in close proximity to or even form part of the rooting zone of reclaimed sites.

In this region of boreal forest, oil sand outcrops occur naturally, and forests have developed on these deposits over thousands of years post-glaciation. However, lean oil sand differs from oil sand outcrops in that it has not undergone weathering. As such, there are concerns that the disruption and placement of LOS in a new environment may pose a risk to vegetation on reclaimed lands. Specifically, LOS may act as a barrier to root growth with subsequent effects on the aboveground functioning of trees, shrubs and herbaceous plants, which are establishing on sites reclaimed over this material. This program will contribute to a growing body of science-based evidence guiding LOS reclamation and the associated regulatory framework.

The focus of the research program is to build knowledge on belowground features that support self-sustaining forests in both reclaimed and natural systems. The overarching research question is whether LOS acts as a barrier or medium to root growth of plants (herbaceous, shrubs and trees) comprising a typical boreal forest. Several lines of inquiry will be followed through the research to answer these overarching questions:

1. What are the natural dimensions and mechanisms underlying rooting zones of boreal plants?
2. What are the effects of oil sand on root structure and function?
3. Do root microbial symbionts mediate tree survival on oil sand?

PROGRESS AND ACHIEVEMENTS

1. What are the natural dimensions and mechanisms underlying rooting zones of boreal plants?

As the bulk of the research under the Industrial Research Chair (IRC) requires the identification of roots by species, our first task was to refine and develop existing molecular tools designed for this purpose. This year, M.Sc. student Metzler, has created a reference data base of DNA fragments for ~ 200 plant species collected last summer. We are also testing the rate of DNA degradation of roots buried in soils in a 5-year field experiment established last summer.

Understanding the ecological factors influencing root distribution of target plant species desired in revegetation of reclaimed sites is an important step in designing cover soils. Together, two M.Sc. students are investigating how abiotic and biotic factors influence root distributions of boreal forest communities. Specifically, one project focuses on characterizing root distributions in soils that differ in texture (M.Sc. student Brown), and a second project focuses on how root profiles change with stand age (M.Sc. student Wasyliw). For this latter project, twenty-four sites in the boreal forest of northeastern Alberta were identified during the summer of 2017. Each site is dominated by jack pine and the sites form an age gradient from approximately 1 to 100-years average tree age, all of fire-origin. In the summer of 2018, Wasyliw will sample for rooting depth and aboveground stand characteristics (tree age, leaf area, tree height and size). The former project is in the design phase; field work consisting of site selection, characterization and sampling will occur during the summer of 2018 and be performed by Brown.

2. What are the effects of oil sand on root structure and function?

Where shallow (<50cm) oil sand deposits occur naturally in this region and forests have been growing on these deposits since the last ice age, the apparent interactions of plant roots with these deposits can provide valuable indications of likely interactions between LOS and vegetation in reclaimed ecosystems. However, locating roots of individual trees is an arduous, time-consuming and destructive activity.

M.Sc. student La Flèche, is using dendrochemical analysis of aboveground tree tissue to determine whether roots interact with these shallow oil sand deposits. Dendrochemistry, using tree rings to monitor changes in soil and atmospheric chemistry over time, is a growing branch of science that has been used largely to study environmental contamination from nearby industrial practices. La Flèche is using this technique to determine the potential of trace metals vanadium (V), molybdenum (Mo), nickel (Ni) and rhenium (Re) to act as indicators of tree rooting behavior in bituminous soils.

Five sites presenting shallow natural bituminous deposits and two sites free of bitumen (all confirmed with tests of soil hydrocarbons) have been sampled for trace metals in boles of jack pine trees and soils. We have collaborated with the Soil, Water, Air, Manure, Peat (SWAMP) lab at the University of Alberta (led by Shotyk) to utilize methods that reduce the risk of metal contamination during sample processing. These samples are currently being analyzed. Along with this project, La Flèche will also characterize root growth and presence of trace metals in tree seedlings growing on a recently reclaimed LOS landform at the Canadian Natural Horizon mine site; this research will be performed during the summer of 2018.

3. Do root microbial symbionts mediate tree survival on oil sand?

Some species or populations of root microbes may be restricted to sites with oil sand present, while others may be found only on sites free of oil sand. Such patterns would suggest specialization. This premise is the basis for screening plants and microbes as candidates for phytoremediation of hydrocarbon contaminated soils.

James Franklin, a PhD student who started in September 2017, will build his research around this particular focus of the IRC. To date, he has conducted a broad survey of natural bituminous sites, and sampled fungi from these sites in addition to soils of several bitumen-free forests. Using Illumina next generation sequencing, he will characterize arbuscular and ectomycorrhizal fungi occurring in the samples. Franklin will develop this project over the next year to include experiments that test for the importance of these symbionts in mediating tree performance in soils impacted by LOS.

LESSONS LEARNED

This project is in the early stages and therefore, no results or conclusions are yet available.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters:

Metzler, P and Karst J. Revealing the belowground diversity of boreal forests with molecular tools. Ecological Society of America, Portland, Oregon, USA (POSTER) August 7-11, 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Justine Karst

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Paul Metzler	University of Alberta	M.Sc.	2016	2018
James Franklin	University of Alberta	PhD	2017	2021
Marc La Fleche	University of Alberta	M.Sc.	2017	2019
Josh Wasyliw	University of Alberta	M.Sc.	2017	2019
Ariel Brown	University of Alberta	M.Sc.	2017	2019
Chloe Christenson	University of Alberta	Lab Technician	2017	
Pak Chow	University of Alberta	Lab Technician	2016	
Dana Hopfauf	University of Alberta	Undergraduate Field Technician	2017	

Jack Pine Establishment

COSIA Project Number: LJ0263

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 2 of 5

PROJECT SUMMARY

Following surface mining, oil sands operators are required to reclaim the disturbed land such that reclaimed soils and landforms are capable of supporting a self-sustaining, locally common boreal forest regardless of the end land use, and to ensure that the reclaimed land is integrated with the surrounding areas. Establishment of jack pine (*Pinus banksiana* Lamb.) stands on sandy materials (a1 ecosites) is often challenging.

During a 2013 site visit to the Kearl River Water Intake (RWI), it was noticed that dense stands of jack pine were establishing along the RWI Right-of-Way (RoW) south of the RWI access road. At the time, it was assumed that the establishment was due to the Richardson Fire that burned the area in May 2011. Prior to the fire, the RoW appeared to be colonized by grasses and early successional herbaceous species through natural regeneration and/or ingress; jack pine seedlings were not planted.

The Jack Pine Revegetation Trial (JPRT) was initiated as a "proof-of-concept" trial to mimic the effect of fire and revegetate two former construction laydown areas (Bouchier and Willbros) at the Kearl site with jack pine seed through three separate cone heating and seeding treatments, and compare the results to plots located in nearby natural burned areas. The three treatments are: Treatment 1: broadcast seeding of jack pine seed; Treatment 2: scattering of untreated, intact jack pine cones; and Treatment 3: scattering intact jack pines cones, and then applying a heat treatment on site using black polyethylene covering for 24 hours. The black polyethylene tarps were in place during June 21-22, 2016. Temperature under the tarp was not measured during this time but prior preliminary field experiments indicated a temperature increase of at least 5-10^{o}C relative to ambient air temperature. The temperature under the tarp might have reached 33-38^{o}C as the air temperature was 28^{o}C at the time.

Specific objectives of the trial include: evaluating jack pine revegetation success (via seeding) based on establishment of desired plant communities and trajectory towards target a1 ecosite phase; comparison of results of the three treatments to jack pine establishment and height in natural burned areas at "Year 5 post-treatment" (2021) to the revegetation results at "Year 5 post-fire" (2016) to make generalizations about stand trajectory and the efficacy of the seeding treatments in relation to regeneration following a fire.

The data and observations made as part of the trial may provide early indications that alternative revegetation strategies (e.g., other than via seedling planting) are possible.

PROGRESS AND ACHIEVEMENTS

Year 2 (2017) vegetation monitoring for the Jack Pine Revegetation Trial, took place in mid-July 2017. Year 2 monitoring captures the second growing season for the treatment plots, and Year 6 post-fire for the natural burned area. Each subplot was assessed for percent cover of trees, shrubs, forbs, graminoids, bryophytes and lichens, leaf litter and bare ground. Vegetation species were identified with reference to the Flora of Alberta (Moss 1983) and Plants of the Western Boreal Forest and Aspen Parkland (Johnson et al. 1995).

As recommended in the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (the Revegetation Guidelines; AENV 2010), information collected from the vegetation quadrats was used to calculate species abundance, richness, evenness, and diversity, using the Shannon Diversity Index. These vegetation metrics from 2017 were compared to 2016 data using analysis of variance. Measured heights were grouped into three height classes (<5 cm, 6-15 cm, and >100 cm) to allow comparison of treatment subplots to Year 5 Natural Burn Subplots.

Jack pine seedlings were present in all treatment plots (100 m^2) at the Bouchier laydown area. However, seedlings have not emerged in all subplots. Seedling emergence at the Wilbros laydown area has been minimal, potentially due to competition with graminoids at the site. At this time, all seedlings are in the lowest height class (< 5 cm) in treatment plots and therefore meaningful analyses of this metric could not be performed. Although not analysed statistically, seedlings in plots established at the natural burned site (plots N1 and N2) were present in much higher abundance and were predominantly in the tallest height class (> 100 cm). The natural stand data is approximately four years older than Year 2 (2017) treatment plot data. Establishment and growth of jack pine seedlings has been slow in the treatment plots, with limited seedling emergence observed in the smallest assessment subplots (0.5 m × 0.25 m). Seedling emergence was observed in the full 100 m^2 plots, particularly at the Bouchier laydown. Seedlings are still too small to be reliably counted in the full 100 m^2. If substantial growth occurs over the next year, field crews may increase the assessment area to the full 100 m^2 plot to collect more meaningful data on seedling emergence in Year 3 (2018).

None of the community metrics calculated were dependent on seeding treatment in 2017. Several of the metrics did change significantly between Year 1 (2016) and Year 2 (2017). Species richness per subplot, total species richness (100 m^2 assessment plot), and evenness increased, while the number of characteristic species decreased. Although statistically significant, the decrease in the number of characteristic species may not be biologically significant; on average, plots contained 0.5 fewer species in Year 2 (2017) than they did in Year 1 (2016).

Statistical comparisons were not made between treatment plots (Year 2 [2017]) and plots in the natural burn area (Year 5 [2016], Year 6 [2017]) in 2017. Values for diversity and total species richness (100 m^2) were comparable between treatment and natural burned plots. In both Year 1 (2016) and Year 2 (2017), percent vegetative cover was greater in treatment plots, while evenness was greater in natural burn plots, suggesting that vegetative cover in treatment plots is still dominated by one or a few species. The number of characteristic species was also higher in the natural burn area (three species) than the treatment plots (0.5 to 1.0 species). The threshold as presented in the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (AENV 2010) for the Dry site type (a1 ecosite phase, pure jack pine dominated) is two species.

LESSONS LEARNED

At this stage of the study, no treatment has been revealed as most effective in establishing jack pine from seed. All treatments at Year 2 (2017) were visibly less effective than the natural burn at Year 5 (2016). However, some performance metrics were similar to, or approaching, those in the natural burn area. Data from vegetation monitoring in subsequent years will be used to track the trajectory of these plots.

LITERATURE CITED

Alberta Environment (AENV). 2010. Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region. CEMA: Cumulative Effects Monitoring Association Terrestrial Subgroup. Fort McMurray, Alberta.

Johnson, D., L. Kershaw, A. MacKinnon and J. Pojar. 1995. Plants of the Western Boreal Forest and Aspen Parkland. Lone Pine Publishing, Edmonton, Alberta. 392 pp.

Moss, E.H. 1983. Flora of Alberta Second Edition (revised by J.G. Packer). University of Toronto Press. Toronto, Ontario.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and & Environmental Consulting Inc.

Principal Investigator: Brittany Flemming

Establishment of Ericoid Mycorrhizal Associated Shrub Species (Blueberry, Labrador Tea and Lingonberry) in Oil Sands Reclamation Soils

COSIA Project Number: LJ0128

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Imperial

Status: Year 2 of 4

PROJECT SUMMARY

The reestablishment of blueberry (Vaccinium myrtilloides), and other plant species from the Ericaceae family in oil sands reclamation areas, is of considerable interest due to their ecological importance in the boreal forest and status as cultural keystone species for First Nation communities (Garibaldi and Straker, 2009). The growth of these species in reclamation sites is severely impacted by different environmental stresses, including high soil pH and salinity. Ericaceous plants are known to form symbiotic associations with ericoid mycorrhizal fungi (ERM) (Sharples et al., 2000; Mitchell and Gibson, 2006). However, the importance of ERM associations in the survival and sustained growth of ericaceous plants under different environmental conditions present in oil sands reclamation sites is not known. In the present project, we examine the diversity of ERM in the roots of several Ericaceous species growing in natural forest sites and reclamation soils, as well as their role in conferring resistance to high pH, salinity, and drought. The results of the study will be used to improve revegetation of oil sands areas with Ericaceous plants.

Specific objectives are to:

1. Identify the ericoid mycorrhizas in the roots of upland and lowland blueberry (Vaccinium myrtilloides Michx.), Labrador tea (Rhododendron groenladicum [Oeder] Kron & Judd) and lingonberry (Vaccinium vitis-idaea var. minus Lodd) plants in natural forest sites, oil sands reclamation soils and nurseries;
2. Examine whether ERM associations enhance high pH, drought and salinity tolerance in these plant species;
3. Determine the effects of ERM associations and pH on water relations of upland and lowland blueberries, and the role of plant and fungal aquaporins in these responses; and
4. Examine the growth responses of ERM colonized plants following planting in oil sands reclamation areas.

The project consists of four studies that include both field and environmentally controlled experimental conditions.

PROGRESS AND ACHIEVEMENTS

Experimental Design

Study 1 - Identify the ericoid mycorrhizas in the roots of upland and lowland blueberry (Vaccinium myrtilloides Michx.), Labrador tea (Rhododendron groenladicum [Oeder] Kron & Judd) and lingonberry (Vaccinium vitis-idaea var. minus Lodd) plants in natural forest sites, oil sands reclamation soils and nurseries.

Collection of fungi isolated from Ericaceous roots

During 2017, fungal isolates were collected from roots of wild blueberry, lingonberry and Labrador tea gathered from natural forest sites in the Athabasca Oil Sands Region (10 root systems per species and collection site, 4 sites for blueberry, 3 for lingonberry and 6 for Labrador tea, for a total of 130 samples). The isolates have been maintained by periodic sub-culturing in Potato Dextrose Agar (PDA). The collection comprises approximately 150 different isolates, of which most have been identified to the species or genus level.

Preliminary seedling growth assessment

Previous in-house assays determined that the three plant species exhibit low germination rates and slow growth. Therefore, surface-sterilized seeds were sown and maintained in agar plates with Murashige & Skoog (MS) medium for two months before being planted for greenhouse experiments. Plants were watered every three days and fertilized with 20-20-20 (N-P-K) fertilizer every two weeks for six months.

Soil preparation and transfer of seedlings

In February 2017, reclamation soils consisting of two types (freshly salvaged topsoil, and topsoil stockpiled for one year) were delivered to the University of Alberta. Nine, 45-cell styrofoam blocks were filled with the soils, and divided between three treatments: fresh topsoil, stockpiled soil, and stockpiled soil that had been autoclaved). Seedlings were transplanted to soil from MS media. Plants were watered every two days and fertilized weekly with 20-20-20 NPK.

Physiological measurements

Photosynthesis and transpiration measurements were started in August, 2017, using an IRGA portable photosynthetic system. After these measurements, all plants were harvested to measure other physiological parameters: chlorophyll, dry biomass (shoot and root), and tissue elements. Roots of all plants were then thoroughly washed and subdivided into two parts, one part was stored in FAA fixative solution for microscopy analysis, and another part was stored at -80^{o}C for molecular analyses.

Study 2- Examine whether ERM associations enhance high pH, drought and salinity tolerance in these plant species.

This study focuses on the effects of ERM on drought resistance of blueberry populations (*Vaccinium myrtilloides*) that have been taken from both upland and lowland sites. A total of 400 plants, 20 per population per fungus, were used to examine the effects of ERM on drought stress resistance. This study was carried out under controlled environmental conditions in a sterile growth medium. Seeds from the lowland and upland populations of blueberry were collected in 2015 in the boreal forest near Fort McMurray. These seeds were surface-sterilized with 5% sodium hypochlorite and germinated in pots containing autoclaved sand and peat moss mixture (1:2, by volume). The studies were carried out in a growth chamber set to 18-h photoperiod, 400 µmol m^{-2} s^{-1} photosynthetic photon flux density, and day/night temperature of 23/18°C.

Seed germination

Lowland and upland blueberry seeds were sterilized and sown in the sterile culture medium in early March 2017. Seeds started germinating in May, and by the end of June lowland and upland blueberry seed germination rates reached about 20% and 50% respectively. The seedlings were fertilized with 25% Hoagland's mineral solution every two weeks. In the later stages of seedling growth, Hoagland's solution was not effective for blueberry seedlings and an acidic commercial fertilizer was used instead. In the middle of July, most of the seedlings reached 3cm in height, and 400 individual seedlings were transplanted into 3.5 Kordlok square pots for the growth. In September, seedlings reached about 7-9 cm in height and were ready to be inoculated.

Study 1 - Identify the ericoid mycorrhizas in the roots of upland and lowland blueberry (Vaccinium myrtilloides Michx.), Labrador tea (Rhododendron groenladicum [Oeder] Kron & Judd) and lingonberry (Vaccinium vitis-idaea var. minus Lodd) plants in natural forest sites, oil sands reclamation soils and nurseries;

Collection of fungi isolated from ericaceous roots:

Due to different problems during sample processing (poor DNA extraction, non-specific PCR amplification, low concentration of the final purified PCR product to be sent for sequencing, etc.) A subset of isolates had to be re-cultured again onto cellophane membranes in order to get more material. All DNA extractions on these remaining samples are complete and are ready for further analysis.

From this collection we identified 12 isolates corresponding to five ERM species and one dark-septate root endophyte that commonly associates with ericaceous plants: *Rhizoscyphus ericae*, *Pezicula ericae*, *Oidiodendron maius*, *Geomyces* sp., *Meliniomyces* sp. and *Phialocephala fortinii*. Four of these isolates were selected, re-cultured onto cellophane membranes and their ID re-checked (BLASTed in both NCBI and JGI) before proceeding to the subsequent inoculation studies.

Survey of ERM inoculum potential in reclamation soils (LFH topsoil and peat mineral soil):

Root samples are currently being processed for DNA analysis. For microscopy assessment of ERM, a protocol for root clearing and staining with 5% ink vinegar has been optimized for very fine root hairs. Colonization percentage and colonization intensity tests are currently being performed.

Study 2 - Examine whether ERM associations enhance high pH, drought and salinity tolerance in these plant species.

ERM selection and inoculation

Based on the result of Study 1, four ERM species were selected for the drought stress experiment: *Pezicula ericae* (isloate #38), *Rhizocyphus ericae* (#50), *Meliniomyces bicolor* (#82), and *Oidiodendron maius* (#96).

The ERM fungi were cultured in solid potato-dextrose-agar (PDA) medium. For the inoculation, the fungal colonies were transferred to the liquid Modified Merlin Norkrans (MMN) medium. ERM fungal inoculation started from early September 2017. Approximately 10 ml of the liquid culture was injected with a syringe into the deep layer of soil around the roots. Fertilization was stopped one month before the inoculation to improve the inoculation rate. One month later, root samples were taken to inspect for fungal growth.

Drought treatment

Two months after inoculation, the plants were divided into, the non-stressed control group, and the drought treatment group.

The drought treatment started on December 30, 2016. Three cycles of drought stress were applied to seedlings of the drought group. These seedlings were watered every 8 days. Control seedlings were watered every two days.

Daily change of soil moisture content was monitored with the time-domain reflectometry (TDR) probes. Daily change of gas exchange parameters, including stomatal conductance, transpiration and net photosynthesis, were measured with the Li-6400 portable photosynthesis system.

Seedlings were harvested for leaf, shoot and root fresh and dry weight determinations. Part of each rootsamples was fixed by FAA solution for the examined for mycorrhizal colonization, and part of the roots was kept in -80°C freezer for the DNA analysis.

Status and results

The experimental part of the drought stress experiment has been completed. All shoot, leaf and root samples from 360 plants had been collected for further analysis.

a) Mortality rate

The drought treatment resulted in high mortality in the blueberry populations. Results show that inoculation with ERM fungi was effective in reducing the mortality rate when compared with the non-inoculated control. In the non-mycorrhizal group, the upland population had a lower mortality rate compared to the lowland blueberry population. For the inoculated plants, the mortality rate varied among different mycorrhizal species innoculations.

b) Biomass

The following results were obtained:

- The total fresh weights of the upland blueberry population were about 170%, 81% and 42% higher than the non-inoculated control in fungal strain innoculations with strains #38, #50 and #83, respectively.
- For lowland blueberry, the total fresh weight was about 81%, 38% and 9% higher than in the non-inoculated control in #38, #50 and #83 strains, respectively, under drought stress.
- Lowland blueberry seedlings inoculated with #38, #50 and #96 strains had a higher fresh weight than the non-inoculated control.
- For upland blueberry, seedlings inoculated with #38 and #82 strains had a higher fresh weight than the non-inoculated control.

c) Water potential

The results indicate that, ERM fungi were effective in maintaining relatively higher water potential in both upland and lowland blueberry in comparison to the non-inoculated control plants. And under well-water treatment, lowland blueberry population had higher water potential levels than the upland blueberry.

d) Gas exchange parameters

The gas exchange parameters measurements were carried out daily following the drought application. The leaf area data is currently being analyzed.

e) Inoculation rate

Fine roots were subdivided into two samples; one was stored at -80°C for assessment of ERM colonization by the DNA analysis while the other one was stored in the FAA fixative for the microscopy analysis. Root samples are currently being processed for the DNA analysis.

Study 3 - This study focuses on the effects of soil type (fresh vs. stockpiled) and salinity on mycorrhizal and non-mycorrhizal ericaceous plants.

Plant performance in fresh and stockpiled reclamation soil

Blueberry plants showed higher growth rates in fresh soil compared with the reclamation soil that had been stockpiled for one year in both autoclaved and non-autoclaved treatments.

Labrador Tea plants showed higher growth in both fresh soil and autoclaved stockpiled soil compared with the non-autoclaved stockpiled soil.

Chlorophyll Concentration

Chlorophyll concentration of blueberry plants in fresh soil was higher than that of plants in non-autoclaved stockpiled soil, but there was no significant difference between fresh soil and autoclaved stockpiled soil.

Elemental analysis

Plant and soil samples are currently being analyzed for N, P, K, Mg, Ca, and Na concentrations as well as pH, electrical conductivity (EC) and sodium adsorption ratio (SAR) parameters.

Colonization rates

Microscope assessment showed that mycorrhizal colonization of roots in fresh soil was higher than that of roots in stockpiled soil (both autoclaved and non-autoclaved) for all three plant species.

Effect of ericoid mycorrhizal fungi on salinity tolerance in ericaceous plants

This experiment was carried out with blueberry, cranberry, and Labrador tea from June to December, 2017. The seeds of three ericaceous plants were surface sterilized and sown on the MS medium before transplanting to the autoclaved potting mix. Concurrent to plant growth, two ericoid mycorrhizal fungi strains (*Oidiodendron maius* [strain #96] and *Meliniomyces variabilis* [strain #81]), which were identified in Study 1, were cultured in the solid PDA medium and transferred to the liquid MNM medium for the inoculation.

The plants were divided into 3 groups: inoculated with strain #96, inoculated with strain #81, and control (no inoculation). Plants were inoculated two times with 4 ml of fungal culture for each plant. The experimental treatments involved 0 mM NaCl (control) and 30 mM NaCl.

The treatments were completed on December 15 and included net photosynthesis, transpiration, leaf chlorophyll concentrations, dry biomass (shoots and roots), and tissue elemental concentrations. Roots of all plants were thoroughly washed and stored in the fixative solution for microscopy assessments. All data are being presently analyzed.

Preliminary results indicate that the inoculated plants, especially cranberry, had greater salinity tolerance compared to non-inoculated plants.

LESSONS LEARNED

The preliminary results indicate that the ERM fungi #38, #50 and #82 are candidates for further investigation on growth of the two blueberry populations under well-watered conditions.

In all experiments conducted, ERM inoculation improved the growth rates in ericaceous plants and also improved their tolerance to drought and high salinity conditions. While most of the data for the salinity and drought experiments are being still analyzed, the differences between ERM and non-ERM plants are striking. The results also indicate that the stockpiled soil was less suitable compared with fresh soil for the growth of ericaceous plants.

LITERATURE CITED

Garibaldi A, Straker J. 2009. Cultural keystone species in oil sands mine reclamation, Fort McKay, Alberta, Canada. In British Columbia Mine Reclamation Symposium. Available from http://hdl. handle. net/2429/24607.

Mitchell DT, Gibson BR. 2006. Ericoid mycorrhizal association: ability to adapt to a broad range of habitats. Mycologist 20:2-9.

Sharples JM, Chambers SM, Meharg AA, Cairney JW. 2000. Genetic diversity of root-associated fungal endophytes from Calluna vulgaris at contrasting field sites. New Phytologist 148:153-62.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Janusz Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Sepideh Fadaei	University of Alberta	M.Sc.	2016	2019
Deyu Mu	University of Alberta	M.Sc.	2016	2019

Effects of Non-Segregated Tailings (NST) on Growth of Oil Sands Reclamation Plants

COSIA Project Number: LJ0303

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Ongoing

PROJECT SUMMARY

Non-Segregating Tailings (NST), are a waste product of oil sands processing in northeastern Alberta. In the near future, NST deposits at the Horizon lease must be reclaimed: capped with suitable overburden, upland subsoils, upland cover soils, and revegetated. However, there are significant knowledge gaps to the potential success of NST reclamation, such as how vegetation will tolerate the potentially limited nutrient supply, high pH, elevated salt concentrations, or the presence of phytotoxic substances such as fluoride and naphthenic acids. These factors can adversely affect water and nutrient uptake of the plants used for reclamation, as well as microbial activities and community structures, particularly of mycorrhizae, in the reconstructed soils. It is therefore crucial to understand how species that are used in reclamation revegetation activities and representative of the locally-common Boreal forest, will respond in the reclamation of NST deposits.

Several plant species used in reclamation are of special significance to Aboriginal communities living in the area. Therefore, an important part of the investigation of NST reclamation will be to understand if potential contaminants from within the NST in reconstructed soils could greatly reduce establishment, growth and yield, as well as the quality of these plants, especially for medicinal uses. Additionally, successful growth of many plants in oil sands reclamation areas is dependent on the successful establishment of mycorrhizal associations, but to that effect there is little understanding of the impacts of NST on the inoculation potential of mycorrhizal fungi on reclamation plants. These associations are essential to provide plants with sufficient nitrogen and phosphorus nutrition, as well as protection from abiotic stressors.

The objectives of the project are:

1. To examine growth and physiological parameters in 20 native boreal forest plant species growing in 6 types of growth media containing a combination of NST, reclamation cover soils, or coke.
2. To examine effects of NST on uptake and tissue distribution of trace elements in three selected species of plants of special significance to Aboriginal communities.
3. To examine effects of NST on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in reconstructed soils and roots of reclamation plants.
4. To examine effects of different nitrogen and phosphorus supplies on plants growing in NST-amended soil.

PROGRESS AND ACHIEVEMENTS

Towards the achievement of objectives of 1 and 2, four rounds of a plant growth experiment were undertaken in 2017. Each phase studied different plant species common to upland reclamation. The species selected, study design and findings from each experimental phase are outlined below.

Study design:

One-year-old nursery obtained seedlings, were grown in PVC pipes of 50-cm length and 10-cm diameter in a controlled-environment growth room.

The PVC pipes were filled with six types of growth media:

A: 40-cm topsoil (upland forest floor-mineral mix, control);
B: 40-cm peat-mineral mix (PMM, control);
C: 40-cm NST (non-segregating tailings, control);
D: 30-cm NST capped with 10-cm topsoil;
E: 30-cm NST capped with 10-cm PMM; and
F: 30-cm NST capped with 10-cm coke and 10-cm top soil.

The seedlings were growing in these media for three months. Plants were watered every two days and fertilized with 50% modified Hoagland solution weekly. Seedling shoot heights were measured at the beginning and end of treatment period. At the end of the each round of experiments, leaf gas exchange parameters (net photosynthesis and transpiration rates) were measured with a LICOR-6400 photosynthesis instrument, leaves were sampled for chlorophyll and elemental analysis, and shoots and roots were harvested and oven-dried for biomass measurements.

Species selected for each study:

Round 1 (December 2016 to February 2017): black spruce (*Picea mariana*), Labrador tea (*Ledum groenladicum*), balsam fir (*Abies balsamea*), and blueberry (*Vaccinium myrtilloides*)

Round 2 (May to August 2017): balsam poplar (*Populus balsamifera*), tamarack (*Larix laricina*), Canadian buffaloberry (*Shepherdia canadensis*), jack pine (*Pinus banksiana*) and raspberry (*Rubus sp.*)

Round 3 (September to November 2017): red-osier dogwood (*Cornus sericea*), paper birch (*Betula papyrifera*), green alder (*Alnus viridis*), and Schubert chokecherry (*Prunus virginiana*)

Study findings to date:

So far, all the analyses for Round 1, as well as biomass and gas exchange analyses for Round 2 have been completed. Chlorophyll and elemental analyses for Round 2, and all tissue analyses for Round 3 will be completed in February, 2018. Preliminary results are interesting, and showcase a large degree of variability between interactions of species and treatment type.

- Among all the species that were examined in Rounds 1 and 2, only Labrador tea and Canadian buffaloberry showed no mortality in all treatments. However, these two species also showed reduced growth and lower gas exchange rates in treatment C (40-cm NST). Blueberry showed 100% mortality in treatment C (NST control). Overall, plants had higher mortality rates in the treatments with media containing NST compared with the control treatments containing only top soil or peat mineral mix (Treatments A or B).

- In Round 1, there was no significant difference in relative shoot height growth (RSHG) between treatments with black spruce, Labrador tea, and balsam fir, although generally the RSHG was lower in plants growing in media containing NST.
- In Round 2, balsam poplar, tamarack and Canadian buffaloberry, had generally higher RSGH rates in treatments A (topsoil control) and B (peat-mineral mix control).
- There was no significant difference in dry weight in balsam fir, tamarack and jack pine. In black spruce, Labrador tea, and Canadian buffaloberry, dry weights were higher in treatments A and B than treatments involving NST.
- For black spruce, blueberry, Labrador tea, and balsam poplar, there was no significant difference in net photosynthesis rate. For balsam fir, tamarack, and Canadian buffaloberry, net photosynthetic rates of plants grown in NST containing treatments were generally lower than in treatments A and B. For jack pine and raspberry, net photosynthetic rate in treatment C (NST control) was much lower compared with the remaining treatments.
- Overall, the responses of transpiration rates for all studied species were similar to those of net photosynthetic rates.
- In Labrador tea, the chlorophyll concentration of seedlings in treatment C (NST control) was significantly lower, compared with other treatments. In blueberry, the chlorophyll concentration of plants in treatment B (peat-mineral mix control) was higher than that in other treatments.
- In black spruce, the foliar Na concentrations in treatment C (NST control), D (NST with topsoil cap) and F (NST with coke and topsoil caps) were significantly higher compared with the other treatments. Also, foliar Ca concentration in treatment C was significantly lower than that in other treatments. In Labrador tea and balsam fir, foliar Na concentration in treatment C was significantly higher than in all other treatments. In Labrador tea, in treatment D (NST with peat-mineral cap) foliar K concentration was lower than the other treatments. For balsam fir and blueberry, there was no significant difference in the foliar elemental concentrations between the treatments.

LESSONS LEARNED

Labrador tea and balsam poplar had low mortality rates in NST treatments and showed similar growth and physiological responses across all treatments. Generally, plants grew better in a media profile of NST covered with topsoil or peat mineral mix compared with those grown in only NST, however the benefits of the capping material over NST might be different for different species. Blueberry was quite sensitive to NST, as all the seedlings in the NST control treatment had died by the end of the experiment. Balsam fir, jack pine and raspberry were also quite sensitive to NST – more than half of seedlings of these species did not survive the NST control. Sodium toxicity is the main factor in NST that inhibited plant growth. Contrary to the initial expectation, there were no severe nutrient deficiencies in plants grown in NST.

Labrador tea and balsam poplar showed relatively higher growth rates in the NST treatments compared with the other examined species. Therefore, these two species should be further examined for their potential use in the reclamation of NST-affected sites. As the permeability of NST is quite low, the plants might also have been under hypoxic stress that likely aggravated the responses of plants to the applied treatments. However, we found similar beneficial effects of the topsoil and peat mineral mix camps over NST in terms of plant growth. Additionally, it was found that capping NST with coke produced limited effects. The growth of blueberry, balsam fir, jack pine and raspberry in NST was severely inhibited in NST treatments, indicating that revegetation of these species in NST reclamation areas might need require intensive management.

Plants did not show any nutrient deficiencies in these experiments, however the experimental period was quite short. In the longer term, there is a possibility that reclamation plants could suffer nutrient deficiencies in NST-containing soils profiles. Therefore, longer term controlled environment and field studies will be needed to monitor nutrient uptake of plants grown in NST reclamation areas.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Janusz Zwiazek

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Wenqing Zhang	University of Alberta			

Long-Term Plot Network

COSIA Project Number: LJ0295

Research Provider: Paragon Soil and Environmental Consulting Inc., FORCORP

Industry Champion: Canadian Natural Resources Limited

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

Status: Ongoing

PROJECT SUMMARY

The Long-Term Plot Network (LTPN) is a cooperative set of re-measured plots established to monitor the ongoing development of vegetation and soils in both reclaimed and natural upland forest sites in the Athabasca Oil Sands Region (AOSR). The program and associated data sets are expected to be an information source from which industry can analyze and research upland reclamation outcomes observed over multiple decades. Specifically, the program will develop a knowledge base contributing to an understanding of long term patterns of ecosystem development and diversity on reclaimed ecosystems following oil sands mining. The program was formerly housed and managed by the Cumulative Environmental Management Association (CEMA). Following the suspension of CEMA's operations in 2016, the program has been managed by industry partners.

PROGRESS AND ACHIEVEMENTS

2017 marked a transition year for the Long-Term Plot Network program. To ensure that the LTPN datasets remain accessible, applicable, and relevant to future reclamation monitoring and research in the AOSR, an initiative was undertaken to re-draft the program objectives with a renewed emphasis on the original intent of the program, and the preparation of an associated program rationale document.

The scope for a Project Coordinator was developed to fulfill high-level strategic planning and program coordination functions that were previously filled by the Program Coordinator at CEMA. FORCORP was retained to fill this role, which included development of the previously mentioned rationale document. As in 2016, FORCORP also provided crucial database support including field data uploading, database management, data QA/QC, and further development of the LTPN database.

The annual field sampling program was conducted by Paragon Soil and Environmental Consulting, and included re-measurement of 30 plots following the pre-established schedule. Beyond standard measurement required by the sampling protocol, the program also piloted field application of the *Forest Floor Recovery Index* (FFRI), an assessment protocol created by Natural Resources Canada. The FFRI required field testing to inform its further development, and the LTPN reclamation plots presented an ideal field testing opportunity.

Further strategic development of the program (e.g., re-instating guidance, program coordination, ongoing development of the database), is aligned with meeting the long-term, revised program objectives.

LESSONS LEARNED

In a process of re-evaluating program objectives in 2017, it became clear that the program's focus had strayed over time, with the emergence of explicit linkages to testing assumptions in guidance documents such as *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region*. This shifted emphasis was deemed inappropriate by the industry partners, with the result being a return to the original program intent.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Bob Christian	FORCORP	Program Coordinator		
Kerry Nice	FORCORP	Application Development Manager		
Vincent Futoranski	Paragon Soil and Environmental Consulting	Field Coordinator		

Wildlife Research and Monitoring

Wildlife Monitoring – Horizon Oil Sands

COSIA Project Number: LJ0186

Research Provider: Canadian Natural Resources Limited, LGL Limited Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Status: Year 12 - Ongoing

PROJECT SUMMARY

Remote wildlife cameras are a useful tool for assessing and monitoring various aspects of terrestrial wildlife, especially the wildlife's return to and use of anthropogenically altered habitats (Hawkes, et al. 2017). The proper implementation of these cameras increases the likelihood of detecting the use and distribution of certain species of wildlife across specific areas and habitats (Burton et al. 2015).

Wildlife cameras have been deployed on the Horizon Oil Sands lease consistently since 2006. Cameras are currently deployed in a number of areas for regulatory requirements and in other areas to assess key habitat types including riparian, reclamation and compensation lake habitat types. Remote camera use contributes important data on the occurrence and distribution of wildlife, and the time of day and year that certain species occupy and utilize various habitats. For species with enough data, we evaluated the efficacy of species-specific occupancy models based on their variances under different sparseness and detection criteria (Hawkes et al. 2016).

Wildlife camera data can be used to test assumptions of potential use of reclaimed habitats relative to area and proximity to intact habitats. However, species-specific detection rates will also vary relative to multiple factors, which may be related to the population abundance of a given species, but also to camera location, movement patterns, and inter-specific interactions (Burton et al. 2015), and of relevance to Canadian Natural Resources Limited (Canadian Natural), to mitigation strategies implemented to deter wildlife from using certain portions of the Horizon Oil Sands Lease (Hawkes et al. 2016). These variations are being considered when assessing wildlife use based on camera trap data.

PROGRESS AND ACHIEVEMENTS

Note: Results of the 2016 monitoring program became available after the publication of the COSIA Land EPA 2016 Mine Site Reclamation Research Report and are therefore presented in this report.

Overall, wildlife cameras in all locations have documented the presence of 41 birds and 22 mammals with the number of bird species recorded annually ranging from 1 (2006) to as high as 26 (2013) and the number of mammals ranging from 8 (2006 and 2007) to as high as 19 (2012).

Horizon Lake

Ten species of wildlife were present in >1% of all photographs obtained. Red fox, white-tailed deer, and wolf were the most frequently photographed species. The number of red fox photographed appears to have declined since 2012, although numerous photographs are obtained each year. The number of wolves photographed appears to have remained relatively stable over time (following an initial increase in 2007, which could be related to camera effort). White-tailed deer activity patterns have also remained relatively constant since 2010, with the exception of 2015. Patterns of presence and activity for moose, black bear, coyote, and have been consistent over time. Very few snowshoe hares and Canada lynx have been photographed in habitats around Horizon Lake.

Reclamation Area 1

Fewer species were documented from Reclamation Area 1, which is expected given the age of the reclamation area relative to the Riparian Habitats and the proximity of the Horizon Lake cameras to relatively intact mature forest. Some species were documented only a few times (e.g., red fox, black bear, wolf, and mallard), while others were abundant and seemingly omnipresent (e.g., coyote and white-tailed deer). Although few individuals of red fox, black bear, and wolf were reported on Reclamation Area 1, other data (e.g., visual observations, winter-active animal surveys) indicate these species are present across the reclamation area. The lack of photographs of a given species should not be correlated with a lack of individuals or a low incidence of use. Other species not recorded on wildlife cameras but documented from Reclamation Area 1 include moose and several weasels.

Riparian Habitats

The presence of wildlife in Riparian Habitats has been relatively consistent over time. Of the nine species of wildlife present in >1% of all photographs obtained, white-tailed deer were the most frequently photographed species, present in all years and active in most months and throughout the day and night. The number of photographs assigned to white-tailed deer started to increase mid-way through 2011, with similar numbers obtained between 2012 and 2016. This could be an indication of an increase in white-tailed deer abundance, white-tailed deer density, or increased activity levels around wildlife cameras, but is more likely related to the increased number of cameras deployed in Riparian Habitats starting in 2012 (15 vs. a maximum of 9 in previous years). Coincident with an increase in the number of white-tailed deer photographs was an increase in the number of wolf photographs, again likely due to an increase in the number of cameras. Black bears have been documented from Riparian Habitats since 2006 with little variation in the number of photographs or time of day they are active. Snowshoe hare exhibit a notable diurnal pattern, which is not surprising given the crepuscular nature of this species. A similar, though less obvious pattern was observed for coyote, red fox, and possible lynx, all of which are potential predators of snowshoe hare. The number of moose detections has been relatively consistent over time.

Occupancy Modelling

Occupancy models were developed for select species in each cluster of cameras by habitat type. Because occupancy models account for variable effort, it is possible to use the camera trap data to assess trends over time.

Occupancy models were produced for red fox, coyote, Canada lynx, grey wolf, American black bear, snowshoe hare, white-tailed deer, and moose based on their photograph records comprising > 1% of the total detections and being species of interest. Sparseness criterion of 2.5% and 10% and detections of 1, 2, or 3 photos per month were considered for generating all eight of the select species' encounter histories. As the sparseness criterion increases from 2.5% to 10% (along with the number of detections) the ability to generate occupancy declines. This is observed in the overall reduction of models generated for all species and various closure periods under the 10% sparseness criterion and the lack of any models generated for snowshoe hare and red fox in Riparian Habitats. A sparseness criterion of at least 2.5%, for species with at least 1% of the total detections, was determined to be adequate data to model occupancy and the encounter histories under these parameters are reported. Comparing the models based on sample area (Horizon Lake, Reclamation Area 1, and Riparian Habitats), we observe that, regardless of the detection criterion (i.e., 1, 2, or 3 sightings per month) the patterns of occupancy are similar over time, with occupancy consistently higher and more stable across the Riparian Habitat for the majority of species and seasons. Most analyses in the Riparian Habitats meet the lower data sparseness cut-off (i.e., 2.5%) for most species and detection criteria. Exceptions include red fox and Canada lynx at higher detection criteria. No winter black bear analyses met the data sparsity cut-offs, which can be expected given that hibernation behaviour of black bears. Analyses for the Horizon Lake tended to only meet the lower data sparseness cut-off for the lower detection criterion, indicating potentially lower relative usage. The exception to this generalization was for red fox, which meet the higher sparseness cut-off for all detection criteria, and snowshoe hare, which did not meet even the lowest cut-off. Reclamation Area 1 analyses only met the sparseness criterion cut-off for species at the lower detection criteria and only in few closure periods. Occupancy also varied between species and closure periods.

Red fox was the single species that modelled a higher use around Horizon Lake sites versus Reclamation Area 1 and the Riparian Habitats, with an annual increase from 2010 through to a decrease starting around 2012-2014 depending on the closure period under consideration. Coyote analyses consistently indicated a higher use in Riparian Habitats showing increasing use in winter and spring, but a contrasting evidence for a decrease use in summer and fall, a trend also seen in most models generated around Horizon Lake. Canada lynx analyses predominantly met data sparsity criterion for Riparian Habitats, but also showed indications of higher use around Horizon Lake in the spring and fall from 2011 to 2013. Wolf analyses showed relatively stable use across Riparian Habitats and inconclusive fluctuations around Horizon Lake. Black Bear analyses showed higher usage in Riparian Habitats with slight fluctuations in the spring, high stable levels throughout summer, general increases throughout the fall, and absent during winter months of hibernation. Snowshoe hare analyses were generally limited to Riparian Habitats with subtle fluctuations between seasons. While analyses showed the highest usage in the Riparian Habitats, White-tailed Deer was the only species consistently modelled in Reclamation Area 1. For analyses and years (i.e., 2013 to 2016) where there were enough detections to meet data sparsity criteria for all three habitat types was only consistently met for white-tailed deer, which showed similar usage trends for the three habitat types with usage trends that were relatively high and stable, with some minor fluctuations in the spring closure period. Other species where all three habitat analyses were available for some of the closure periods were, black bear, coyote and red fox. Black bear showed a similar summer usage trend as for all three habitat types, but lower in the fall, while for coyote usage patterns across the tree habitat types were similar, albeit more unstable. Red Fox analyses only showed two instances where all three habitat types met sparsity criteria, which is not enough to draw conclusions about usage trends across the three habitat types.

LESSONS LEARNED

Occupancy was used as a proxy for usage and was estimated using the occupancy modelling framework, which was originally designed for discrete field surveys rather than continuous monitoring as provided by camera traps (MacKenzie et al. 2002). As a result, some challenges had to be overcome to modelling camera trap detections with occupancy models. Occupancy trends under different sighting thresholds were relatively constant, with only a few instances where the higher threshold produced a lower estimate of the percentage of sites occupied (e.g., black bears). This may indicate the efficacy of the data sparsity cut-off or it may reflect the need to have a larger distance between detection thresholds or the need to set detection thresholds on a per species basis. The sparsity cut-offs of 2.5% and 10% produced much more notable differences, with some species showing either no or few qualifying analyses at the higher cut-off (e.g., snowshoe hare and Canada lynx). The higher sparsity cut-off also showed evidence of some species-specific habitat preferences (e.g., red fox for the Horizon Lake cluster of cameras) or the ubiquity of sightings for some species (e.g., white-tailed deer). Further work is required to develop a formalized statistical framework.

We also acknowledge that the number of photographs is not a representation of population abundance nor do they provide absolute assessments of wildlife use on a seasonal or annual basis. The data provide evidence of occupancy (use) that can be modelled over time to determine whether any trends in occupancy are apparent. Because species-specific detection rates will vary relative to multiple factors including population abundance of a given species, camera location, movement patterns, and inter-specific interactions (Burton et al. 2015), consideration of how these factors influence species detectability is required when assessing wildlife occupancy. The current study took some steps towards this goal by allowing detection rates to be independently estimated for each combination of species, habitat and sighting threshold. That said, for this exercise we did not consider how various environmental factors directly affected these rates.

The overall trend that appeared to emerge was the wildlife use of Riparian Habitat and Horizon Lake areas was higher than Reclamation Area 1, which is likely related to seral stage, proximity to intact boreal forest, the generally higher use of riparian areas by wildlife, and the location of Reclamation Area 1, which is bordered by roads to the north and south, which may reduce wildlife use of the area.

Data collected from remote cameras also revealed interesting patterns of habitat use over time for a variety of wildlife and for select species, finer-scale temporal trends (daily and seasonal) are also indicated, but in general, there does not appear to a decline in occupancy (or use) by wildlife relative to the camera trap locations sampled in both areas.

The results of the remote wildlife camera analyses also show consistent use of Riparian Habitat and Horizon Lake by multiple species of wildlife across all years surveyed. While occupancy and activity of wildlife may differ between and within areas, the composition of the species and their occupancy of specific sites in either area remain relatively stable seasonally and annually.

LITERATURE CITED

Burton, A.C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J.T., Bayne, E., and S. Boutin. 2015. REVIEW: Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. J Appl Ecol 52(3): 675–685. doi: 10.1111/1365-2664.12432.

Hawkes, V.C., C.M Wood, N. Hentze, B. McKinnon, J. Sharkey, J. Gatten, W. Challenger, N.N. Johnston, and M. Miller. 2017. Early successional wildlife monitoring program Canadian Natural Resources Limited Horizon Oil Sands. Year 4 2015–2016 annual report. LGL Report EA3368C. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources Limited, Fort McMurray, AB. 104 pp + Appendices.

Hawkes, V.C., N.N. Johnston, N. Hentze, W. Challenger, C.M Wood, and S. Roias. 2017. Early successional wildlife monitoring program Canadian Natural Resources Limited Horizon Oil Sands. Year 5 2016–2017 annual report. LGL Report EA3368D. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources Limited, Fort McMurray, AB. 115 pp + Appendices.

Mackenzie, D.I., and W.L. Kendall. 2002. How should detection probability be incorporated into estimates of relative abundance? Ecology 83:2387–2393.

Rowcliffe, J.M., J. Field, S.T. Turvey and C. Carbone. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology 45: 1228–1236.

Royle, J. A., Link, W. A., 2005. A general class of multinomial mixture models for anuran calling survey data. Ecology 86 (9), 2505–2512.

PRESENTATIONS AND PUBLICATIONS

Hawkes, V.C., N.N. Johnston, N. Hentze, W. Challenger, C.M Wood, and S. Roias. 2017. Early successional wildlife monitoring program Canadian Natural Resources Limited Horizon Oil Sands. Year 5 2016–2017 annual report. LGL Report EA3368D. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources Limited, Fort McMurray, AB. 115 pp + Appendices.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Limited Environmental Research Asssociates

Principal Investigator: Virgil C. Hawkes

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Virgil Hawkes	LGL Limited	Senior Wildlife Biologist, Vice-President		
Wendell Challenger	LGL Limited	Biostatistician		
Jordan Smith	Canadian Natural Resources Ltd.	Environmental Coordinator		
Devon Versnick-Brown	Canadian Natural Resources Ltd.	Summer Student	BSc	January 2018
Jordyn Renaud	Canadian Natural Resources Ltd.	Summer Student	BSc	2018

Monitoring Avian Productivity and Survivorship in the Oil Sands Region (Boreal MAPS)

COSIA Project Number: LJ0214

Research Provider: Owl Moon Environmental Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: ConocoPhillips Canada, Hammerstone Corporation, Husky Oil Operations Ltd., Suncor Energy, Devon Energy, Nexen Energy ULC

Status: 2011 - Present (annual participation)

PROJECT SUMMARY

Monitoring Avian Productivity and Survivorship (MAPS) is a continent-wide mark-recapture (bird-banding) program dedicated to understanding population demographics and vital rates of landbirds (passerines and woodpeckers), most of which are Neotropical migrant species. Indices of avian vital rates provide a strong indication of habitat quality and complexity in consideration of the varying life history requirements of each species. Data collected using captured and banded birds are useful in evaluating many aspects of landbird dynamics, including effects from industrial activities. In northeastern Alberta, there is significant interest in boreal forest ecology in response to industrial operations, habitat disturbances, and reclamation efforts. The overall value from this program is the understanding of avian population dynamics and diversity for bird species nesting in the boreal forest near the oil sands region.

Vital-rate data are lacking for landbird species that rely on the boreal forest (Thompson 2006; Wells 2011), limiting our ability to address underlying causes of population changes for those species that are experiencing population declines (Rosenberg et al. 2016). The underlying causes of population changes are poorly understood, and vital rate data may provide insight into the underlying causes of these population trends. Measurement of vital rates within reclaimed, fragmented or otherwise disturbed, and natural habitats over time provides an assessment of local scale effects, including habitat performance, and regional effects resulting from pressures or stress experienced during migration or on the wintering grounds. Low or declining productivity would indicate that effects are occurring on the breeding grounds, while low or declining survivorship would suggest that the effects are caused on the wintering grounds or during migration (Newton 2004). Understanding factors within the annual cycle leading to population declines is critical to the effective management and recovery of bird populations, including decisions on whether to devote resources to management on breeding or wintering grounds.

The industry specific value from this program is twofold:

1. It advances the understanding of local effects and those encountered during migration or on the wintering grounds; and
2. It provides the opportunity for industry to potentially optimize reclamation and habitat restoration best practices considering the habitat requirements of select species that are experiencing population declines as a result of low productivity on the breeding grounds.

The Monitoring Avian Productivity and Survivorship in Oil Sands Region Program (Boreal MAPS Program) has been established to address two objectives:

1. To advance the understanding of avian population dynamics and diversity in reclaimed habitats and in habitats subject to disturbances associated with industrial and human activities, as compared to natural, unaffected areas; and
2. To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest.

A third goal, although not a formal program objective, is to provide a platform for use by other researchers undertaking complementary programs. This will result in opportunities for the leveraging of data and collaboration.

In 2011, 6 MAPS stations were established in the oil sands region and the program was expanded to 24 stations in 2012, to 35 stations in 2013, to 37 stations in 2014, and to 38 stations in 2015. In 2016 and 2017, 33 of the 38 MAPS stations were operated. Operations at five stations were either truncated or suspended in 2016 and 2017 due to safety and access constraints imposed by the Horse River wildfire, or not operated due to funding constraints.

MAPS stations have been established in natural (reference condition), reclaimed, and disturbed habitats (e.g., cutlines, exploration well pads, roads). Six stations in natural habitats have been affected by flooding (one station in 2013) and wildfire (5 stations in 2016). Each MAPS station consists of 8 to 14, 12-m mist nets operated for six hours per day on six days between June 10 and August 8 each year, in accordance with the standardized protocol developed by The Institute for Bird Populations (DeSante et al. 2015).

For captures of unbanded birds, a uniquely numbered, aluminium leg band issued by Canadian Wildlife Service was applied to the leg. Data on species, age, sex, breeding characteristics, moult status, and other physical characteristics were recorded, along with biometrics such as wing length and weight. Age classes were assigned as HY (hatched during the monitoring year) or AHY (hatched before the monitoring year) and most AHY birds were separated into SY (hatched in the previous year) or ASY (hatched before the previous year) (Pyle 1997).

Computer entry, data proofing, and verification of banding, mist-net effort, and breeding status data were completed using specially designed data entry, verification, and editing programs. For analyses, the number of adult birds captured per 600 net-hours was used as an index of adult population size, and post-fledging productivity was estimated by the ratio of individual young to adult birds captured. For species with sufficient capture and recapture data, survivorship was estimated using Modified Cormack-Jolly-Seber capture-mark-recapture models (Pollock et al. 1990; Lebreton et al. 1992).

PROGRESS AND ACHIEVEMENTS

In 2017, field work comprised 11,475 net-hours of operation at 33 stations, resulting in 3,466 birds being newly banded, 50 being released unbanded, and 1,190 recaptures of previously banded birds, for a total of 4,706 captures (246 captures per 600 net-hours). These values are lower than those recorded in 2016 (5,087; 279 per 600 net-hours) and much lower than in 2015 (8,315; 393 per 600 net-hours). A downward trend was apparent for adult population size from 2015 (186 per 600 net-hours) to 2016 (142.5 per 600 net-hours), and preliminary analyses indicate that this trend continued into 2017 (estimated at 120 adults per 600 net-hours). Productivity (the number of young relative to adult captures, normalized for effort) decreased from 2015 (0.85) to 2016 (0.58), and appears to have remained between 0.50 and 0.60 in 2017 (preliminary estimate). Since 2011, there has been an overall downward trend in the nesting (adult) landbird populations in the region. It is not yet known if this trend represents an effect of the forest fire in 2016, natural cycles in local populations, regional resource development, or is a reflection of the general decline in landbird populations continent-wide.

The 2016 Horse River wildfire likely affected regional landbird populations, and possibly productivity. Any effects will likely continue to be apparent as burned habitats recover. With continued operation of the five stations that were burned in 2016, we expect to be able to track avian breeding populations as habitats develop. Although avian use of recovering burn habitats is expected to differ from that in reclaimed and disturbed habitats, understanding resilience in a naturally-recovering system may help inform reclamation and habitat restoration programs. It is worth noting that avian vital rates were relatively high in 2011, the year during which the Richardson wildfire affected a large area, but which was north of the majority of our MAPS stations.

1. To advance the understanding of avian population dynamics and diversity in reclaimed habitats and in habitats subject to disturbances associated with industrial and human activities, as compared to natural, unaffected areas:

Across all stations and over all seven years, 37,620 bird captures of 95 species have been recorded, of which 28,931 were newly banded, 614 were released unbanded, and 8,615 were recaptures of birds banded earlier in the same season or in previous seasons. Adult population size and productivity (all species pooled) at stations with reclaimed and/or disturbed habitats was within the range of natural variability, as characterized by stations at which more than 70% of the habitat was undisturbed (see Figures 1 and 2 in the COSIA Land EPA 2016 Mine Site Reclamation Research Report, pg. 198). Species richness (the number of species captured) at stations with reclaimed and/or disturbed habitats also was within the range of natural variability, as shown in Figure 3 in the COSIA Land EPA 2016 Mine Site Reclamation Research Report. The 2017 banding data are currently being analysed.

Monitoring at the five stations at which the habitat burned in the 2016 Horse River wildfire provides an opportunity to track avian community recovery in a natural disturbance area and compare it to that observed in habitats recovering from anthropogenic disturbances. In 2017 (1-year post-fire), early colonizing sparrow species predominated in the recovering burn habitats. A few late colonizing warbler species present before the fire were also captured in 2017. It is expected that as the burned habitats grow and mature, a broader range of species will occur.

The intention is to formally characterize the habitat structure at all MAPS stations in 2018. This will provide data allowing for comparisons among undisturbed natural habitats, natural habitats recovering from the 2016 wildfire, disturbed (anthropogenic) habitats, and reclaimed habitats.

The potential use of the age-class structure of nesting landbirds in the evaluation of habitat quality, in reclaimed, disturbed and natural areas is being examined. Preliminary analyses indicate that lower quality habitats (using MAPS habitat structure data acquired in 2012 together with remote-sensing vegetation cover data acquired from external sources) support an overall younger age-class structure (higher proportion of first-time breeding individuals) relative to higher quality habitats, which tend to be occupied by a proportionately higher number of older, experienced birds. This effect appears to be habitat and species-specific, potentially making it a sensitive indicator of habitat quality, adding to the indicators represented by adult population size, productivity, survivorship, and species richness.

2. To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest:

The COSIA Land EPA 2016 Mine Site Reclamation Research Report (pgs. 199-200) describes the six-year (2011-2016) trends in population size, productivity and survivorship for about 30 species, for which sufficient data were then available. Data from 2017 are being integrated into these analyses for updating of vital rate estimates. Data from MAPS banding programs outside of the oil sands region have been acquired (per data-sharing and use agreements), permitting derivation of vital rate estimates for these same species nesting elsewhere in the boreal forest. These analyses are expected to provide insight into the contribution of regional stresses on the population trends for these species, and identify the species that may benefit from regional efforts (e.g., productivity effects indicate breeding ground stresses) and those that would not (e.g., survivorship effects indicate stresses outside the breeding grounds). This analysis is core to the question of whether or not changes in bird populations in the region reflect relatively local stresses or are an expression of changes in these populations at a continental level.

Canada warbler adults showed significant correlations with habitat-specific covariates responding to mature forested habitats (Foster et al. 2016). As indicated in the COSIA Land EPA 2016 Mine Site Reclamation Research Report (pg. 200), our data suggest that Canada warbler (threatened in Canada) populations in the region are reasonably healthy due to high productivity on the breeding grounds, while survival on and away from the breeding grounds may be moderately good.

This project's dataset now contains more than half of the Canada warbler continent-wide MAPS data upon which vital rate estimates may be obtained. Recent analyses indicate that stresses on the wintering grounds are the predominant factor driving the population trend, and that these stresses appear to be having greater effects on the populations of Canada warbler breeding in the eastern portion of their range (Wilson et al. *accepted pending revision*). The population of Canada warbler in the oil sands region is declining at a lower rate than in populations to the east. The western population wintering grounds have been affected to a lesser extent.

Although not an objective of this program, collaboration with other researchers is actively being sought.

In 2017, collaboration focused on the publication of data collected using geolocators that were attached to Ovenbirds in 2013 and then recovered in 2014, at two MAPS stations (Haché et al. 2017). This project's data also contributed to the broader birding community through publication of a guide to identifying juvenile sparrows (Lai et al. 2017). Owl Moon Environmental Inc. is collaborating with other MAPS operators through database integration and analyses to provide a broad perspective on the reasons for landbird population changes and the potential contribution of oil sands regional resource development to these changes.

LESSONS LEARNED

Understanding regional landbird population trends and their underlying vital rates provides necessary context for the interpretation of population trends of species in reclaimed habitats, in areas recovering from anthropogenic disturbance, and in areas subjected to natural disturbances.

- Work is continuing to determine which of the approximate 10 species showing a consistent, regional population decline are driven by low productivity on the breeding grounds, and which species appear to be driven by low adult survivorship during migration or on the winter grounds (Newton 2004, Albert et al. 2016):
  - Low or declining productivity would indicate that effects are occurring on the breeding grounds.
  - Low or declining survivorship would indicate that the effects are occurring on the wintering grounds or during migration, as demonstrated for Canada warbler (Wilson et al. *accepted, pending revision*).
- Species for which resource development is indicated as a stress (reduced productivity on the breeding grounds) contributing to population decline would become candidates for targeted conservation efforts (e.g., avoidance/ protection of key habitat). There is the potential opportunity for industry to leverage this information to revise reclamation and habitat restoration best practices, or potential amendments to select reclaimed lands.
- Habitat structure is an important driver of avian breeding habitat use, as reflected in species richness and total numbers (pooled) and species-specific vital rates (adult population size, productivity) as correlated with habitat structure attributes (Foster et al. 2016). Habitat structure development in reclaimed areas supports the presence and breeding resources necessary for a range of boreal forest-dependent landbirds.

- Habitat use in the study area (e.g., breeding, presence of a diverse bird community, and recapture of birds banded in previous years) suggests the presence of effective wildlife habitat.
- Geolocators, attached to and recovered from Ovenbirds at the VWET station (7 km east of Fort McKay), indicated that the regional Ovenbird population uses wintering grounds in both east and west Central America. This is a different pattern than Ovenbirds nesting in Cypress Hills which use west Central America wintering grounds and those nesting in eastern Canada which use east Central America wintering grounds. (Haché et al. 2017). A previously unknown overwintering area in Mexico was also identified. Interpreting population changes in boreal-nesting species, including those in the oil sands region, must consider the migratory connectivity of the individual species, in order to understand the relative contribution of stresses on the populations through their entire migratory cycle.
- This program is measuring the substantial short-term (annual) variability, superimposed on population cycles that operate on long term (i.e., decadal) time scales. Long term monitoring is important in understanding the contribution of resource development and human activity in the region to avian population changes, in the context of natural variability and population cycles.
- Understanding vital rates for species of conservation concern (e.g., Canada warbler) is a critical requirement in being able to prepare and implement an effective recovery strategy and will help to focus efforts on reducing the more substantial stresses in the life cycle for these species.

LITERATURE CITED

Albert SK, DeSante DF, Kaschube DR, Saracco JF (2016) MAPS (Monitoring Avian Productivity and Survivorship) data provide inferences on demographic drivers of population trends for 158 species of North American landbirds. North American Bird Bander 41:133-140.

DeSante DF, Burton KM, Velez P, Froehlich D, Kaschube D (2015) *MAPS Manual, 2015 Protocol*. Point Reyes Station, CA: The Institute for Bird Populations; 49 pp.

Foster KR, Godwin CM, Pyle P, Saracco J (2016) Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada. Restoration Ecology (Open Access): doi: 10.1111/rec.12478.

Haché S, Bayne EM, Villard M-A, Proctor H, Davis CS, Stralberg D, Janes JK, Hallworth MT, Foster KR, Chidambrara-vasi E, Grossie AA, Gorrell JC, Krikun R. (2017) Phylogeography of a migratory songbird across its Canadian breeding range: Implications for conservation units. DOI: 10.102/ece3.3170. Ecology and Evolution 2017:2-11.

Lai P, Pyle P, Foster KR, Godwin CM (2017) Identifying sparrows in juvenile plumage. Birding 49:62-67.

Lebreton J-D, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67-118.

Newton I (2004) Population limitation in migrants. Ibis 146:197-226.

Pollock KH, Nichols JD, Brownie C, Hines JE (1990) Statistical inference for capture-recapture experiments. Wildlife Monographs, No. 107.

Pyle P (1997) Identification guide to North American birds. Part 1. Slate Creek Press, Bolinas, CA.

Rosenberg KV, Kennedy JA, Dettmers R, Ford RP, Reynolds D, Alexander JD, Beardmore CJ, Blancher PJ, Bogart RE, Butcher GS, Camfield AF, Couturier A, Demarest DW, Easton WE, Giocomo JJ, Keller RH, Mini AE, Panjabi AO, Pashley DN, Rich TD, Ruth JM, Stabins H, Stanton J, Will T (2016) Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 63 pp.

Thompson ID (2006) Monitoring of biodiversity indicators in boreal forests: a need for improved focus. Environmental Monitoring and Assessment 121:263-273.

Wells JV (2011) Boreal birds of North America: a hemispheric view of their conservation links and significance. University of California Press, Berkeley, CA.

Wilson S, Saracco JS, Krikun R, Flockhart DTT, Godwin CM, Foster KR (accepted, pending revision) Integrating migratory connectivity and full life cycle analysis to examine the source of declines for a threatened migratory bird. Scientific Reports (accepted January 8, 2018, pending revision).

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Haché S, Bayne EM, Villard M-A, Proctor H, Davis CS, Stralberg D, Janes JK, Hallworth MT, Foster KR, Chidambara-vasi E, Grossie AA, Gorrell JC, Krikun R. (2017) Phylogeography of a migratory songbird across its Canadian breeding range: Implications for conservation units. DOI: 10.102/ece3.3170. Ecology and Evolution 2017:2-11.

Lai P, Pyle P, Foster KR, Godwin CM (2017) Identifying sparrows in juvenile plumage. Birding 49:62-67.

Wilson S, Saracco JS, Krikun R, Flockhart DTT, Godwin CM, Foster KR (accepted, pending revision) Integrating migratory connectivity and full life cycle analysis to examine the source of declines for a threatened migratory bird. Scientific Reports (accepted January 8, 2018, pending revision).

RESEARCH TEAM AND COLLABORATORS

Institution: Owl Moon Environmental Inc.

Principal Investigator: Kenneth R. Foster

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Christine Godwin	Owl Moon Environmental Inc.	Co-Principal Investigator		
Peter Pyle	The Institute for Bird Populations	Staff Biologist		
Ron Taylor	The Institute for Bird Populations	Staff Biologist		
Danielle Kaschube	The Institute for Bird Populations	MAPS Coordinator		
James Saracco	The Institute for Bird Populations	Research Ecologist		
Lauren Helton	The Institute for Bird Populations	Staff Biologist		
Steve Albert	The Institute for Bird Populations	Assistant Director for MAPS and MoSI		

Research Collaborators:

Geolocator deployment and recovery as a component of the examination of migratory connectivity of Ovenbird

Geolocator deployment and recovery as a component of the examination of migratory connectivity of Ovenbird
Collaborators: Dr. Erin Bayne, University of Alberta; Dr. Samuel Haché, Canadian Wildlife Service, Yellowknife

The Boreal MAPS program provides feather samples for analyses; these data are integrated with data from samples provided by researchers across Canada.

Examinations of the isotopic composition of feathers as related to the continental deuterium gradient
Collaborators: Dr. Erin Bayne, University of Alberta; Dr. Samuel Haché, Canadian Wildlife Service, Yellowknife

Canada Warbler vital rates relative to habitat conditions on the breeding and wintering grounds
Collaborators: Dr. Scott Wilson, Canadian Wildlife Service, Ottawa; Dr. Tyler Flockhart, University of Maryland & Lesser Slave Lake Bird Observatory; Richard Krikun, Lesser Slave Lake Bird Observatory

Bison Research, Mitigation and Monitoring Program

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck Resources Limited

Industry Collaborators: Canadian Natural Resources Limited

Status: Year 3 of 5

PROJECT SUMMARY

The goal of the Bison Research, Mitigation and Monitoring project is to fill knowledge gaps, which have been identified by the Ronald Lake Bison Herd Technical Team[1], related to the habitat and population ecology of the Ronald Lake wood bison herd in northeast Alberta[2]. Ultimately, this project will inform herd management planning by the Government of Alberta as well as strategies to mitigate the potential effects of industrial activities (operational as well as reclamation) on the Ronald Lake herd. Specifically, the Bison Research, Mitigation and Monitoring project will address the following four key questions:

1. What is the spatial distribution of male and female bison in relation to season, habitat type and natural and anthropogenic disturbances?
   a. What is the spatial distribution of male and female bison on an annual and seasonal basis?
   b. What are the patterns of habitat selection?
   c. What is the influence of natural and anthropogenic disturbances on habitat selection?
2. What bottom-up (forage & habitat supply) or top-down (predation) factors limit the Ronald Lake wood bison herd?
   a. What are the projected changes in forage supply for wood bison with resource developments?
   b. Does insect harassment and ground firmness affect summer forage availability?
   c. How do winter conditions and wolf predation risk influence winter habitat use and survival?
   d. What mechanisms promote selection for dry marsh meadow habitat in summer and what influence does this have on recruitment and calf survival?
3. What is the expected response of the Ronald Lake wood bison herd to resource development?
   a. How do anthropogenic disturbances affect forage availability, habitat selection, and bison movement?
   b. What can be done to manage the expected response of the herd to projected resource development?
4. What mitigation and reclamation strategies can be used to minimize adverse effects of development if it does occur?

Teck and Shell Canada Energy (prior to 2017) and now Canadian Natural Resources Limited provide funding for this project and the work is technically directed by the Ronald Lake Bison Herd Technical Team, as the work is of keen interest to multiple parties.

1 The Ronald Lake Bison Herd Technical Team is a multi-stakeholder group (i.e., Aboriginal communities, government, and industry) with a mandate to identify and address information needs that will inform regulatory and management decisions.

2 Wood bison (*Bison bison athabascae*) are federally listed as Threatened under Schedule 1 of the Species at Risk Act due to small population sizes, restricted distribution, and threats from disease outbreaks (COSEWIC 2013). The Ronald Lake wood bison herd also is culturally significant for local aboriginal communities (Candler et al. 2015). The proposed Frontier Oil Sands Mine Project intersects a portion of the home range of the Ronald Lake wood bison herd.

PROGRESS AND ACHIEVEMENTS

Progress that occurred in 2017 that supports achieving the stated objectives included:

1) What is the spatial distribution of male and female bison in relation to season, habitat type and natural and anthropogenic disturbances?

a) What is the spatial distribution of male and female bison on an annual and seasonal basis?

Global Positioning System (GPS) collar data collected from 2013 to 2017 were compiled to assess potential inter-annual and gender-specific variation in space use. To inform landscape-level planning in the region, predictive seasonal maps of bison habitat selection were generated.

Over the monitoring period, collared Ronald Lake bison demonstrated relatively high fidelity to seasonal ranges. Bison primarily use relatively expansive areas in the eastern portion of their home range during spring, summer, and winter. During the calving season, a relatively small area around a distinct upland meadow site was used.

b) What are the patterns of habitat selection?

GPS collar data collected from 2013 to 2017 were compiled to assess potential inter-annual and gender-specific variation in habitat selection. Males and females differed in their patterns of habitat selection. Females showed high selection for meadow marshes across all seasons while males were more variable and season-dependent in their selection of land cover types.

c) What is the influence of natural and anthropogenic disturbances on habitat selection?

In general, bison avoided cut-blocks. Avoidance of these areas increased significantly if human activity was also present. Indeed, no bison locations occurred in areas of active logging during the winters of 2015 and 2016 suggesting strong avoidance of forest harvest activities. The exception was that male bison males selected more recent cut-blocks (post-2005) in the summer/fall.

2) What bottom-up (forage & habitat supply) or top-down (predation) factors limit the Ronald Lake wood bison herd?

b) Does insect harassment and ground firmness affect summer forage availability?

Our study quantitatively assessed forage biomass (dry biomass), soil firmness (soil bulk density; soil penetration), biting fly (horsefly, midge, mosquito) abundance and bison use (dung counts) at 36 sites representing four habitats (deciduous forest, pine forest, marsh, and esker) to explore the effects of biomass, soil firmness and biting fly abundance on bison habitat use.

We found more total biomass in marshes than any other land-cover type. We also found soil firmness to be lower and biting fly abundance to be higher in marshes during summer months. Similar to Tan et al. (2014) and DeMars et al. (2016), we observed relatively low bison activity in marshes during summer months and relatively high activity during winter months, suggesting that bison activity in marshes in the summer may be limited by a combination of soft footing (ground) that increases energy expenditure and greater exposure to predation by biting flies.

d) What mechanisms promote selection for dry marsh meadow habitat in summer and what influence does this have on recruitment and calf survival?

During the calving season, a relatively small area around a distinct upland meadow site was used. Camera traps were deployed in and around this meadow, including on game-trails leading into the meadow, to further examine meadow use. Black bear use of the meadow peaked during the period when bison and calves were present. Compared to the spring, wolf use was more noticeable in the fall when moose were more common.

LESSONS LEARNED

This reporting period highlighted the following emerging outcomes:

- The Ronald Lake herd roams a confined range throughout the year, which is an important finding to help explain why the Ronald Lake bison herd remains disease free.
- The upland meadow is associated with calving. A more detail understanding of the meadow use will help define its importance to Ronald Lake bison.
- Forage may be only one of several factors contributing to summer bison habitat use, which is an important finding to consider during reclamation planning.
- Patterns of species co-occurrence in the upland meadow site highlighted possible predator-prey relationships: bear occurrence peaked during the bison calving period and wolf occurrence was more strongly associated with moose. These relationships are important to design potential future monitoring programs and population dynamics studies.

LITERATURE CITED

Belanger, R.J., C.A. DeMars, L.J. Hecker, M.A. Edwards, and S.E. Nielsen. 2017. Ronald Lake Wood Bison Research Program: Annual Report 2017. University of Alberta, Edmonton, Alberta, Canada T6G 2H1. 77 pp.

Demars, C. A., S. E. Nielsen, and M. A. Edwards. 2016. Range use, habitat selection, and the influence of natural and human disturbance on wood bison (*Bison bison athabascae*) in the Ronald Lake area of northeastern Alberta. Ronald Lake Bison Report. 80 pp.

DeMars, C.E., Scott E. Nielsen, and Mark A. Edwards. 2017. Range Use, Habitat Selection, and the Influence of Natural and Human Disturbance on Wood Bison (*Bison bison athabascae*) in the Ronald Lake Area of Northeastern Alberta March 2017 Update. University of Alberta, Edmonton, Alberta, Canada T6G 2H1. 40 pp.

Tan, T., S. E. Nielsen, and M. A. Edwards. 2015. Ronald Lake bison (*Bison bison*) preliminary summary report: March 2013 – March 2014 telemetry data study. Ronald Lake Bison Report. 58pp.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott Nielsen

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Scott Nielsen	University of Alberta	Associate Professor		
Mark Edwards	University of Alberta	Adjunct Professor		
Robert Belanger	University of Alberta	M.Sc. Candidate	2015	2018
Lee Hecker	University of Alberta	PhD Candidate	2017	2020

Research Collaborators: Alberta Environment and Parks, Environment Canada, Parks Canada, Fort Chipewyan Metis, Fort McKay First Nation, Fort McKay Metis, Fort McMurray First Nation, Fort McMurray Metis, Mikisew Cree First Nation.

Human & Wildlife Risk Assessment of Oil Sands Reclamation & Closure Landscape Scenarios

COSIA Project Number: LJ0272

Research Provider: Golder Associates Ltd. and Intrinsik Corp.

Industry Champion: Suncor Energy Inc.

Status: Year 2 of 3

PROJECT SUMMARY

Golder Associates Ltd. (Golder) and Intrinsik Corp. (Intrinsik) have been retained by Suncor Energy Inc. (Suncor) to conduct a Human and Ecological Risk Assessment of Suncor's Reclamation and Closure Landscapes planned for operational oil sands sites (hereafter referred to as the Environmental Risk Assessment). The Environmental Risk Assessment and supporting tasks will be conducted for four sites: the Suncor Base Mine; the Fort Hills Oil Sands Mine Project; the Firebag In Situ Oil Sands; and the MacKay River and Dover In Situ Oil Sands. In addition to potential risks to human health, the Environmental Risk Assessment will focus on aquatic and terrestrial wildlife risk receptors (an aquatic health risk assessment was conducted previously for consolidated tailings; Golder 2009). The overall aim of the Environmental Risk Assessment is to provide guidance to Suncor's closure and reclamation planning.

Specific objectives for the Environmental Risk Assessment are provided below:

- Review background documents, including recent closure plans, risk assessments, and data collected as part of previous studies.
- Compile historical environmental data (e.g., soil, water, and tissue chemistry).
- Conduct a gap analysis based on the results of data review and compilation.
- Conduct a field sampling program to address data gaps and supplement existing data.
- Identify key wildlife receptors and determine if they require further assessment.
- Integrate the above information in a problem formulation that sets the scope for the wildlife and human health risk assessment in support of reclamation for various ecosystem and substrate types.
- Conduct a quantitative human and wildlife health risk assessment (including exposure calculations) applicable to the various ecosystem types, considering the ranges of substrates that will need to be placed/managed as part of reclamation over various time periods.
- Summarize the risk assessment findings in a knowledge transfer document (including a risk matrix/registry) to guide engineering/reclamation planning.

PROGRESS AND ACHIEVEMENTS

An Environmental Risk Assessment was conducted in early 2017 using historical data and data collected as part of a field program carried out in the summer of 2016. The risk assessment targeted seven fully-reclaimed landform-substrate combinations: Structural fill (sand and coke capped consolidated tailings, consolidated tailings, regular tailings, suitable overburden, and unsuitable overburden), End Pit Lake (mature fine tailings), non-structural fill (dewatered mature fine tailings). However, the majority of the landform-substrate combination field sites were not fully reclaimed, with the exception of structural fill – overburden, structural fill – regular tailings and structural fill – unsuitable overburden. Surface water, soil, sediment, vegetation and fish tissue samples were still collected and, consequently, represent a "worst case scenario". Results are summarized below.

Human Health Risk Assessment

Maximum concentrations in surface water, sediment, soil and fish tissue were compared to screening values to identify contaminants of potential concern (COPCs) for the human health risk assessment. The following COPCs were identified in each landform-substrate, meaning these scenarios must undergo an environmental risk assessment (see below):

- Structural Fill – Consolidated Tailings (unreclaimed): cobalt, iron, lithium, manganese, molybdenum, total dissolved solids, chloride, fluoride, sodium, sulphate, naphthenic acids, petroleum hydrocarbon fraction F3.
- Structural Fill – Sand and Coke Capped Consolidated Tailings (unreclaimed): cobalt, iron, lithium, manganese, molybdenum, vanadium, total dissolved solids, chloride, sodium, sulphate, Polycyclic Aromatic Hydrocarbons (PAHs; parent and alkylated compounds), naphthenic acids.
- Structural Fill – Regular Tailings (reclaimed): arsenic, iron, lithium, manganese, molybdenum, total dissolved solids, fluoride, sodium, vanadium, naphthenic acids.
- Structural Fill – Suitable Overburden (reclaimed): cobalt, lithium, manganese, nitrite, total dissolved solids, fluoride.
- Structural Fill – Unsuitable Overburden (reclaimed): lithium, manganese, total dissolved solids, sodium, sulphate, naphthenic acids.
- End Pit Lake – Mature Fine Tailings (unreclaimed): iron, lithium, molybdenum, vanadium, total dissolved solids, chloride, fluoride, sodium, sulphate, naphthenic acids, petroleum hydrocarbon fraction F3.
- Non-structural Fill – Dried Mature Fine Tailings (unreclaimed): cobalt, iron, lithium, manganese, molybdenum, vanadium, total dissolved solids, sodium, naphthenic acids, alkylated PAHs.

Chloride, fluoride, nitrite, sodium and sulphate were evaluated for the surface water pathways only (e.g., ingestion and dermal contact). Carcinogenic parent and alkylated PAHs were grouped for evaluation in the human health risk assessment. The COPCs identified in each landform-substrate above were also retained for media for which there are no screening criteria (e.g., vegetation and wild game). Substances with concentrations that exceeded a screening value but were of low toxicological hazard were not retained as COPCs.

The following receptors were identified for the human health risk assessment:

- Aboriginal: Seasonal and Year-Round use.
- Recreational: Hikers and Sport Fishers & Hunters.
- Resident Trapper.

The exposure pathways evaluated in the human health risk assessment included:

- Surface Water: ingestion (as a drinking water source), incidental ingestion (while swimming or bathing), dermal contact.
- Sediment: incidental ingestion, dermal contact.
- Soil: incidental ingestion, dermal contact, dust inhalation.
- Traditional Foods (berries, traditional plants, wild game, fish): ingestion.

The different receptor scenarios were selected to represent a range of exposure combinations. For example, the recreational hiker was assumed to be exposed to soil, sediment and surface water (swimming or bathing) and to consume berries whereas the aboriginal receptors were assumed to be exposed to all media, including traditional foods (wild game and traditional plants).

The preliminary results and uncertainties of the human health risk assessment are summarized as follows:

- Five exposure scenarios were evaluated in the human health risk assessment. Risk estimates were lowest for the recreational hiker scenario and highest for the seasonal and year-round Aboriginal scenarios. This is not surprising, as the Aboriginal scenarios included consumption of food (berries, traditional plants, wild game and fish) and use of surface water as a source of drinking water. The recreational hiker scenario included only direct contact pathways (soil, sediment, water) and the consumption of berries. Risk estimates for the other scenarios (resident trapper and sports fisher/hunter) generally fell between the hiker and the Aboriginal scenarios.
- The data used to evaluate landform-substrate types were collected from oil sands sites in various states of reclamation. Some sites were unreclaimed (e.g., dried mature fine tailings and coke and sand capped consolidated tailings sites), whereas others were considered more fully reclaimed (e.g., structural fill – regular tailings). In general, the risk estimates for the unreclaimed landform-substrate combinations were higher in magnitude than those for the reclaimed sites.
- Risks, where identified, are expected to be reduced and removed once the landform-substrate scenarios are fully reclaimed (e.g., topography modified, capped and vegetated).
- The primary terrestrial contributor to risk among the landform-substrates was the ingestion of berries and wild game. Terrestrial pathways contributed negligibly to overall risk for organic COPCs (e.g., PAHs and petroleum hydrocarbons).
- Aquatic pathways were the main drivers of risk for the organic parameters and vanadium, as well as those parameters that were assessed for water only (e.g., fluoride, sodium, sulphate).
- The risk estimates for alkylated PAHs are considered conservative. There were limited samples analyzed for alkylated PAHs (approximately 2 to 3 per environmental medium at each substrate); therefore, the exposure concentrations used in the human health model were based on maximum concentrations. This may have overestimated risks for alkylated PAHs. Also, a conservative approach was applied for assigning relative potencies for alkylated PAHs, whereby the entire group of alkylated PAHs was assigned a potency factor (relative to benzo(a)pyrene) equal to the most toxic individual parameter. Additional analytical resolution (if possible) may allow for a refinement in risks estimates for alkylated PAHs.
- Human health risks from exposure to naphthenic acids could not be evaluated quantitatively due to the lack of a toxicity reference value and limited toxicological data.

Wildlife Health Risk Assessment

Maximum concentrations in surface water, sediment and soil were compared to ecological screening values to identify COPCs for the wildlife health risk assessment (WHRA). The following COPCs were identified in each landform-substrate, meaning these scenarios must undergo an environmental risk assessment (see below):

- Structural Fill – Consolidated Tailings (unreclaimed): total dissolved solids, fluoride, sulphate, boron, cobalt, manganese, selenium, thallium, sodium, high molecular weight PAHs, alkylated PAHs, naphthenic acids, petroleum hydrocarbon fractions F1, F2, F3 and F4.
- Structural Fill – Sand and Coke Capped Consolidated Tailings (unreclaimed): total dissolved solids, sulphate, boron, cobalt, manganese, molybdenum, nickel, selenium, thallium, vanadium, sodium, benzo(a)pyrene, high molecular weight PAHs, alkylated PAHs, naphthenic acids, phenols, petroleum hydrocarbon fractions F2 and F3.
- Structural Fill – Regular Tailings (reclaimed): fluoride, boron, cobalt, manganese, molybdenum, selenium, thallium, sodium, alkylated PAHs, naphthenic acids, phenols, petroleum hydrocarbon fraction F3.
- Structural Fill – Suitable Overburden (reclaimed): fluoride, naphthenic acids, phenols.
- Structural Fill – Unsuitable Overburden (reclaimed): fluoride, phenols.

- End Pit Lake – Mature Fine Tailings (unreclaimed): fluoride, arsenic, boron, cobalt, molybdenum, nickel, selenium, thallium, sodium, high molecular weight PAHs, alkylated PAHs, naphthenic acids, phenols, petroleum hydrocarbon fractions F3 and F4.
- Non-structural Fill – Dried Mature Fine Tailings (unreclaimed): boron, cobalt, manganese, molybdenum, nickel, selenium, thallium, vanadium, sodium, high molecular weight PAHs, alkylated PAHs, naphthenic acids, phenols, petroleum hydrocarbon fractions F2, F3 and F4.

Due to limited exposure and toxicity information, the following COPCs could only be evaluated qualitatively:

- Field parameters: total dissolved solids.
- Anions and nutrients: fluoride, sulphate.
- Salinity: sodium.
- Organics: naphthenic acids, phenols, alkylated PAHs.

The COPCs included in the multiple pathway exposure assessment for each landform-substrate are as follows:

- Metals: arsenic, boron, cobalt, manganese, molybdenum, nickel, selenium, thallium, vanadium.
- Organics: PAH group (high and low molecular weight PAHs), petroleum hydrocarbon fractions F1, F2, F3 and F4.

Wildlife receptors of concern (ROC) were grouped according to feeding environment (i.e., terrestrial and aquatic) and feeding guild (i.e., herbivore, insectivore, piscivore, carnivore and omnivore).

The exposure pathways evaluated in the WHRA included ingestion of the following media:

- Terrestrial: soil, plants, berries, invertebrates, small mammals.
- Aquatic: water, sediment, plants, invertebrates, fish.

The preliminary results and uncertainties of the qualitative WHRA are summarized as follows:

- Measured alkylated PAH concentrations in the closure landform-substrates are similar to concentrations measured from other natural locations in the oil sands region.
- Measured fluoride concentrations in water were generally less than the derived risk-based water quality concentration.
- Due to limited toxicity information for naphthenic acids, uncertainty remains with respect to the overall risks to wildlife.
- Adverse effects to receptors of concern from direct exposure to phenol in surface water from each landform-substrate are not expected due to the margin of safety between the exposure concentrations and guidelines. Uncertainty remains with respect to avian wildlife as no toxicological data were available to characterize risks.
- Adverse effects from exposure to sodium are not expected.
- Concentrations of total dissolved solids in water are unlikely to cause significant effects in wildlife species using the ponds for occasional drinking water sources.

Multiple pathway risks (i.e., hazard quotient values) were predicted for all wildlife receptors of concern and COPC combinations in each landform-substrate. A hazard quotient less than one indicates that health risks are negligible. A hazard quotient greater than one does not necessarily mean that there is a health risk but rather that the risks may need to be evaluated further in context with the potential uncertainties identified in the risk assessment. The preliminary results and uncertainties of the quantitative wildlife risk assessment are summarized as follows:

- Structural Fill – Consolidated Tailings (unreclaimed): The predicted boron hazard quotient values exceed 1.0 for the deer mouse (hazard quotient=1.2), mallard (hazard quotient=1.4) and meadow vole (hazard quotient=1.7). When considering average concentrations, predicted boron hazard quotient values were below the benchmark value of 1.0. The predicted CCME petroleum hydrocarbon F3 hazard quotient values marginally exceed 1.0 for the muskrat.

- Structural Fill – Sand and Coke Capped Consolidated Tailings (unreclaimed): Predicted nickel and vanadium hazard quotient values exceed 1.0 for the blacked-capped chickadee (hazard quotient=1.8 and 7.4, respectively), common nighthawk (hazard quotient=1.5 and 5.3, respectively), and tree swallow (hazard quotient=1.8 and 6.3, respectively). The predicted mallard hazard quotient values for manganese, nickel and vanadium are 2.0, 3.7 and 170, respectively. In addition, the predicted muskrat hazard quotient values for manganese and vanadium are 2.4 and 4.5, respectively, while the vanadium hazard quotient value for the whooping crane is 11. Finally, the marginal exceedances of the hazard quotient values for the horned grebe (hazard quotient=1.3), northern myotis (hazard quotient=1.3) and short-eared owl (hazard quotient=1.4) are considered to be of minor consequence.
- Structural Fill – Regular Tailings (reclaimed): Only boron hazard quotient values were predicted to exceed 1.0 for the mallard only (hazard quotient=1.7). Use of average concentrations in the model results in boron hazard quotient values that are just above the benchmark value of 1.0 for the mallard (hazard quotient=1.1).
- End Pit Lake – Mature Fine Tailings (unreclaimed): predicted hazard quotient values for receptors of concern and COPCs were below the benchmark value of 1.0. Adverse effects from these COPCs are not expected in this landform-substrate. The marginal exceedance of the CCME petroleum hydrocarbon F3 hazard quotient value for the muskrat is considered inconsequential.
- Non-structural Fill – Dried Mature Fine Tailings (unreclaimed): Predicted hazard quotient values are above 1.0 for nickel and/or vanadium for avian species (i.e., black-capped chickadee, common nighthawk, horned grebe, mallard, short-eared owl, tree swallow and whooping crane). For most of the receptors of concern (i.e., black-capped chickadee, common nighthawk and tree swallow), predicted invertebrate concentrations were the dominant pathway of exposure followed by direct ingestion of sediment for the remaining receptors of concern (i.e., horned grebe, mallard and whopping crane).

The WHRA identified potential adverse effects to avian and mammalian receptors of concern for a number of closure landform-substrates. The unreclaimed structural fill – sand and coke capped consolidated tailings landform-substrate presented the highest level of risk in terms of the number of receptors of concern and COPC exceedances and the overall magnitude of the estimated risks. The second highest level of risks was predicted for the unreclaimed non-structural fill – dried mature fine tailings and unreclaimed structural fill – sand and coke capped consolidated tailings landform-substrates, while the single structural fill – regular tailings landform-substrate exceedance for the mallard from exposure to boron was quite low. Predicted exceedances of boron and CCME petroleum hydrocarbon F1 in the partially reclaimed structural fill - consolidated tailings were generally marginal. No elevated risks were identified for the unreclaimed end pit lake – mature fine tailings landform-substrate. Wildlife health risks were not assessed for overburden because only historic aquatic data were available and the other media (e.g., soil, sediment, and vegetation) needed to conduct a multiple pathway assessment were unavailable.

Recommendations

Based on the results of the Environmental Risk Assessment, the following was recommended to address the identified data gaps:

- Collect berry samples (if possible) from sand and coke capped consolidated tailings and consolidated tailings, preferably fully-reclaimed sites, to refine the risk estimates for these landform-substrates. If berries do not occur at the targeted sites, consideration can be given to planting berries in a controlled area representative of these fully reclaimed landform-substrate combinations as a pilot test.
- Obtain additional toxicity data for naphthenic acids for the derivation of a human health toxicity reference value. Opportunities may exist to collaborate with universities that are currently conducting this type of research. Obtaining a better understanding of wildlife naphthenic toxicity and exposure potential is also recommended. It is suggested that the naphthenic acid toxicity issues should be a regional rather than project specific initiative.

- Explore the possibility of obtaining higher resolution alkylated PAH data to refine risks for these parameters.
- Collect soil, sediment, and vegetation data representative of the suitable and unsuitable overburden substrates. These data are required to complete the multimedia risk assessment for these substrates.
- Collect terrestrial data (soil and vegetation) for dried mature fine tailings substrate, if feasible, since only a limited number of samples were obtained during the 2016 field program.
- Collect additional aquatic plant data for Structural Fill – Consolidated Tailings and Non-Structural Fill – Dried Mature Fine Tailings since only a limited number of samples were obtained during the 2016 field program. In addition, an evaluation of the potential link between sediment and aquatic plant concentrations for these two landform-substrate combinations should be considered. Bioaccessibility studies or field surveys could also be useful to provide additional lines of evidence to supplement the risk calculations.

In the summer of 2017, a field program was conducted to collect environmental samples (soil, water, sediment, vegetation) for the purposes of addressing some of the data gaps identified above and to evaluate substrates that were not targeted in the previous field program (e.g., muskeg, froth tailings, fly ash). The new data have been compiled and screened and will be incorporated into an updated risk assessment in 2018.

LESSONS LEARNED

Risk assessment results are still preliminary and data gaps will be addressed in 2018 to refine risk estimates and conclusions; therefore, results and emerging lessons are not yet ready for publication.

PRESENTATIONS AND PUBLICATIONS

Presentations (Presenting Author)

Wagenaar, A.K., Koppe, B., Meloche, L.M., McFarland, C. 2017. Human Health Risk Assessment of Various Reclaimed Substrate Materials and Landform Types at Oil Sands Facilities. 2017 Society of Toxicology Annual Meeting, March 15, 2017, Baltimore, Maryland, USA.

Wagenaar, A.K., Koppe, B., Meloche, L.M., McFarland, C. 2017. Human Health Risk Assessment of Various Reclaimed Substrate Materials and Landform Types at Oil Sands Facilities. Oil Sands Innovation Conference, March 21 and 22, Calgary, Alberta.

Meloche, L.M., Koppe, B., Wagenaar, A.K., Hart, V., Quinn, C. 2017. Human Health and Ecological Risk Assessment of Reclamation and Closure Landscapes Planned for Operational Oil Sands Sites. Science Advisory Board for Contaminated Sites in British Columbia 7th Annual Conference and Workshop. September 27-28, Vancouver BC.

Koppe, B., Bresee, K., Meloche, L.M., Wagenaar, A.K. 2017. Ecological Risk Assessment of Oil Sands Reclamation and Closure Landscapes. Remediation Technologies Symposium (RemTech). October 11, 2017. Banff, AB.

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Early Successional Wildlife Dynamics Program

COSIA Project Number: LJ0013

Research Provider: LGL Limited Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Imperial

Status: Year 3 of 5

PROJECT SUMMARY

Wildlife use of naturally occurring upland and wetland habitat in the Athabasca Oil Sands Region is relatively well understood; however, the ability for reclaimed upland habitats to promote the return to and use of previously disturbed habitats remains under-studied.

To address this deficiency, a 5-year program is underway to fulfill various objectives including:

1. Addressing the requirements for reclamation certification;
2. Evaluating wildlife use of reclaimed habitats and areas adjacent to the development;
3. Assessing the return and re-establishment of wildlife on reclamation areas; and
4. Evaluating the effectiveness of practices and principles applied in reclamation areas to improve biodiversity.

Focal taxa representing aquatic, semi-aquatic, terrestrial, and avian species were selected for annual monitoring from reclaimed habitats, mature forest, cleared, burned, and logged juvenile stands on leases operated by Canadian Natural Resources Limited, Suncor Energy Inc., Fort Hills Partnership and Imperial Oil Resources Limited. Annual sampling is underway to generate a 5-year dataset that can be used to assess how different species of wildlife are distributed relative to reclaimed habitats and to assess whether reclaimed habitats are on a developmental trajectory similar to other juvenile stands in the region. Data collected from reclaimed and juvenile stands will be compared to mature forests, which represent the desired endpoint of upland reclamation in the Athabasca Oil Sands Region (AOSR), and to other sites recovering from other human or natural disturbances (logging, clearing, forest fire). The results obtained from the wildlife program will be used to quantify the successful re-establishment of wildlife habitat on each operator's lease and will ultimately demonstrate to stakeholders and regulators that wildlife habitat is being successfully established and maintained within each operating footprint. These data will also be used to ensure that oil sands operators are in compliance with the terms and conditions of their Environmental Protection and Enhancement Act (EPEA) approvals. The design of the program is flexible enough to ensure expandability and adaptability over time. The wildlife sampling protocols are aligned with other regionally-relevant and accepted methods and are part of a "living document"; one that will be updated as new information becomes available or to adapt to changing goals and objectives.

Wildlife sampling occurs from habitats representing several distinct types of sites: (1) reclaimed upland habitats, (2) burned, logged, and cleared sites regenerating naturally or via planting, (3) compensation lakes, and (4) mature forested stands. A standardized sample unit is used that includes a small mammal live-trapping grid, songbird point count stations, and winter-active animal sampling via remotely-triggered cameras. Focal taxa include amphibians (Canadian toad [*Anaxyrus hemiophrys*]), mammals (Canada lynx [*Felis canadensis*], beaver [*Castor canadensis*], common muskrat [*Ondantra zibethicus*], moose [*Alces alces*], American black bear [*Ursus americanus*], snowshoe hare [*Lepus americanus*]), and various groups of birds (songbirds, waterfowl, owls, and raptors [diurnal and forest-nesting]), specific species of birds (Ruffed Grouse [*Bonasa umbellus*], yellow rail [*Coturnicops noveboracensis*], pileated woodpecker [*Dryocopus melanoleucus*]), small mammals (Deer Mouse [*Peromyscus maniculatus*], meadow vole [*Microtus pennsylvanicus*], and southern red-backed vole [*Myodes gapper*]), bats, and winter-active animals. All other wildlife observed on each lease that are not the focus of systematic surveys are recorded as incidental observations. These data can often provide important insights regarding the use of an area by all wildlife species.

Annual sampling occurs in most months with the majority of work occurring during the snow-free period. Survey methods include the use of qualified and proficient biologists to (1) document songbird species occurrence and distribution, (2) conduct waterfowl surveys, (3) capture and identify amphibians, (4) live trap and identify small mammal species, (5) assess vegetation species composition, cover, and height at all sample sites, and (6) make reliable observations of all wildlife species during all seasons of the year. Autonomous passive recording devices such as Wildlife Acoustics Song Meters are being used for bats, amphibians, and some species of birds (yellow rail, owls). Wildlife cameras are deployed throughout each lease to track the presence and distribution of medium and large-sized mammals. All data are collected in a standardized manner so that appropriate statistical tests can be applied.

PROGRESS AND ACHIEVEMENTS

This project started in 2015 with a projected completion of Phase 1 in 2020 (a 5 year program). Sampling in 2017 occurred from 38 sites on Canadian Natural's Horizon Oil Sands (n=12 sites); Suncor Energy's Base Lease (n=11 sites) and Fort Hills mine (n=4 sites); Canadian Natural's Albian Sands, Muskeg River and Jackpine Mines (n=7 sites); and Imperial Oil's Kearl Oil Sands (n=4 sites). The 38 sites were distributed among six main habitat types:

Site Type	Canadian Natural	Suncor (Base)	Canadian Natural Albian Sands	Fort Hills	Kearl Oil Sands	Total
Reclaimed	5	7	1	-	1	14
Comp Lake	3		1	1	1	6
Cleared	-	2	-	1	-	3
Logged	-	-	3	-	-	3
Burned	2	-	-	1	1	4
Mature Forest	2	2	2	1	1	8
Total	12	11	7	4	4	38

Site type defined: Reclaimed sites are those reclaimed to upland habitats (with the year of reclamation ranging from 1984 to 2015), comp lake sites are habitat adjacent to compensation lakes, cleared areas were cleared (vegetation removed) and left to regenerate on their own, logged sites were planted with tree species following clear cut logging, burned sites are sites that were burned to mineral soil in 2011 (part of the Richardson fire), and mature forest sites are mixedwood forests at least 60 years of age (usually 80 to 120 years) that represent the desired end point of upland reclamation in the Athabasca Oil Sands Region.

The establishment of the regional early successional wildlife dynamics program in the AOSR will ensure that the return to and use of reclaimed lands by wildlife is properly quantified and compared to an appropriate natural analogue. This approach is necessary for determining the patterns of colonization of reclaimed lands by wildlife and how reclaimed lands develop into functional ecosystems that are comparable to the naturally occurring and surrounding boreal forest (as per AENV 2010). By developing a regionally-based dataset regarding early successional wildlife use of reclaimed habitats relative to naturally-occurring juvenile and mature stands, all operators will have a means of determining whether their current or planned reclamation activities are likely to be successful and beyond that, what species are likely to re-colonize their reclaimed habitats. Because wildlife are not uniformly distributed across the landscape, there will be differences in wildlife use of reclaimed habitats, but many of the same species are expected to occur during the early years of development and beyond. The only way to generate a regional data set applicable to all operators is to sample from as broad an area as possible. To ensure that region-wide and lease-specific biodiversity objectives are met and maintained, the early successional wildlife use of reclaimed habitats needs to be assessed at an appropriate spatial scale. Studying early successional wildlife of reclaimed habitats relative to naturally occurring, juvenile and mature stands is required to understand region-wide patterns of diversity, relative abundance, and habitat associations of early successional wildlife. Because the regional dataset is constructed from data collected on individuals leases, the data will serve at least three purposes: 1) the data will help individual operators meet requirements for reclamation certification, 2) broader-level biodiversity goals associated with reclamation in the Athabasca Oil Sands Region can be quantified and achieved, and 3) the regional data set can be used to develop profiles of wildlife use of mature forest stands that represent the desired endpoint of reclamation, of the juvenile regenerating stands, and of the reclaimed stands. These data profiles can then be used to determine if the developmental trajectory of reclaimed habitats parallels that of naturally regenerating juvenile stands and at what point in the development the reclaimed habitats represent the desired endpoint.

The continuation of the early successional wildlife dynamics program on partner leases will ensure that the return to and use of reclaimed lands by wildlife is properly quantified and compared to appropriate natural analogues. This approach is necessary for determining the patterns of colonization of reclaimed lands by wildlife and how reclaimed lands develop into functional ecosystems that are comparable to the naturally occurring and surrounding boreal forest (as per AENV 2010). By pooling data from the various leases, we are confident that our project goals can be achieved over time. This phase 1 data collection period is providing useful data on the return to and use of reclaimed habitats by wildlife, and how reclaimed lands compare to natural analogues and desired endpoints.

The following data were collected from each site in 2017:

- Small mammal live trapping: spring and fall sampling; no small mammal trapping on Kearl Oil Sands in 2017;
- Songbird point counts: all leases;
- Deployment of autonomous recording units (ARUs): all leases;
- Wildlife camera data collection: all leases;
- Incidental wildlife observations (animals not targeted during systematic surveys): all leases;
- Vegetation sampling: all leases;
- Amphibian surveys: all leases (some via incidental observations);
- Insect sampling (pilot): Canadian Natural's Horizon Oil Sands, Canadian Natural's Albian Sands, Suncor Base Lease, and Fort Hills; and
- Remotely-triggered cameras were deployed in late-2017 to target winter-active animals. This methodology replaced snow-tracking. Cameras were deployed on all leases except for Suncor's Base Lease.

Data collection occurred in all months of the year with most occurring during the snow-free period (May to October). The data collected in 2017 contribute to the development of a dataset that will be used to assess the developmental trajectories of reclaimed habitats relative to natural analogs (i.e., the burned, logged, and cleared sites) and to the desired endpoint of reclamation (i.e., the mature forest sites). Because compensation lakes are being built to offset fish habitat loss on most leases, it is also desirable to understand how wildlife is using habitats adjacent to those features. To ensure that the variability associated with animal populations is considered in the development of the trajectories associated with each type of site, a multi-year dataset is required. The 2017 data constitute year 3 of the 5-year phase 1 dataset.

All data collected in 2017 are undergoing quality analysis/quality control (QA/QC) and integration with previous data (into a relational and fully-documented SQL database). Annual reports for each lease will be prepared in Q1, 2018.

Data collected via systematic wildlife surveys (e.g., small mammal live-trapping, songbird point count surveys) are augmented by data collected incidentally (i.e., non-systematic, observer-based data collection). In total, 184 species from three taxonomic groups (amphibians [n=3], mammals [n=35], and birds [n=146]) were documented between 2014 and 2016. More species were documented incidentally (n=141) than through systematic surveys (n=131), due to the non-rigorous and untargeted nature of data collection associated with incidental data. For example, songbird point count surveys capture birds that occur during the summer months only whereas bird species can be recorded incidentally throughout the year. Despite the unstructured nature of observation-based data collection, only one mammal species (common muskrat, [*Ondatra zibethicus*]) was documented solely via incidental observations. As expected, and based on detectability and diversity in the three taxonomic groups, bird species were most frequently detected incidentally, followed by mammals and amphibians. An assessment of key indicator resource species illustrates that some species (e.g., songbirds, bats, black bear [*Ursus americanus*]) are widespread and documented from all treatments and leases, while others (e.g., North American river otter [*Lontra Canadensis*] and North American beaver [*Castor canadensis*]) are not, having been documented from only one treatment so far. While incidental data help to assess the occurrence and distribution of wildlife species, statistical analyses are not performed on those data for various technical reasons. To rigorously assess certain species and species groups, we use data specific to small mammals, bats, songbirds, wildlife cameras, arthropods, and vegetation to assess the efficacy of upland reclamation relative to our objectives.

The results of small mammal live-trapping revealed a strong seasonal difference in both the relative abundance and number of species captured, with more species and individuals trapped in the fall compared to the spring. Relative abundance of herbivorous species (deer mouse [*Peromysucs maniculatus*], meadow vole [*Microtus pennsylvanicus*], and southern red-backed vole [*Myodes gapperi*]) increased over time, with an increase in abundance in each subsequent year (2014-2016). Trends in abundance for herbivorous species differed by treatment type depending on the species suggesting general habitat preferences characteristic for these species. For example, southern red-backed vole was more abundant in mature forest, meadow vole was more abundant in open habitats with grasses (reclaimed and compensation lake), and deer mouse abundance was not associated with any specific habitat type (i.e., habitat generalist). Continued monitoring of small mammal responses to natural and reclaimed vegetation communities over time will assist in providing information on wildlife use of reclaimed habitats relative to natural analogues.

Autonomous bat detectors were deployed for a total of 52,458 hours between 2014 and 2016. All seven species of bat expected to potentially occur in the Athabasca Oil Sands Region based on known or suspected distributional records were documented based on acoustic call signatures. These include five species of provincial conservation concern, including two federally endangered species (northern myotis [*Myotis septentrionalis*] and little brown myotis [*Myotis lucifugus*]). All seven species were documented from all treatments in all years, except for the cleared treatment in 2016 where only five species were found. The abundance of calls varied by species in a given treatment and certain species were more often documented in certain treatments (notably the compensation lake treatment). In particular, the mature forest has a substantially different detection rate compared to other treatments, likely related to habitat structure. Temporal activity of bats both daily and seasonally was not influenced by treatment.

Songbirds have been surveyed across all treatment types and on all leases. A total of 207 point count stations have been surveyed between 2011 and 2016, resulting in 9,113 observations of 137 species. This data set was constrained based on several factors, including limiting it to songbirds detected within 75 m of the point count centre, resulting in 4,407 observations of 70 species. Results indicate that songbirds were abundant and widespread across all treatment types; however, the abundance of species varied widely among species and relatively few species made up the majority of detections. Rarefaction techniques suggest that majority of species have been detected within each treatment and few new species would be added by increasing sample size. However, by increasing sample size at the treatment level (i.e., adding more logged, burned, cleared, and mature forest habitats), more species are likely to be added and the strength of the results increased. Species also differed in their occurrence and abundance among treatments. In particular, the mature forest treatment had relatively low Sørensen Similarity compared to other treatment types. This trend held true when non-metric multidimensional scaling ordinations were plotted. Most other treatments also clustered distinctly, though the cleared treatment had the greatest breadth in ordination space and contained songbird assemblages not different from reclaimed, compensation lake, burned and logged treatments. The dissimilarities in species composition among treatments allowed for the identification of multiple potential indicator species for treatments and groups of treatments. These indicator species are utilizing treatments based on the habitat characteristics of those sites and are selecting habitats consistent with known life-history attributes. Combined, these results provide a good understanding of the current distribution, abundance, and use of various treatments by songbirds in the Athabasca Oil Sands Region (AOSR), including those of reclamation sites. However, these early-successional habitats are not static, and we expect to see shifts in the distribution, abundance and composition of songbird species as vegetation communities advance.

Wildlife camera data were used to derive usage patterns (i.e., occupancy estimates) of mammals (especially medium to large species) that are otherwise seldom detected by human observers. Out of the 269,393 photographs, 16% were used for analysis (with others representing false triggers [e.g., vegetation movement], multiple photos of the same individual or unidentifiable species), representing 78 species. Standardized sighting rates revealed that wildlife sightings in general increased after 2009 with a peak in 2012 and a subsequent decline to pre-2009 levels. The cause of this peak of activity remains unknown. Analyses into patterns of occurrence focused on the most commonly detected mammals (nine species). Most of these species showed relatively consistent patterns across time and habitat types. However, there were notable differences in usage among treatments. For example, red fox, gray wolf, and white-tailed deer use was greatest in compensation lake sites, while mule deer, snowshoe hare, and coyote were sighted most frequently in reclaimed habitats. Species had individual patterns to their apparent habitat preferences and intensity and seasons of usage within those habitats. For example, white-tailed deer, black bear, and moose had consistent sighting rates across years in mature forest and riparian habitats, but appeared to be increasing in reclaimed areas, potentially as habitat succession proceeds. These analyses have provided important data that may help reveal trends that emerge in future years as reclamation advances, which should be associated with shifts in species usage or activity patterns over time.

Pitfall trap surveys yielded 7,404 arthropods, including 397 spiders and 909 beetles. Spiders were identified to 60 species, while interim beetle identifications yielded 32 species of ground and rove beetles (additional beetle specimens were retained for future identification and analyses). Standardized abundance, richness, and composition of spiders differed among treatment types. The species composition of reclaimed and compensation lake treatments were also significantly different from all other treatments sampled (cleared, burned, and mature forest). The spider species characteristic of the compensation habitat were, open-habitat, ground-running species in the family of Wolf Spiders (Lycosidae). The differences in vegetation structure between sites and species-specific habitat requirements, is the likely driver of observed compositional differences.

Vegetation is an integral component of forest ecosystems, influencing wildlife use. Wildlife respond to different vegetation characteristics, which in turn differ among different treatments. A total of 253 vascular plants were documented in 2015 and 2016. Species richness varied by treatment, with logged sites having the lowest species richness and reclamation and burned sites having the highest. Introduced and invasive species (i.e., weeds) are prevalent in disturbed habitats. The highest number of exotic species was found in reclamation sites, while logged and mature forest sites had the lowest number. We found that while the proportion of vegetation cover by native species was approximately equal among treatments, exotic vegetation was disproportionately prominent in reclamation, compensation lake, and cleared treatments, reflecting the early seral conditions on those sites. Vegetation cover varied by treatment in 2015, with Mature Forest having significantly greater cover than Reclamation and Logged treatments, though this trend did not hold in 2016 when no significant treatment differences were found. Overall there were significant differences in vegetation communities among treatments. Many plant species were indicative of one or several treatment types. Species with the strongest habitat associations tended to be native species, while several exotic species were indicative of early successional habitat types. We expect changes in vegetation richness and composition over time, and as individual sites continue along revegetation trajectories influenced by characteristics (e.g., time since disturbance, moisture/nutrient profiles, light availability, etc.) particular to each site.

Systematic wildlife surveys and remote-sensing technologies (ARUs and remote cameras) each target a group of species located in an area at a particular time (e.g., time of day, season, etc.) or in a particular way (e.g., use of traps, auditory counts, etc.). However, because detectability differs among species and may decrease with decreasing abundance, the effectiveness of a given monitoring approach varies. Further, and perhaps more problematic, is that rare or elusive species may go undetected when systematic survey methods are used. The use of autonomous recording units and remote cameras can mitigate for differential detectability and potential lack of observations of rare and elusive species. Standardized surveys are necessary when assessing trends over time or when comparing wildlife use between treatments or leases. Incidental observations contribute to our understanding of which wildlife species are using reclaimed habitats in the AOSR. The combination of directed and standardized surveys and incidental wildlife observations are providing a thorough understanding of which species are utilizing reclamation areas in comparison to other early successional and mature habitat types.

LESSONS LEARNED

None to report for 2017.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Hawkes, V.C., C.M Wood, N. Hentze, N.N. Johnston, W. Challenger, and S. Roias. 2017. Regional Early Successional Wildlife Dynamics on Reclaimed Habitats in the Athabasca Oil Sands Region Fort McMurray, Alberta. Year 1 2016. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources Limited, Fort McMurray, AB. 133 pp + Appendices.

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Environmental Research and Monitoring

Reclamation Carbon Life Cycle Analysis

COSIA Project Number: LJ0271

Research Provider: University of Alberta and Natural Resources Canada

Industry Champion: Suncor Energy Inc.

Status: Year 2 of 3

PROJECT SUMMARY

Increased environmental concerns have necessitated the move to more sustainable practices in oil sands reclamation. Ecosystems, including those in the oil sands, contain large amounts of sequestrated carbon. Maintaining carbon storage in the oil sands or returning the land to its similar or equivalent functional capability is an important responsibility for those in energy production sectors. In addition, Alberta's recently announced Climate Change Leadership Plan focuses further attention on greenhouse gas emissions (GHG) from the oil and gas industry.

The goal of this study is to conduct a comprehensive carbon cycle analysis on reclamation-associated activities and to identify opportunities for increasing carbon stock. A Suncor project will be used to conduct a reclamation carbon cycle assessment (LCA) of an oil sands mine.

Key objectives:

- Evaluate carbon balances of energy operations throughout the land use cycle from pre-disturbance to the end of reclamation;
- Develop carbon stock and carbon emission factors applied to boreal forest, wetland, lakes, rivers, and streams ecosystems;
- To scale up a carbon balance model from one small landform to an entire oil sands mine; and
- Provide recommendations to reduce carbon loss from oil sands operations.

This study assessed environmental impacts associated with all the stages of a system from beginning to end use. It followed the four-phase (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation), International Organization for Standardization (ISO) 14040:2006 standard for life cycle assessment.

The following phases were developed for this study:

Phase 1: Determine the goal and scope of the carbon analysis.

Phase 2: Develop the carbon stock and emissions associated with materials and energy.

Phase 3: Focus on a small reclaimed watershed as a case study (Wapisiw Lookout), and, then scale-up to an entire oil sands mine (Suncor 86/17 lease); include both a carbon balance assessment result and an interpretation.

Phase 4: Conduct a detailed interpretation of the results and develop a set of recommendations for future land use and reclamation activities.

PROGRESS AND ACHIEVEMENTS

Wapisiw Lookout was a tailings pond known as Pond 1 and was renamed Wapisiw Lookout after being reclaimed in 2010. It is the first oil sands tailing pond to undergo surface reclamation work. We examined the initial pre-disturbance ecosystem, which included approximately 198 hectares of wetland and 152 hectares of forest, site preparation and associated energy consumption, carbons emissions from tailings during the land forming stage (1966-1995), and carbon return through soil placement and revegetation. With the developed carbon balance model for Wapisiw, we can predict the soil carbon return and the change in biomass carbon for the 90 years after reclamation.

Further, we scaled up the carbon balance model from one landform (a reclaimed tailings pond) to an entire oil sands mine lease, Lease 86/17. The scale-up model includes landform categories that have been used or are in use for reclamation, in some cases since the mid-1960s.

This study looked at forests, wetlands, streams and rivers, and lakes and analyzed carbon flows, carbon stock of materials (i.e., soil, tailings) and carbon emissions from energy consumption through human operations (i.e., site preparation, road construction). The carbon balance model will support identification of a range of options on how to avoid carbon emissions from various reclamation activities and where and how to plan for enhanced carbon storage during reclamation develop and project closure.

A draft report of the work was completed in 2016, but peer review identified deficiencies in some aspects of the model. Consequently, forest and soil carbon modeling experts, at Natural Resources Canada, were identified and added to the existing team in 2017. The enhanced team commenced optimization of the pre-disturbance and reclamation ecosystem model phases in fall 2017. An enhanced model and final report are expected in mid-2018.

The study was conducted during the year 2015-17. Start date: Aug. 1, 2015. End date: 2018.

LESSONS LEARNED

Outcomes and lessons learned are not currently available for release to the public since the carbon balance model is still under development. Results and recommendations will be available in 2018.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta and Natural Resources Canada

Principal Investigator: Drs. Amit Kumar and Cindy Shaw

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Hao Zhang	University of Alberta	Postdoctoral Fellow	2015	2016
Giovanni Di Lullo	University of Alberta	PhD Student	2017	2018
Eskinder Gemechu	University of Alberta	Postdoctoral Fellow	2017	2018

Amit Kumar	University of Alberta	Professor, NSERC/Cenovus/ Alberta Innovates Associate Industrial Research Chair in Energy and Environmental Engineering, Cenovus Energy Endowed Chair in Environmental Engineering		
Cindy Shaw	Natural Resources Canada	Forest Carbon Research Scientist		
Darrell Hoffman	Natural Resources Canada	Forest Carbon Research Assistant		
Christine Daly	Suncor Energy Inc.	Senior Advisor – Land and Reclamation		

Biological Control of Scentless Chamomile

COSIA Project Number: LJ0301

Research Provider: McClay Ecoscience

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 2

PROJECT SUMMARY

Scentless chamomile (*Triplospermum inodorum*) is characterized as a noxious weed within the province of Alberta, and must therefore be controlled. Populations of scentless chamomile exist on the Horizon lease, but until recently, these populations were fairly small and restricted to an area that is not frequently accessed. However, in the past two years, scentless chamomile invasions have increased dramatically in new reclamation areas that were constructed with directly placed soils from the mine advance. This suggests that these salvaged soils contain a considerable volume of chamomile seed, and that future reclamation areas constructed with soils from this area could be vulnerable to substantial chamomile invasions.

Herbicides have been applied to chamomile populations in non-reclamation areas, however they have been minimally effective. Due to the vulnerability of soil biota and vegetation in early seral stages of reclamation, manual removal is preferred to herbicide application on these areas. However, this option is no longer viable given resource constraints, frequency requirements, and the risk of low-impact injuries it presents. Therefore, controlling scentless chamomile invasions on reclamation areas is increasingly problematic.

A pilot study was established in 2016 to investigate the potential of using specific insects to control populations of scentless chamomile on reclamation areas. Two species of insects that feed exclusively on scentless chamomile – a gall midge (*Rhopalomyia tripleurospermi*) and a seed weevil (*Omphalapion hookeri*) – were sourced from McClay Ecoscience for use in the pilot study. The two insects reduce the reproductive fitness of chamomile by destroying developing seed, or by damaging leaves or flower heads, respectively.

The objectives of the study are to determine: 1) if the biological control agents (insects) are able to colonize chamomile populations and damage plants: and 2) the efficacy of biological control in managing scentless chamomile populations on reclamation areas. The significance of this study is that it will investigate if biological control agents can be used as one effective tool alongside other management options to control scentless chamomile populations on site over the long term.

PROGRESS AND ACHIEVEMENTS

In early summer 2017, McClay Ecoscience worked with Canadian Natural Horizon reclamation staff to investigate the success of the previous summer's biocontrol releases of gall midges (*Rhopalomyia tripleurospermi*) and seed weevils (*Omphalapion hookeri*). They were released into scentless chamomile populations at two locations in June 2016: Dedicated Disposal Area 1 (the legacy chamomile population– not a reclamation area), and within an area of the North Toe Berm reclamation area. Galls from gall midges were found on young plants in all release areas, however identification of galls was challenging. Seed weevils were not detected in preliminary flower examinations, indicating a possibility that the population had not spread as successfully as hoped.

Given results from 2016 and 2017, it was concluded that Objective #1 of the study was met (determine if biological control insects are able to colonize chamomile populations and damage plants).

As of the summer of 2017, the efficacy of the biocontrol agents in managing scentless chamomile populations was unclear. As part of the program's tasks in 2017, a more formalized monitoring procedure to obtain more robust data to evaluate the program's effectiveness was to be developed.

Plans to release additional biocontrol agents as part of a future weed management strategy were discussed with the Alberta Energy Regulator (AER) in summer 2017. However, AER was not supportive of future biocontrol releases, as they felt that potential risks had not been adequately managed. As such, the biocontrol program is to remain in the pilot stage. Approval for future releases will require a comprehensive risk management plan under the review of the AER.

Due to time and resource constraints, a more robust monitoring of the biocontrol releases was not possible in the 2017 field season. Although initial inspection of release sites revealed the presence of galls on a few young plants, galls were not found on mature plants, and seed weevils were not found in dissected flowers of either young or mature plants. It was concluded that monitoring for impacts to scentless chamomile was very time-consuming, with results being difficult to interpret (for gall midges), all while scentless chamomile populations had continued to mature and grow in size and thus were outpacing the biocontrol impacts. Although biocontrol insects represent a novel and passive additional means to control scentless chamomile populations on reclamation areas, it is not possible to determine the efficacy to control scentless chamomile in reclamation areas, at least one year after release. Therefore, Objective #2 of the study was not fulfilled. In the future, given appropriate approvals and resources to develop a program involving a robust monitoring program and multiple, overlapping releases, it would be possible to re-evaluate the ability for the program to meet Objective #2.

This program was started in 2016 and a decision was made to end it in 2017, although it was intended to end in 2018.

LESSONS LEARNED

Although the insects used for this study (*Rhopalomyia tripleurospermi* and *Omphalapion hookeri*) have been used extensively in Southern Albertan agricultural systems to control scentless chamomile, this project represents the first time that seed weevils and gall midges have been released in the Boreal Forest. Preliminary monitoring efforts did not show significant impacts to scentless chamomile populations, however effective control often requires multiple releases and longer timelines to evaluate.

After evaluating the program to date, and after additional discussions with the AER, Canadian Natural has decided not to release more of these insects. Given the large population size and ability of scentless chamomile to spread very rapidly, it seems unlikely that biocontrol insects would be able to effectively control the noxious weed on reclamation areas on the Horizon oil sands lease.

PRESENTATIONS AND PUBLICATIONS

There have been no publications in 2017.

RESEARCH TEAM AND COLLABORATORS

Institution: McClay Ecoscience

Principal Investigator: Alec McClay

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Alec McClay	McClay Ecoscience	Professional Biologist		

Habitat Equivalency Analysis

COSIA Project Number: LJ0306

Research Provider: Arcadis

Industry Champion: Suncor Energy Inc.

Status: Year 1 of 1

PROJECT SUMMARY

This study explored the use of Habitat Equivalency Analysis (HEA) as a potential methodology to quantify ecological services that are provided after reclamation. HEA was originally developed by the Department of Interior (DOI), the United States federal entity responsible for protecting the natural resources of the United States on behalf of its citizens. The National Oceanic and Atmospheric Administration (NOAA) of the United States then tested it to determine interim lost use of ecosystem services due to impacts to natural resources, and to calculate the amount of restoration/reclamation/conservation required to compensate for that interim loss use.

HEA can be used to quantify the level of ecosystem services that: (1) existed prior to the implementation of a project; (2) were affected or interrupted during the project's implementation; and (3) were achieved through reclamation or mitigation activities.

HEA quantified ecological service gains and losses in a spatially and temporally explicit manner in present ecological value without assigning monetary values. The HEA methodology is relatively easy to implement, is sufficiently flexible for a variety of sites, habitats, disturbances, and reclamation activities. It also provides a means to directly compare the impact of disturbances to the value of different reclamation or mitigation approaches.

This pilot study examined the utility of HEA to assess and quantify ecosystem services throughout the life cycle of an oil sands project, the North Steepbank Mine Expansion (NSE), with the goal of maximizing ecosystem service creation through reclamation planning. Data previously collected as part of the Environmental Impact Assessment (EIA) process were used in the HEA analysis.

In concept, this HEA pilot in the oil sands is a summation of the proportional change in services (reclamation) relative to baseline (pre-disturbance, natural ecosystem) and discounted to present value. The services gained or lost were summed over the period of interest (project lifecycle), scaled to the habitat of reference, and multiplied by the number of hectares of area.

PROGRESS AND ACHIEVEMENTS

The HEA methodology allowed for a comparison of future services provided by three different reclamations scenarios. The three scenarios are hypothetical, but represent a range of potential reclamation options to demonstrate how choices in reclamation may affect long-term biodiversity goals for the NSE project. The scenarios include:

Scenario 1: Current Plan – includes 83% reclaimed upland habitat, mostly fast-growing deciduous forest and some coniferous and mix-coniferous forest. The remaining 17% was reclaimed wetland, primarily marsh and shallow open water wetland types. Both are rare in the oil sands region, but provide important biodiversity functions such as nesting habitat for sensitive waterfowl.

Scenario 2: Wetland-Focused – includes 80% wetland distribution, including 30% fen wetland type, and 20% upland. This scenario may be impractical to implement due to cost, logistics and topographical constraints, but it provides an example of how dramatically changing the composition can alter ecological services.

Scenario 3: Balanced Plan – a more practical scenario for implementation, but certainly a stretch for the reasons described in scenario 2. This plan consists of 60% reclaimed upland, mostly coniferous forest with some mixed and deciduous forest, and 40% reclaimed wetland (primarily marsh and shallow open water wetland, and a small amount of fen wetland).

The study area is 923 ha and naturally included 580 ha of wetland types and 342 ha of upland forests.

Twenty-two land cover types from a Biodiversity Environmental Setting report for NSE, were grouped into eight general habitat types: fen, swamp, bog, marsh, shallow open water, conifer forest, mixed forest, or deciduous forest.

A review of potential environmental services was conducted. Plant biodiversity was the ecosystem service selected as the best metric to evaluate in this HEA Pilot. It was selected for the following reasons:

1. Preservation is a priority in reclamation and for the province of Alberta;
2. Regional plant diversity data was available; and,
3. Plant community evaluation methods are standardized and transferable between reclamation scenarios, mitigation opportunities, project sites and other geographic locales within the oil sands region.

Typically, other factors are included in addition to plant biodiversity. These could include, mine by-product disposal, tailings settlement optimization, economics, regulatory requirements (e.g., soil placement prescription), wildlife habitat, stakeholder and Aboriginal needs and values, etc. However, for the case of simplicity in this pilot HEA, only plant biodiversity was evaluated.

Establishing equivalence between habitats allows for direct comparison of total ecological services – lost or gained – between reclamation alternatives.

Six metrics were selected to evaluate plant biodiversity:

1. Rarity of habitat
2. Land cover type
3. Plant species richness
4. Plant species overlap
5. Rare plant species potential
6. Structure and wetland – to emphasize the unique water quality provided by wetlands and overall uniqueness in the landscape

Each habitat type had their biodiversity metrics scaled to the habitat with the highest service value. Establishing equivalence between habitats allows for direct comparison of total ecological services between reclamation alternatives using the HEA approach. Spatially-weighted average scores for each habitat type were developed based on an average of land cover type metrics for each habitat type. A spatially-weighted average for each habitat type was scaled against the highest scoring land cover type found within NSE, the woody fen.

Baseline ecosystem services were assumed in this pilot to be 100%, implying habitat had not been impacted by anthropogenic activities. However, natural events, such as drought, fire, climate change or flooding are natural processes that could subtract from the assumed baseline service. In this manner, reclamation scenarios could improve ecosystem services, over time, relative to baseline. Additionally, an assumption was made that biodiversity was the only factor that needed consideration during reclamation and closure design. Other assumptions include: reclamation services begin accruing the year that reclamation begins; service gain is calculated up to 100 years unless perpetuity function is enabled; reclaimed level types are assumed to not provide the same level of service that a natural habitat would (i.e. 80% of baseline).

Overall, the HEA model output calculated:

- Differing levels of biodiversity services provided by each habitat type in the three reclamation scenarios
- Wetlands provide >60% more plant biodiversity service per hectare than uplands.
- **Scenario 1** assumes a traditional reclamation scenario with higher proportions of upland forests, particularly deciduous forests, and low proportion of wetland marsh and shallow open water wetland
    - Scenario 1 generated the highest debit of all three scenarios.
    - The lower value of upland plant biodiversity services translates to lower credit to be accrued through the extensive planting of forest, particularly deciduous and mixed forest types which provide lower biodiversity services than coniferous forests.
    - A small portion of the area is expected to be reclaimed as wetland habitats that provide higher plant biodiversity services. However, reclaimed wetlands are limited to marsh, swamp and shallow open water, which provide lower service and less credit than the fen habitat they replace.
- **Scenario 2** includes extensive reclaimed wetlands, including 277 ha of engineered fen.
    - Upland habitats only represent 20% of the reclaimed area, but include twice as much coniferous forest as deciduous and mixed forest.
    - The resulting debit is nearly half of that calculated for Scenario 1. Most of the credit comes from reclaimed wetlands.
    - Shifting from primarily deciduous planting to coniferous plantings in upland areas provides additional credit to offset services during oil sands mining disturbance.
- **Scenario 3** provides a more realistic alternative to the traditional reclamation scenario, with 40% of restored habitats being wetland and 60% being upland. A reclaimed fen was included and upland habitat comprised of twice as much coniferous forest as mixed or deciduous forest.
    - Wetland reclamation offsets 42% of disturbance; and upland reclamation offsets upland habitat disturbance.
    - Overall, both the wetland and upland habitat restoration result in a 24% improvement over the traditional reclamation scenario.

The study commenced and was completed in 2017.

LESSONS LEARNED

Arcadis developed an HEA model as a proof-of-concept for quantification methodology, which oil sands companies can use to:

- Quantify the baseline services of a natural area in terms of ecological values prior to execution of an oil sands project; and
- Quantify the ecological services generated from the implementation of reclamation activities.

The modeled values of these services, before and after development and reclamation, could be used to determine if reclamation goals have been achieved or what alternatives would be most effective in achieving reclamation goals.

Opportunities for refinement of this pilot HEA approach in the oil sands sector include:

- Evaluating natural (e.g. forest fire) and anthropogenic disturbance to set baseline service;
- Considering nonlinear recovery trajectories for upland habits – fertilization, control of competitive plant species or wildlife forage, and age of planted trees are all factors that may influence the recovery time of upland forest;

- Exploring alternate reclamation scenarios, particularly those that integrate upland habits with higher biodiversity; and
- Applying geospatial data analyses or utilizing other available datasets to evaluate parameters not evaluated.

Additionally, these results illustrate the value of reclaiming to some habitat types over others, and provide a framework for oil sands companies to better understand the consequence of design choices. In turn, the HEA tool can support oil sands companies in planning for future development with a minimized impact on boreal ecosystems and their ecosystem services.

PRESENTATIONS AND PUBLICATIONS

At this time, no published articles are available.

RESEARCH TEAM AND COLLABORATORS

Institution: Arcadis

Principal Investigator: Ginny King

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ginny King	Arcadis	Consultant, HEA Expert		
Christine Daly	Suncor	Sr. Advisor – Land & Reclamation		